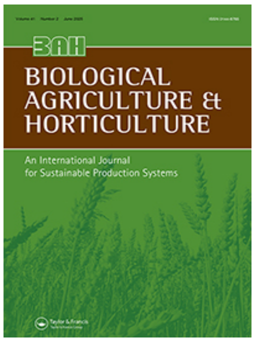

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Sole and integrated applications of legume crop residues and poultry manure: effects on performance and quality of *Trichosanthes cucumerina* (L.)

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ABSTRACT

Many organic agricultural waste materials can be used as sustainable resources to improve soil fertility, crop performance and fruit quality in intensive and organic agricultural systems. This study was conducted during the rainy seasons in 2021 and 2022 to determine the impact of sole and combined applications of poultry manure (PM) and crop residue of cowpea (CP) or soybean (SB) on the performance and quality of snake tomato (*Trichosanthes cucumerina)*. Treatments with three application rates of PM (50%, 100%, and 150%), CP (50%, 100%, and 150%), SB (50%, 100%, and 150%), and a control were tested in a trial arranged as a randomised complete block design with three replications. The study revealed that among the sole applications, PM performed better than sole applications of CP and SB in terms of effects on yield, vitamins, minerals and proximate compositions. All treatments with combined applications of PM and residues of cowpea (CP) or soybean (SB), at both the lower and the higher application rates, significantly improved all parameters measured compared with the control. The study also showed that due to their C:N ratios, the PM + CP combinations performed better than the PM + SB combinations. The study concluded that there was a consistent increase in the performance, yield and quality characteristics of the test crop with the application of 100% CP + 50% PM, indicating that this can be successfully used as a soil amendment for improved performance and quality attributes of the test crop in the study area.

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Crop residues; *Glycine max*; snake tomato; *Vigna unguiculata*; yield

Introduction

Snake tomato (*Trichosanthes cucumerina* L.), an annual climber belonging to the family *Cucurbitaceae* and commonly also called snake gourd, viper gourd or lone tomato

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(Sandhya et al. 2010), is consumed as a vegetable due to its high nutritional value. As the fruits mature, they develop a soft, red, tomato-like pulp that can be used as a substitute for tomato puree or paste in stews and sauces. During the fruit ripening process, changes occur including the synthesis of pigments, the development of compounds responsible for flavour and aroma, and increased biosynthesis of carotenoids, particularly lycopene (Toor and Savage 2006). The fruit is a rich source of functional components such as flavonoids, carotenoids, phenolic acids, soluble and insoluble dietary fibres, and essential minerals, which make it pharmacologically and therapeutically active (Sandhya et al. 2010). Snake tomato fruits have high contents of proteins, fat, fibre, carbohydrates, minerals, and vitamins A and E. Potassium (121.6 mg $100\,g^{-1}$) and phosphorus (135 mg $100\,g^{-1}$) are the predominant mineral elements in the fruit, with sodium, magnesium, and zinc also present in significant amounts (Ojiako and Igwe 2008).

T. cucumerina has significant economic value in its place of origin as well as in many other regions where it is commercially cultivated and consumed, and the crop can provide income opportunities for farmers, hence contributing to local economic development (Uwumarongie et al. 2022). There is an increasing demand for nutrient-rich produce and growing awareness of the benefits of indigenous crops, therefore, farmers stand to capitalise on this emerging market, securing sustainable livelihoods and at the same time contributing to food security and economic development. However, despite this, in Africa, and particularly in Nigeria, *T. cucumerina* is gradually becoming extinct as farmers are no longer growing this crop, and despite its use in alternative medicine the crop is rarely seen on farms, in home gardens or even as grown for aesthetics. The gradual decline in the cultivation of *T. cucumerina* appears to be as a result of a lack of awareness of the potential uses of the crop and the competition with tomatoes (*Solanum lycopersicon*). Medicinal use of *T. cucumerina* ranges from using its pharmacological potentials such as antioxidant, antidiabetic activities of the fruits and seeds, hepatoprotective, anti-inflammatory, larvicidal effects, and cytotoxicity against some cancer lines (Arawwawala et al. 2013). The medicinal value due to the nutrients and vitamin-dense fruits, seeds, and leaves of this plant is an indicator that its cultivation and utilisation should be promoted.

The use of crop residues of cowpea (*Vigna unguiculata*) and soybean (*Glycine max*) as soil amendments in areas where these crops are cultivated is highly justified due to their potential to enhance the fertility, structure and biological activity of the soil. Cowpea and soybean, both leguminous crops, can contribute significantly to soil nitrogen levels through biological nitrogen fixation. When the residues are incorporated into the soil, they add organic matter and essential nutrients like nitrogen, phosphorus, and potassium, which become available to subsequent crops as the organic matter decompose (Fu et al. 2021). Incorporation of cowpea and soybean residues can also help improve soil structure by increasing organic matter content, enhancing water retention, aeration, and root development (Zachary et al. 2020). This is particularly valuable in tropical soils, which often suffer from low fertility and poor structure.

In addition, amendments with leguminous crop residues promote microbial activity by providing a substrate for soil microorganisms, thus stimulating nutrient cycling and improving soil health (Giller 2001). By using these residues, farmers can reduce their dependence on synthetic fertilisers, promoting more sustainable, low-input agricultural practices (Kassam et al. 2009). Furthermore, the incorporation of crop residues enhances soil carbon sequestration, which helps mitigate the effects of climate change by trapping carbon in the soil (Lal 2004).

Crop residues and poultry manure are frequently used as organic soil amendments to improve soil fertility and enhance crop productivity (Onunwa et al. 2021). The pattern of nutrient release from crop residues and poultry manure applied on their own or in combination will depend on the type of crop residue and poultry manure applied, and on the environmental conditions at the site (Amusan et al. 2011). Generally, crop residues and poultry manure applied on their own or combined will release nutrients such as nitrogen (N), phosphorus (P), and potassium (K) over time. The rate of nutrient release will vary depending on factors such as the rate of decomposition, soil temperature, soil moisture, and the microbial activity in the soil. When crop residues and poultry manure are applied as sole amendments, the nutrient release rate is expected to be slower than when applied together. This is because the crop residue and poultry manure provide a variety of nutrients to the soil and when applied together the nutrients are released at a faster rate due to the synergistic effect of the two. When applied to soils used for growing *T. cucumerina* (L.), the applications of crop residues and poultry manure on their own and combined will likely affect the performance and quality of the crop. Crop performance is likely to be improved with increased nutrient availability in the soil, while quality is expected to improve due to increased nutrient uptake and utilisation by the plants.

Limited information exists on the use of sole or combined applications of legume residues and poultry manure as organic soil amendments to improve the yield and nutritional quality of *T. cucumerina*. Therefore, this study was designed to determine optimum combinations of legume residues and poultry manure applications and the nutrient release patterns for increasing yields and improving quality parameters of the crop. Based on this objective, it was hypothesised that the vegetative growth, yield and quality parameters of *T. cucumerina* would be influenced differently by the application and the nutrient release pattern of different rates of the sole and combined applications of poultry manure and residues of cowpea and soybean.

Materials and methods

Description of the experimental site

The study was conducted during the 2021 and 2022 cropping seasons at the Teaching and Research Farm, College of Agricultural Sciences, Landmark University, Omu-Aran, Nigeria, located on the geographical coordinates of latitude 8° 8' 0' North and longitude 5° 6' 0' East, with an altitude of 555.85 m above sea level. In 2021 and 2022, the experiments were undertaken in two field areas adjacent to each other at the same geographical location.

The experimental site had been cultivated with vegetables continuously for over five years, utilising various organic inputs such as animal manure, green manures, leguminous cover crops, and crop residues. However, the land had been left fallow for two years before the start of this experiment. Although the site is not officially certified for organic production, it has been managed according to organic agricultural standards for more than seven years. The study site falls within the transitional rainforest of the derived savanna agro-ecological zone of Nigeria with an annual average temperature of 24.9 °C and rainfall of 1300 mm which begins around April and ends around October/November each year.

Pre-cropping soil samples were collected from each plot before the cropping seasons and were bulked to determine the physicochemical properties of the soil. The composite soil sample was taken to the University Crop and Soil Science Laboratory for routine analysis.

In both seasons, the land was ploughed once and harrowed twice to give a well-pulverised soil, after which beds were made to create plots of 2.5 m ×1.5 m (3.75 m^2) size, with 1 m margin between blocks and 0.5 m margin within the plot.

Collection of amendments used in the study and their applications

In both years, cowpeas and soybeans were grown at the Teaching and Research Farm of Landmark University, Omu-Aran, in areas separate to where the experiments were undertaken. At maturity, the crops were harvested, threshed to gather the seeds, and the crop residue was then collected. The poultry manure was collected from the layers section of the poultry house of the Teaching and Research Farm. The collected crop residues were sundried for two days after which they were milled using a vertical feed mill machine produced by Konet mills Limited, Nigeria. The capacity and grinding/crushing power of the milling machine are 1 t hr^{-1} and 7.5 kw respectively. The residues were milled to give room for faster and easier decomposition.

The poultry manure (PM) and residues of cowpea (CP) and soybean (SB) were incorporated to the soil to a depth of approximately 5 cm two weeks before transplanting the snake tomatoes to allow for mineralisation. All of the amendments were incorporated at rates of 5, 10 and 15 t ha^{-1}, which were equivalent to 1.875 (50%), 3.746 (100%) and 5.625 (150%) kg $plot^{-1}$, respectively.

Nursery establishment of snake tomato seedlings and transplanting

Seedlings of the snake tomato (*Trichosanthes cucumerina* L. cv. un-named) were raised in the screen house of Landmark University Teaching and Research Farm. This cultivar is characterised by long fruit with deep green background and white stripes at the unripe stage, which then turns to an orange background whilst still retaining the white stripes when ripe. One seed was sown in each polythene bag (size 10 × 10 × 10 cm) filled with sandy loam soil and was then watered. The polythene bags were perforated at the base to allow for easy drainage of excess water. Seedlings with high vigour and uniform size were transplanted on the prepared bed 3 weeks after sowing (WAS), using a spacing of 0.5 m × 1 m inter and intra row (20,000 plants ha^{-1}).

Treatment combinations and experimental design

The treatments consisted of three levels each of cowpea (CP) (50, 100, and 150%) and soybean (SB) (50, 100, and 150%) residues and poultry manure (PM) (50, 100, and 150%). No amendment was applied in the control plots. The organic amendments were applied on their own (sole) and in combination, as follows: 50% CP + 100% PM; 50% SB

+ 100% PM; 100% CP + 50% PM; 100% SB + 50% PM; 150% CP; 150% SB; 150% PM; 50% CP + 50% SB + 50% PM; and the Control (no amendment). The experiment was laid out in a Randomised Complete Block Design (RCBD) and replicated three times.

Trellising/training and weed control

T. cucumerina, being an herbaceous climber, trellising of the vines were carried out on a weekly basis and as the need arose. Trellising and training of snake tomato plants is important for growing the best possible crop. Trellising helps to provide support to the plants and keep them off the ground, while training encourages the plants to grow in an upright position and improves air circulation. Bamboo poles of about 1.5 m in height were vertically fixed to the ground at the edge of each plot (2.5 m ×1.5 m). Horizontal poles were thereafter placed at the top of two adjacent poles. At intervals of 1 m, which was the intra-row spacing between the plants, a rope was tied to the horizontal pole to train and assist the vines of the young plants in reaching the horizontal pole. Trellising/training of *T. cucumerina* allows for increased sunlight exposure of the crop, makes it easier for pollinators to pollinate the crop, reduces exposure to fungal diseases, deters insect pests, increases air circulation within the crop, increases the number of plants that can be grown in any given amount of space and improves the fruit quality of the crop.

Weeding was accomplished by manually removing the emerged weeds in each plot at intervals of 2, 4, and 6 WAT (weeks after transplanting), as the need arose.

Observations and data collection

In both years of the experiment, the growth, yield and quality the fruit were assessed by measuring the following parameters: vine length, number of leaves, number of branches, days to flowering, days to fruit maturity, number of fruits per plant, fruit length, fruit girth, fruit weight and concentrations of vitamins (A, E, C), lycopene, minerals (Fe, Zn, Ca, Mg, P and K) and proximate analysis (moisture, ash, fat, protein, fibre and carbohydrate) of the fruit.

Harvesting the fruit

Mature and ripe fruits were harvested at intervals of five days for four weeks before the experiment was terminated. Harvested fruits were weighed using OHAUS Corporation, USA precision balance, having a capacity of 2100 g and readable at 0.01 g. Samples from each treatment were thereafter taken to the laboratory for minerals, proximate and vitamins, determination.

Laboratory determination of the mineral composition of T. cucumerina pulp

Mature and ripe fresh fruits were collected based on treatments and taken to the laboratory of Landmark University, Nigeria for analysis. The pulp of selected fruit samples was extracted based on treatments and was digested with concentrated nitric and perchloric acids. K and Na were determined with the aid of corning 400 flame photometer as described by Oyeleke (1984). Phosphorus was determined using UV-visible Spectrophotometer (JASCO V-630) at 436 nm (AOAC 2010). Ca, Mg, Zn, Fe, and Mn were determined by Atomic Absorption Spectrophotometer (Model 3030 Perkin Elmer, Norwalk, U.S.A.) according to the established procedures of Perkin-Elmer (1982).

Laboratory determination of the proximate composition of T. cucumerina *pulp*

Extracted pulp samples collected based on treatments were blended into a paste. The paste was then analysed for moisture, protein, fat, carbohydrates, crude fibre, and ash as described by the procedures of the Association of Official Analytical Chemists (AOAC 2010).

Laboratory determination of vitamins A, E, C and lycopene composition of T. cucumerina *pulp*

The pulp extraction and laboratory determination of vitamins A and E were conducted according to the method as described by Okonwu et al. (2018) using 616/626 Water HPLC. Determination of vitamin C was done by using the titrimetric method (Okwu 2004) while the lycopene content was determined by the method as described by Toor and Savage (2005).

Statistical analysis

Results of the two years were analysed separately using one-way analysis of variance (ANOVA) with $\alpha = 0.05\%$ to analyse the data. The statistical test used for the separation of means was Tukey's test with 95% confidence level. All statistical analyses were performed using GENSTAT Discovery 2014.

Results

Physical properties and nutrient status of the experimental soils before the experiment

The physical properties and nutrient status of the experimental soil for the 2021 and 2022 cropping seasons are as shown in Table 1. The soil had a sandy loam texture, was acidic (pH 4.4), and the organic matter (2%) content was at the lowest value below which its effects may not be observed. The concentration of total N at 0.1% was below the critical level for the cultivation of crops, suggested as 0.2%, and the values for available P and

Table 1. Physical and chemical properties of the soil prior to the application of amendments.

Parameter	2021	2022	Parameter	2021	2022
Sand (%)	75	77	Organic matter (%)	2.03	2.05
Silt (%)	13	12	K (mg kg^{-1})	0.14	0.12
Clay (%)	12	11	Ca (mg kg^{-1})	1.92	2.02
Textural class	Sandy loam	Sandy loam	Mg (mg kg^{-1})	0.30	0.31
pH (H_2O) 1:1	4.30	4.45	Available P (mg kg^{-1})	9.11	9.10
Total nitrogen (%)	0.102	0.101	Zn (mg kg^{-1})	0.35	0.38

exchangeable K, Ca, and Mg were close to the lower critical levels, suggested as 10.0 mg kg^{-1} for available P, 0.15 mg kg^{-1} for exchangeable K, 2.0 mg kg^{-1} for exchangeable Ca, and 0.40 cmol kg^{-1} for exchangeable Mg (Aboyeji 2022). The Zn value for the two years of analyses were also found to be below the recommended critical level as suggested by WHO/FAO (2010).

Laboratory results of the chemical composition of the amendments used in the experiment

The poultry manure and the residues of cowpea and soybean showed different chemical attributes (Table 2) and contained varying quantities of nutrients needed for plant growth. The highest values for all the parameters were found in the poultry manure, except for OC and C:N ratio. Higher concentrations for N, K, Mg, and OC were also found in cowpea residue when compared with soybean residue. The poultry manure had the lowest C:N ratio, while soybean residue had the highest C:N ratio (Table 2).

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on vine length of *T. cucumerina*

The effects of sole and combined applications of poultry manure and residues of cowpea and soybean were significant ($p < 0.05$) on the vine length of the test crop (Table 3). At 4 WAT in both years, all treatments containing poultry manure (PM) showed a significantly improved vine length, while there were no significant differences between the sole applications of cowpea residue (CP) and soybean residue (SB), except at 6 WAT in 2022 when the vine length was significantly

Table 2. Chemical composition of the amendments used in the study.

Amendment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	OC (%)	Zn (%)	C:N
Cowpea residue	2.65	0.29	1.09	1.32	0.30	45.20	1.27	17.05
Soybean residue	1.13	0.52	0.90	1.43	0.21	40.00	0.88	35.39
Poultry manure	2.88	1.30	1.67	3.30	0.54	21.61	4.75	7.50

Table 3. Effects of sole and combined applications of poultry manure, cowpea and soybean residue on vine length of *T. cucumerina* during 2021 and 2022 cropping seasons.

	Vine length (cm)					
	2021			2022		
Treatments	4 WAT	6 WAT	8 WAT	4 WAT	6 WAT	8 WAT
50% CP + 100% PM	66.76 a	115.83 a	168.10 a	63.25 a	100.58 a	163.52 a
50% SB + 100% PM	64.50 a	100.48 ab	159.60 b	61.55 a	105.96 a	154.40 b
100% CP + 50% PM	64.83 a	109.17 a	171.45 a	62.57 a	111.98 a	167.41 a
100% SB + 50% PM	62.83 a	95.33 b	155.22 b	60.45 a	97.90 ab	153.74 b
150% CP	35.17 b	79.67 c	140.40 c	33.00 b	77.32 b	131.78 c
150% SB	32.23 b	72.33 c	132.33 c	31.63 b	68.22 c	128.53 c
150% PM	62.50 a	85.67 cd	124.88 d	63.85 a	81.72 b	119.00 d
50% CP + 50% SB + 50% PM	66.00 a	112.50 a	174.00 a	61.12 a	110.22 a	169.20 a
Control	20.83 c	32.67 f	49.70 e	22.76 c	35.90 d	61.20 f

Means within columns followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. WAT = Weeks after transplanting, CP = Cowpea residue, SB = Soybean residue, PM = Poultry manure.

shorter for plants grown with the application of 150% SB. There were no substantial differences in the values obtained across the two years for the treatment that comprised SB, CP and PM, though the differences between the years were not statistically verified. Plants grown in the control had the shortest vine length in both years.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on the number of leaves of T. cucumerina

At 4 and 6 WAT in both years, there were no significant differences in the number of leaves between the treatments containing PM (Table 4). At 8 WAT in both years, treatments 100% CP + 50% PM, 50% CP + 100% PM, and 50% CP + 50% SB + 50% PM produced the highest number of leaves, with statistically similar values. A significantly lower number of leaves was recorded in plots treated with sole cowpea and soybean residues when compared with treatments fortified with PM. The lowest number of leaves were produced for plants grown in the control plots.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on the number of branches of T. cucumerina

The number of branches of *T. cucumerina* as affected by the applications of poultry manure and residues of cowpea and soybean is as presented in Table 5. At all sampling times in 2021 and 2022, plants grown in plots treated with 100% CP + 50% PM produced the highest number of branches, with values statistically similar to those grown in plots treated with 50% CP + 100% PM, 50% SB + 100% PM and 50% CP + 50% SB + 50% PM, except at 8 WAT in 2022 where plots treated with 50% SB + 100% PM produced a lower number of branches. Other treatments produced varying numbers of branches with the control having the lowest number of branches when compared with all other treatments.

Table 4. Effects of sole and combined applications of poultry manure, cowpea and soybean residue on the number of leaves of *T. cucumerina* during 2021 and 2022 cropping seasons.

	Number of leaves					
	2021			2022		
Treatments	4 WAT	6 WAT	8 WAT	4 WAT	6 WAT	8 WAT
50% CP + 100% PM	12.67 a	16.33 a	23.00 a	12.21 a	14.79 ab	23.21 a
50% SB + 100% PM	12.00 a	14.30 ab	20.65 b	11.78 a	14.62 ab	21.00 b
100% CP + 50% PM	12.87 a	16.50 a	24.17 a	11.92 a	15.88 ab	23.57 a
100% SB + 50% PM	12.20 a	14.50 ab	20.88 b	11.72 a	14.66 ab	19.90 b
150% CP	10.10 b	13.42 b	18.17 c	10.52 b	13.52 b	17.58 c
150% SB	10.00 b	13.20 b	18.00 c	10.44 b	13.20 b	17.24 c
150% PM	10.15 b	12.67 bc	18.20 c	10.42 b	13.33 b	18.00 b
50% CP + 50% SB + 50% PM	13.00 a	17.33 a	23.50 a	12.58 a	15.90 a	24.10 a
Control	7.35 c	9.17 d	13.27 d	6.71 c	10.22 c	12.24 d

Means within columns followed by the same letter are not significantly different at $p \le 0.05$ according to Tukey's test. WAT = Weeks after transplanting, CP = Cowpea residue, SB = Soybean residue, PM = Poultry manure.

Table 5. Effects of sole and combined applications of poultry manure, cowpea and soybean residue on the number of branches of *T. cucumerina* during 2021 and 2022 cropping seasons.

	Number of branches					
	2021			2022		
Treatments	4 WAT	6 WAT	8 WAT	4 WAT	6 WAT	8 WAT
50% CP + 100% PM	1.33 a	1.67 a	3.97 a	1.37 a	1.76 a	4.32 a
50% SB + 100% PM	1.32 a	1.65 a	3.88 a	1.35 a	1.70 ab	3.40 b
100% CP + 50% PM	1.35 a	1.68 a	4.53 a	1.40 a	1.80 a	4.61 a
100% SB + 50% PM	1.30 a	1.67 a	3.63 a	1.35 a	1.60 b	3.88 b
150% CP	0.50 c	1.33 b	3.00 b	0.62 c	1.36 c	2.98 c
150% SB	0.42 c	1.29 b	2.83 b	0.45 c	1.31 c	2.92 c
150% PM	1.25 b	1.33 b	2.98 b	1.25 b	1.40 c	3.00 c
50% CP + 50% SB + 50% PM	1.29 a	1.65 a	3.83 a	1.34 a	1.70 a	4.63 a
Control	0.00 d	0.00 c	0.17 c	0.00 d	0.00 d	0.21 d

Means within columns followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. WAT = Weeks after transplanting, CP = Cowpea residue, SB = Soybean residue, PM = Poultry manure.

Table 6. Effects of sole and combined applications of poultry manure, cowpea and soybean residues on days to first flowering, days to fruit maturity and number of fruits of *T. cucumerina* during 2021 and 2022 cropping seasons.

	2021			2022		
Treatments	Days to first flowering	Days to fruit maturity	Number of fruits plot^{-1}	Days to first flowering	Days to fruit maturity	Number of fruits plot^{-1}
50% CP + 100% PM	48.67 c	94.00 b	4.97 ab	49.60 c	94.35 b	5.25 b
50% SB + 100% PM	49.00 c	89.33 c	4.12 b	50.12 c	90.22 b	4.84 b
100% CP + 50% PM	48.83 c	86.33 bc	6.00 a	49.85 c	86.85 c	6.21 a
100% SB + 50% PM	49.00 c	86.50 bc	4.54 b	50.00 c	87.00 c	4.55 b
150% CP	52.17 b	91.00 b	4.22 b	53.25 b	92.75 b	4.36 b
150% SB	52.83 b	93.67 b	4.10 b	53.55 b	93.50 b	3.88 b
150% PM	53.60 b	94.00 b	3.33 c	51.93 bc	94.58 b	4.51 b
50% CP + 50% SB + 50% PM	46.67 c	85.50 bc	5.67 a	49.50 c	81.72 bc	6.05 a
Control	61.17 a	100.83 a	3.33 c	62.17 a	107.00 a	3.02 c

Means within columns followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. WAT = Weeks after transplanting, CP = Cowpea residue, SB = Soybean residue, PM = Poultry manure.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on days to flowering and maturity and number of fruits of T. cucumerina

The data revealed that the combinations of amendments significantly affected the number of days to first flowering, number of days to fruit maturity and the number of fruits harvested per plot (Table 6). In both years, plants in the control had a significantly higher number of days to first flowering and days to fruit maturity when compared with all other treatments. Early flowering was observed with the applications of 100% CP + 50% PM, with values statistically similar to those for 50% CP + 100% PM, 50% SB + 100% PM, 100% SB + 50% PM and 50% CP + 50% SB + 50% PM. Sole application of 150% CP and 150% SB delayed the number of days to first flowering and fruit maturity when compared to their mixtures with poultry manure.

Treatment 100% CP + 50% PM recorded the maximum number of fruits per plot, which was similar to that for 50% CP + 50% SB + 50% PM, but significantly different from other treatments, while the lowest number of fruits produced per plot was in the control.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on fruit parameters of T. cucumerina

The fruit length, fruit girth and fruit weight of the test crop varied significantly with the application of different soil applied amendments (Table 7). The application of 100% CP + 50% PM produced higher values for fruit length, though in 2021 the values were similar to those obtained for the other treatments, except the control and the sole application of cowpea and soybean residues (which were lower in both years). For fruit girth, all treatments produced similar values, apart from for sole application of cowpea and soybean and the control, where fruit girth was smaller. In both years, the highest fruit weight was recorded with the application of 100% CP + 50% PM, though in 2022 the fruit weight was statistically similar to that recorded for 50% CP + 50% SB + 50% PM and for 150% PM. Other treatments resulted in varying fruit weights, with the lowest weights recorded in the control in both years.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on the vitamin and lycopene compositions of T. cucumerina

Irrespective of the PM levels, there were no significant differences in the concentrations of vitamins A, E, C and lycopene in plots amended with sole PM or PM combined with residues of cowpea and soybean. Sole application of cowpea (150% CP) or soybean (150%) residue resulted in significantly lower values for these parameters. Plants grown in the control had the lowest concentrations of vitamins (Figure 1).

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on the mineral compositions of T. cucumerina

The fruit of *T. cucumerina* contained varying levels of mineral elements depending on the type, rate and different combinations of the amendments applied (Figure 2). Higher values for Fe, Zn, Mg, and K were recorded with the application of 50% CP + 100% PM, though these values were not statistically different from the application of 100% CP + 50% PM, 150% PM or 50% CP + 50% SB + 50%. In a similar vein, higher concentration of Ca and P were obtained from all combinations containing soybean residue and the sole application of PM. The lowest values for all the mineral elements were recorded in the control plots.

Effects of sole and combined applications of poultry manure, cowpea and soybean residues on the proximate compositions of T. cucumerina

The moisture content of the *T. cucucmerina* fruit were similar in all treatments (Figure 3). There were varying levels of ash content for the different treatments, with treatments with 100% CP + 50% PM, 100% SB + 50% PM and 50% CP + 50% SB + 50% PM recording higher and statistically similar values. There were no significant differences in the concentrations of fat between the treatments. Significantly higher values for protein and fibre content were recorded when 100% CP + 50% PM and 100% SB + 50% PM were applied. The control gave higher values for carbohydrates, which were similar to the values obtained when 100% CP + 50% PM, 100% SB + 50% PM or 50% CP + 50% SB + 50% PM were applied.

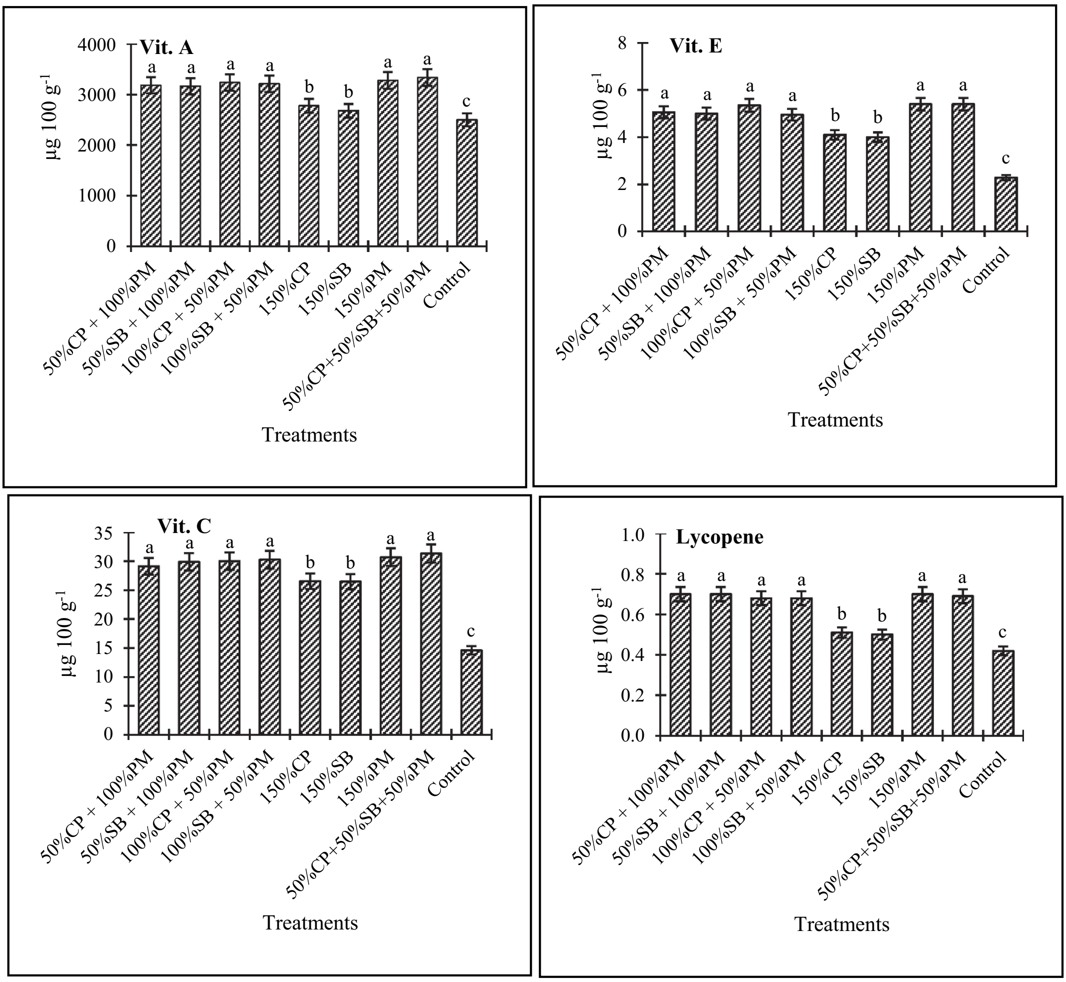

Figure 1. Combined analysis of 2021 and 2022 cropping seasons of the effects of sole and combined applications of poultry manure, cowpea and soybean residue on vitamin A, E, C and lycopene concentrations of *T. cucumerina*. Means/bars with the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. CP = cowpea residue, SB = soybean residue, PM = poultry manure.

Table 7. Effects of sole and combined applications of poultry manure, cowpea and soybean residue on fruit parameters of *T. cucumerina* during 2021 and 2022 cropping seasons.

	2021			2022		
Treatments	Fruit length (cm)	Fruit girth (cm)	Fruit weight plot^{-1} (g)	Fruit length (cm)	Fruit girth (cm)	Fruit weight plot^{-1} (g)
50% CP + 100% PM	60.50 ab	40.02 a	345.23 b	60.74 b	39.58 a	342.50 b
50% SB + 100% PM	59.67 ab	38.27 a	340.55 b	60.45 b	39.00 a	342.22 b
100% CP + 50% PM	65.73 a	41.52 a	383.52 a	66.00 a	41.10 a	379.30 a
100% SB + 50% PM	60.17 ab	39.52 a	307.63 b	60.58 b	38.70 a	310.36 c
150% CP	55.83 b	35.28 b	273.50 c	53.37 c	33.26 c	280.50 d
150% SB	55.00 b	33.05 b	268.66 c	51.85 c	32.75 c	276.44 d
150% PM	65.17 a	39.25 a	340.00 b	64.74 a	40.01 a	351.52 ab
50% CP + 50% SB + 50% PM	64.17 a	40.60 a	356.52 b	66.20 a	42.32 a	360.00 a
Control	45.00 c	29.40 c	157.74 d	47.62 d	28.00 c	200.08 e

Means within columns followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. WAT = Weeks after transplanting, CP = Cowpea residue, SB = Soybean residue, PM = Poultry manure.

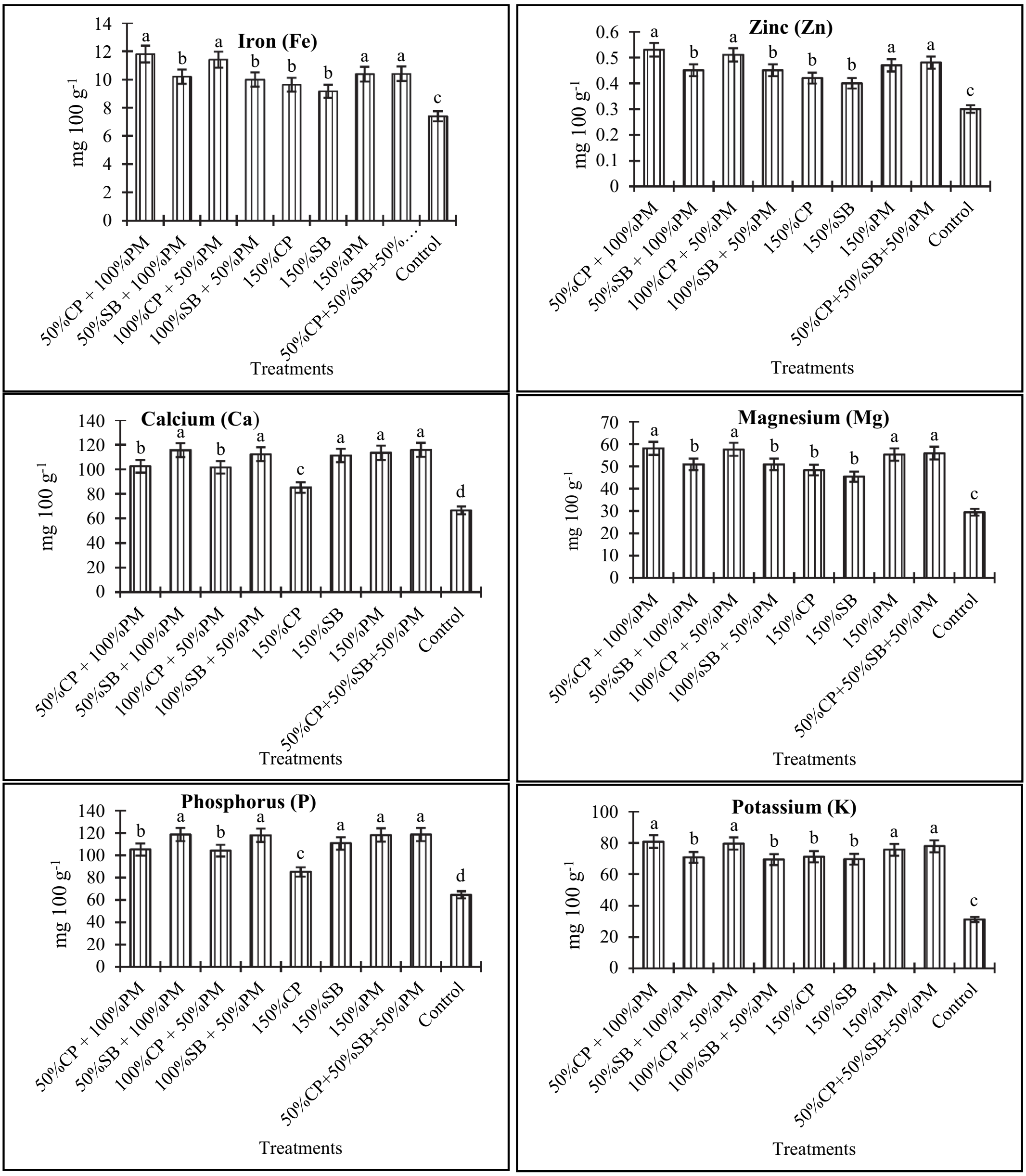

Figure 2. Combined analysis of 2021 and 2022 cropping seasons of the effects of sole and combined applications of poultry manure, cowpea and soybean residues on the mineral compositions of *T. cucumerina*. bars with the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. CP = cowpea residue, SB = soybean residue, PM = poultry manure.

Discussion

The response of *T. cucumerina* in terms of increased vegetative growth and fruit yield with sole and combined applications of PM and residues of cowpea and soybean at different rates was an indication of the inherent low levels of available nutrients in the soil, insufficient for crop growth. It was also an indication that these organic waste materials can be repurposed to provide a natural source of organic matter and nutrients to enrich and improve the properties of the soil (Kong 2014).

The combined applications of PM and residues of cowpea and soybean, at both the lower and the higher rates, significantly improved the vegetative parameters (vine length, number of leaves and number of branches) of the test crop when compared with the control and the sole application of each of the amendments. The significant increase in the vegetative growth of *T. cucumerina* was likely a result of the increased nutrient status, especially nitrogen, of the soil resulting from the applications of PM and crop residues. Soil containing high amounts of N has been shown to result in enhanced vegetative growth (Brandt and Mølgaard 2001). These results were also consistent with Adekiya et al. (2022), where they used organic and inorganic amendments for tomatoes and found that the growth of the crop improved due to the greater availability of nutrients, particularly nitrogen, which is essential for vegetative growth. The increased vegetative performance could also be ascribed to the N release pattern as a result of the applications of PM and residues of cowpea and soybean. The utilisation of crop residues can affect soil N dynamics due to enhancement of water- and N-use efficiency as well as to the incorporation of organic matter to the soil (Sugihara et al. 2012).

The amount and quality of the biomass applied to the soil through crop residue management can have a major effect on soil quality and durability, as well as on the agricultural productivity (Udeata 2008). The results showed that the use of PM and cowpea and soybean residues as organic amendments may have had multiple benefits, as they not only served as a reservoir of major and minor nutrients, but may also have enhanced the physical, chemical, and biological properties of the soil thereby enhancing more extensive root systems. Li et al. (2002) discovered that plants in plots that had been given manure developed root systems that were deeper and more extensive, and so were able to extract more water from the deeper soil layers than those in plots that had not been manured. Organic manure has not only been shown to have direct effects on crop yield and soil fertility, but it has also been found to promote the release of growth hormones, vitamins, and the expansion of microbial populations during the decomposition process (Naik and Sri Hari Babu 2005). This was further corroborated by Mitra et al. (2010). Similar results were shown by van Donk et al. (2012) where they reported that the decomposition of incorporated crop residues released nutrients for crop use and improved the soil physical and chemical properties and plant growth. The increased vegetative growth may also have been a result of synergistic effects of the applications of PM and residues of cowpea and soybean and synchrony in nutrient release and uptake.

Phosphorus (P) is essentially required for healthy growth and efficient root systems. It is also considered as a limiting factor in plant nutrition due to the deficiency of available soluble phosphate in soils (Uma Maheswar and Sathiyavani 2012). Applications of PM and residues of cowpea and soybean significantly increased plant height, number of leaves and number of branches. The increase in the vegetative growth resulting from the application of the amendments could be ascribed to the moderate level of available P in the soil, which may not have been able to sustain the crop to maturity. It could also be as a result of the beneficial effects of phosphates in the process of photosynthesis and other vital physiological processes.

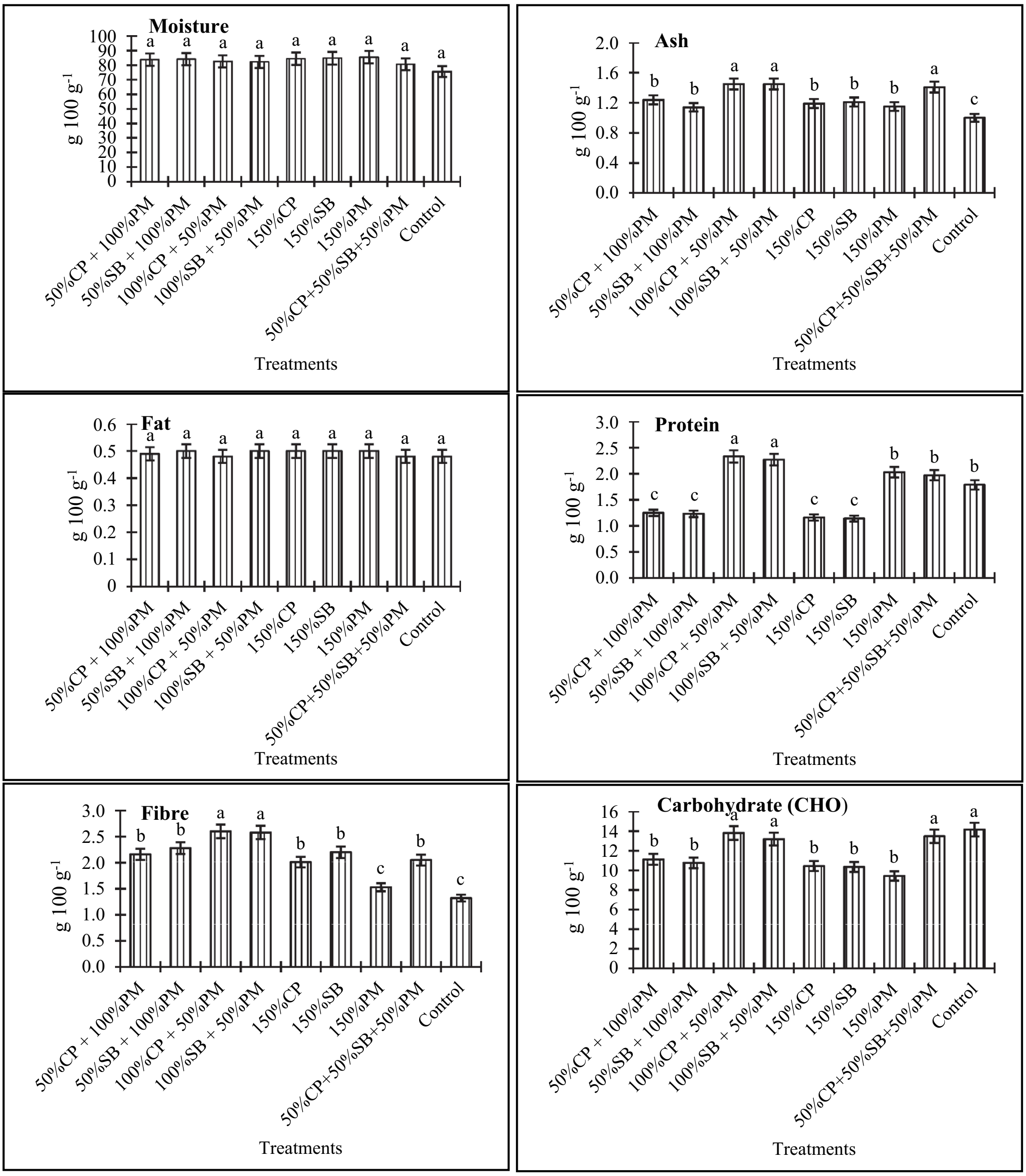

Figure 3. Combined analysis of 2021 and 2022 cropping seasons of the effects of sole and combined applications of poultry manure, cowpea and soybean residues on the proximate compositions of *T. cucumerina*. bars with the same letter are not significantly different at $p \leq 0.05$ according to Tukey's test. CP = cowpea residue, SB = soybean residue, PM = poultry manure.

Organic manure treatments were reported to be responsible for plant growth hormone synthesis and root system development, resulting in increased fruit weight and productivity, as well as in higher nutrient use by tomato plants (Singh and Singh 2013). The use of combined applications of PM and residues of cowpea and soybean at all rates might have increased the microbial activity in the soil, ensuring increased nutrient availability and uptake by crops. These might have resulted in an increase in the number of fruits and in the yield as a result of increased production and accumulation of assimilates in the sinks. It was noted that the increase in the number of fruits from the use of organic amendment could be attributed to the increased availability of mineral nutrients (Beura et al. 2017). Kaur and Singh (2019) discovered that photosynthate production, translocation, and accumulation in the sink may have been enhanced by the presence of nutrients.

Research conducted by Lal (2005) demonstrated that crop residues can have a positive effect on crop yields. Incorporating organic matter into the soil can help reduce soil erosion, increase the soil's ability to retain water, improve the soil structure, and promote the growth of soil microorganisms, leading to more nutrients being available to the plants. The yield increase could also be a result of the application of residues leading to increased availability and nutrient balance for the crop. According to Lal (2005), the use of cover crops can not only help to cut down on nutrient losses from soil but also lead to a more balanced nutrient cycle in agroecosystems.

Phosphorus is known to promote the growth of a more developed root system (Kamara et al. 2011), which in turn helps plants to absorb water and nutrients from deeper soil layers. This may contribute to an increased yield, along with an increase in biomass production, as plants are able to access more assimilates. The reasonable quantities of P present in PM and residues of cowpea and soybean as revealed by their laboratory analyses may have induced plants to form more productive buds, leading to an increased fruit yield and a higher number of fruits per plant.

Heal et al. (1997) reported that the rate of litter decomposition and the release of nutrients from specific plant material depend largely on its chemical and physical characteristics. The utilisation of composted organic amendments sourced from various crop residues typically has a beneficial effect on the physical, chemical, and biological characteristics of soils (Medina et al. 2015). The rate of decomposition of these residues is affected by many factors, including the lignin and cellulose content, the C/N ratio of the particular crop, the environment, and the soil conditions. Application of a combined lower rate of PM and a higher rate of residue of cowpea performed better than the same rate of combined applications of PM and residue of soybean. The reason for the better performance of the combined applications of PM and residues of cowpea as compared to PM and residue of soybean may be linked to its high C:N ratio and chemical composition. Better results from the combination of PM and cowpea residue was reported to be the result of its high biodegradability and mineralisation capacity (Abera et al. 2012; Frimpong et al. 2011). Tian et al. (1998) also noted that a low C:N ratio and lignin content was an indication of the release of high amounts of available nitrogen. Johnson et al. (2007) found that crop residues with a C:N ratio higher than 20 result in immobilisation of nitrogen, while those with a ratio less than 20 result in mineralisation.

Poultry manure has been shown to help plants absorb nutrients more efficiently by acting as a buffer against unwanted pH changes and enhancing soil water availability through retention and aeration, resulting in improved nutrient utilisation by the crop (Adediran et al. 2015). It became clear from this study that application of sole PM or in combination with residues of either cowpea or soybean at lower and higher rates improved growth yield and quality parameters of the test crop. This might be due to the slow-release patterns and improved nutrient use efficiency by the crops (Adeleye and Ayeni 2010).

The improvements of the growth parameters observed in treatments consisting of PM and residues of cowpea and soybean as compared with the amendments with sole residues of cowpea and soybean may be attributed to the slow and constant release of nitrogen from the poultry manure. This provides a sustained supply of nitrogen to the plant, whereas inorganic nitrogen sources are more prone to being lost soon after application.

The test crop showed a poor performance in the control plots, which was likely caused by an inadequate supply of soil nutrients, as seen in the physicochemical properties of the soil. The findings of this study were in agreement with Aluko et al. (2014), who investigated the effect of organic and inorganic fertiliser on the growth and yield of *Corchorus olitorius*. Applying organic fertilisers has been shown to not only enhance soil physical and chemical properties (Janusauskaite and Ciuberkis 2010), as well as soil fertility and water storage capacity (Beeby et al. 2020), but it can also significantly promote both vegetative and reproductive plant growth (Ali et al. 2022), resulting in improved plant and fruit quality (Custic et al. 2003). Vitamins, lycopene, mineral and proximate composition significantly improved with the applications of combined PM and residues of cowpea and soybean than their sole applications. These improvements may be ascribed to the presence and synergy of nutrients released by the amendments, which were easily absorbed by the test crop. Singh et al. (2010) showed similar results, reporting that the quality parameters of the fruit may have increased due to the increased availability of macro- and micro-nutrients, as these are essential for improving the quality of the fruit. It may also have been a result of reduced leaching of nutrients with the application of organic amendments thereby making the nutrients easily available and absorbed by the crop. Applying crop residues to the soil can help to prevent nutrient loss and increase the availability of essential nutrients (Zhang et al. 2021).

Conclusions

The use of agricultural waste materials can have a range of positive effects on crop performance, quality as well as soil health and management. Decomposition and nutrient release patterns of sole and combined applications of PM and residues of cowpea and soybean vary. Applications of combinations of poultry manure (PM) and crop residues of cowpea (CP) and soybean (SB), at both the lower and the higher rates, promoted vegetative growth, yield, yield components and nutritive characteristics of the crop, as compared with when these materials were applied on their own. In this study, it was shown that *T. cucumerina* responded most favourably to application of 100% CP + 50% PM. Although higher values for vegetative growth and nutritional characteristics were generally recorded with the application of 100% CP + 50% PM, for most parameters the effects were statistically similar to that of the other combinations containing PM. 100% CP + 50% PM recorded the highest yields in both years, though in 2022 this yield was similar to that for plants grown with 50% CP + 50% SB + 50% PM and 150% PM. The concentrations of vitamins in the fruit produced with application of 50% CP + 50% SB + 50% PM were similar to that for fruit of plants grown with of 100% CP + 50% PM. Higher values were recorded for concentrations of Ca and P in the fruit with the application of PM and SB. Furthermore, concentrations of protein and fibre were highest with the application of 100% CP + 50% PM and 100% SB + 50% PM. It was concluded that the application of 100% CP + 50% PM resulted in high nutrient use efficiency leading to increased performance and quality characteristics of *T. cucumerina*.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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