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# Photosynthetic pigments concentration, performance, and quality of cucumber (*Cucumis sativus*) in response to the application of organic and inorganic nitrogen sources

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**ABSTRACT**

Nitrogen (N), a macronutrient essential for plant growth and development, plays a crucial role in chlorophyll formation, protein synthesis, and other photosynthetic pigments that affect photosynthesis efficiency and subsequent yield. A screen house experiment was carried out with the objective to investigating the impact of both individual and combined applications of organic and inorganic nitrogen sources as it affects performance, chlorophyll a, b, a + b, carotenoids, and nutritional qualities of cucumber fruit. Different rates of urea (U) fertilizer (0, 60, and 120 kg N $ha^{-1}$) and cow dung (CD) [0, 6, and 12 tonnes $ha^{-1}$] were applied sole and combined. The experimental layout was a completely randomized design (CRD) with three replicates. The collected data were subjected to Analysis of Variance (ANOVA) using GENSTAT Discovery Software, Edition 4. Treatment means were conducted using Tukey's test at a significance level of 0.05. The result indicated that there was an increase in the vegetative parameters of cucumber when applied with combined urea and cow dung as compared with the sole application of the two amendments. The photosynthetic pigments, vitamins and minerals were also found to increase with the application of combined organic and inorganic sources of N. The effects of the application of $U_{60}CD_6$, $U_{60}CD_{12}$, $U_{120}CD_6$, and $U_{120}CD_{12}$ were more pronounced on the vegetative growth, yield, photosynthetic pigments, vitamins and minerals contents of cucumber. Hence, it can be inferred that utilizing urea and cow dung in combination, specifically at the ratio of $U_{60}CD_6$, proves to be cost-effective and well-suited for cultivating cucumbers.

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Cucumber; nitrogen; performance; chlorophyll; carotenoids; quality

## Introduction

Cucumber, scientifically known as *Cucumis sativus* var. sativus L., belongs to the economically significant *Cucurbitaceae* family, which also encompasses squash (*Cucurbita* ssp.), watermelon (*Citrullus lanatus*), and melon (*Cucumis melo* L.). Worldwide, cucumbers and melons are grown more widely than any other vegetable species, next only to tomato (*Solanum lycopersicum* L) and watermelon (Pitrat, Chauvet, and Foury 1999). Cucumbers offer a mild and refreshing flavor alongside their high water content. According to United States Department of Agriculture (USDA) data, a 142 g cup of raw chopped cucumber contains approximately 19.9 g of calcium, 0.3 mg of iron, 17 mg of magnesium, 29.8 mg of phosphorus, and 193 mg of potassium, with just

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2.8 mg of sodium. Additionally, it provides 4.5 mg of vitamin C, 19.9 mcg of folate, 44 mcg of beta carotene, 22.7 mcg of lutein + zeaxanthin, and 10.2 mcg of vitamin K. Cucumbers offer a range of nutrients, including vitamins A, B, and antioxidants, while being low in calories, fat, cholesterol, and sodium.

In agricultural soils, the replenishment of plant nutrients primarily occurs through the utilization of either sole or combined application of inorganic, organic, and biofertilizers (Havlin and Heiniger 2020). The prolonged application of synthetic fertilizers resulted in the degradation of the soil chemical, physical, and biological attributes, ultimately compromising soil health (B. Singh 2018).

Organic manuring is gaining growing importance as a vital component of environmentally sustainable, long-term agricultural practices. Given the increasing demand for safe and nutritious food, as well as the need for long-term sustainability and concerns about environmental pollution caused by the indiscriminate use of chemical fertilizers, organic farming has gained significant prominence on a global scale. While the use of chemical inputs in agriculture remains necessary to meet the rising global food demand, the importance of organic farming cannot be ignored (Karmakar et al. 2007).

Plant growth is often restricted by a lack of nitrogen, which is required in greater quantities than any other elemental mineral. Consequently, the presence of nitrogen plays a crucial role in determining crop yield (Foyer and Noctor 2004). Nitrogen (N) plays a vital role as a key nutrient in influencing the growth, development, yield, and quality of plants (Fernandes and Rossiello 1995). Zhang, Wu, and Hang (2019) discovered that different plant species exhibit varying preferences for nitrogen sources, specifically nitrate ($NO3^-$) and ammonium ($NH4^+$).

Crop growth is influenced by two vital factors: light and nitrogen. Light plays a fundamental role in enabling photosynthesis, a process essential for plant growth. According to a previous investigation (Luo et al. 2018), there is a positive association between N fertilizer and photosynthetic efficiency.

Plant pigments play a crucial role in safeguarding the photosynthetic system and protecting plant organisms from the harmful effects of solar radiation. Among the fundamental pigments, chlorophylls, particularly chlorophyll a and b, possess specialized defensive functions. In this process, accessory pigments called carotenoids also hold significant importance (ĆulafićLj 2000). In today’s context, chlorophylls and carotenoids have gained great significance in the prevention and treatment of various human diseases, including immune system disorders, diverse skin conditions, and their notable antioxidative properties are attributed to these pigments.

The synthesis of chlorophyll relies on mineral nutrition, especially nitrogen (N). Consequently, nitrogen fertilizer application enhances the synthesis of photosynthetic pigments in plant leaves by increasing the levels of stromal and thylakoid proteins (Razaq et al. 2017). The concentration of chlorophyll plays a crucial role in determining the rate of photosynthesis and the production of dry matter (Ghosh et al. 2004).

Availability of nutrients and soil fertility is vital for any vegetable crop to thrive well. According to Huang et al. (2010), it is widely accepted that employing suitable fertilization techniques is essential for enhancing soil structure, boosting nutrient levels, and consequently improving both crop productivity and sustainability. Inorganic fertilizers are renowned for their rich nutrient content and immediate availability in forms easily absorbed by plants. The escalating demands of intensive agriculture worldwide have mandated a surge in the application of inorganic fertilizers to soils. Though very effective in boosting crop yields, long-term and excessive use of chemical fertilizers has led to several issues such as serious degradation, nitrogen leaching, soil compaction, reduction in soil organic matter, and loss of soil carbon (Horrigan, Lawrence, and Walke 2002; Nkoa 2014; Sun et al. 2015).

For good growth and yield of cucumber, good fertile soil is important. Nevertheless, in Nigeria, fertile arable land is on the decline, and this, therefore, necessitates the use of soil amendment to supplement soil nutrients, especially N, which is required for succulent cucumber fruits. In this regard, the use of inorganic fertilizers, like urea, and animal manure has proven to be more convenient in ameliorating soil fertility.

While many researches have been conducted on the use of sole and combined organic and inorganic sources of N fertilizer on soil properties, performance and yield of crops only a little information could be obtained on the effects of the two sources of N fertilizer on chlorophyll a, b, a + b and carotenoid contents of both the leaves and the fruits. Therefore, it is crucial to investigate the impact of both individual and combined applications of organic and inorganic nitrogen sources as it affects performance, chlorophyll a, b, a + b, carotenoids, and nutritional qualities of cucumber fruit. This study hypothesized that the concentration of photosynthetic pigments, performance and quality of cucumber will respond differently to the application of organic and inorganic sources of N fertilizer. To test this hypothesis, studies were conducted to determine which individual or combination of the two N sources would have the most significant effect on the test crop.

## Materials and methods

### *Experimental site*

Two trials were conducted in screen houses installed with heat extractor from September–November 2021 to January–March 2022 at Landmark University's Teaching and Research Farm, located in Omu-Aran, Kwara State. The farm is situated at approximately Latitude 8° 9'N and Longitude 5° 61'E, at an elevation of 495 meters above sea level. This site falls within Nigeria's derived savannah zone, experiencing an average annual rainfall ranging from 600 mm to 1200 mm, primarily occurring between April and September. Throughout the year, temperatures in the area typically range between 33 °C and 34 °C, with a distinct dry season lasting from November to March.

### *Soil collection and filling of grow bags*

In each trial, topsoil was gathered from the area surrounding the screen house, where no farming activities had occurred for 5 years. This soil was meticulously blended using a hand trowel and sieved with a 2 mm sieve. Each grow bag, measuring 30 cm × 17 cm, was filled with twenty (20) kilograms of this topsoil, with perforations at the base to facilitate air circulation and water movement.

### *Analysis of soil physical and chemical attributes*

Soil samples were randomly collected from the filled grow bags before cropping and then bulked to form composite samples for subsequent laboratory analysis for the two trials. The textural classification of the soils was established using the method outlined by Gee and Or (2002). Soil organic carbon (OC) content was assessed utilizing the Walkley and Black procedure employing the dichromate wet oxidation method (Nelson and Sommers 1996). Total nitrogen (N) content was determined *via* the micro-Kjeldahl digestion method (Bremner 1996). Available phosphorus (P) content was evaluated through Bray-1 extraction followed by molybdenum blue colorimetry (Frank, Beegle, and Denning 1998). Exchangeable potassium (K), calcium (Ca), and magnesium (Mg) were extracted using 1 M ammonium acetate. K in the extract was read on a flame photometer, while Ca, Mg and Zn were determined by an atomic absorption spectrophotometer as recommended the Association of Official Analytical Chemists (AOAC (Official methods of analysis of the Association of Official Analytical Chemists) 2006). Soil pH was determined using a soil-water medium at a ratio of 1:2 with a digital electronic pH meter.

### Sources of materials

Cow dung, serving as organic manure, was sourced from the cattle ranch situated within Landmark University farms at the University Teaching and Research Farms. Additionally, urea fertilizer (46%) and cucumber seeds were procured from a reputable agro-allied store located in Omu-aran, Kwara State.

### Laboratory analysis of cow dung

The cow dung utilized in the investigation underwent analysis to assess its nutrient content subsequent to air-drying with warm air (18–21 °C) over a period of 7 days. Following the drying process, the cow dung was pulverized and sifted through a 2-mm mesh sieve. The analysis included the determination of organic carbon (OC) content as well as the overall concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), zinc (Zn), and sodium (Na) (AOAC (Official methods of analysis of the Association of Official Analytical Chemists) 2006).

### Variety of cucumber seed used for the study

The pionsett variety of Cucumber was used for the study. It is a variety of cucumber that can be cultivated outdoors at any time of the year having a maturity period of between 50 and 55 days. The fruit is light green in color with an average length of 15–16 cm and a diameter of 5–6 cm. The flesh of this cucumber variety is crisp, white and tender. It is also a disease-tolerant variety.

### Treatment combinations and experimental design

Treatments consisted of two sources of N fertilizer each applied at three rates viz – 46% N of urea fertilizer (0, 60 and 120 kg N ha$^{-1}$) and cow dung (0, 6 and 12 t ha$^{-1}$). Treatments were combined and tested as follows: $U_0CD_0$, $U_0CD_6$, $U_0CD_{12}$, $U_{60}CD_0$, $U_{60}CD_6$, $U_{60}CD_{12}$, $U_{120}CD_0$, $U_{120}CD_6$, and $U_{120}CD_{12}$. The treatments were arranged in the screen house following a completely randomized design (CRD), with 30 cm by 60 cm spacing both within and between rows, and replicated three times.

### Cultural practices

#### Incorporation of amendments

The application of the amendments was based on the standard agricultural practices and nutrient requirements of cucumber plants based on the chemical analysis of the soil of the experimental area (Nweke and Nsoanya 2015). Cow dung was applied at the rate of 0, 6, and 12 tonnes ha$^{-1}$ and thoroughly mixed with the soil at a depth of about 5 cm two weeks before seed sowing for mineralization and nutrient release to take place while urea fertilizer was applied two weeks after sowing. The equivalent of the application of 0, 60 and 120 kg N ha$^{-1}$ of urea to 20 kg of soil was 0 g, 1.3, and 2.6 g while the equivalent of the application 0, 6, and 12 kg N ha$^{-1}$ cow dung to 20 kg of soil were 0 g, 3.33, and 6.67 g.

### *Seed sowing*

Two cucumber seeds were sown per grow bag at a depth of about 5 cm. Two weeks following the sowing process, a thinning operation was carried out leaving one vigorous and healthy seedling per grow bag.

### *Irrigation, temperature and humidity control in the screen house*

During the initial week after sowing, the drip irrigation system that dispenses 0.5 L of water per grow bag in 30 min on each irrigation day was utilized to apply a modest amount of water for regular irrigation. Following that, a strategy of alternating irrigation days with periods of one to two days of water stress to promote deep rooting was employed. Temperature and relative humidity within the screen house during the period of the experiment was monitored using a Thermograph and a Barograph, and they were at an average of 31 °C and 75%, respectively

### *Training/staking, trellising and weed control*

These activities were performed on a weekly basis and whenever necessary. Training is employed to promote vertical growth in the plants, while trellising aids in their horizontal expansion. These two practices contribute to optimal air circulation within both the plants and the screen house. They facilitate efficient plant and screen house management, while also preventing the fruits from coming into contact with the ground. Weed control involved manually removing weeds from inside and around the grow bags.

### *Harvesting*

Mature fruits were harvested every five days for four weeks, starting 53 days after seed sowing, until the experiment concluded. Harvested fruits were weighed with the aid of an automated weighing balance of a maximum capacity of 2100 g, readable at 0.01 g, and a model by OHAUS Corporation, USA. Subsequently, fruit samples from each treatment were collected and taken to the laboratory to assess chlorophyll a, chlorophyll b, total chlorophyll (a + b), and carotenoid content.

### *Observation and data collection*

The following parameters were monitored and taken during the experiment: vine length (cm), number of leaves, number of primary branches, stem diameter (cm), number of days to first flowering, number of days to 50% flowering, number of days to first fruiting, number of days to 50% fruiting, number of fruits per grow bag, fruit girth, Fruit length, Fruit weight, yield, quality and physiological parameters (photosynthetic pigments).

### *Laboratory determination of levels of photosynthetic pigments*

Laboratory analysis of chlorophyll and carotenoids were conducted for representative leaf and fruit samples per treatment at the expiration of the experiment. Both leaf and fruit samples underwent laboratory analysis to ascertain the levels of chlorophyll a, b, a + b, and carotenoids. Chlorophyll and carotenoids were quantified through the extraction of fresh leaf and fruit tissue using 80% acetone. The absorbance of the resulting centrifuged extract was measured at 663, 645, and 440 nm for chlorophyll a, b, and carotenoids, respectively. The content of chlorophyll a, b, a + b, and carotenoids was calculated using the methodologies as outlined by Ikan (1996). The following equations were used.

Chlorophyll a mg/g tissue $= 12.7\ (A_{663}) - 2.69\ (A_{645}) \times V \div 1000 \times W$
Chlorophyll b mg/g tissue $= 22.9\ (A_{645}) - 4.68\ (A_{663}) \times V \div 1000 \times W$
Total chlorophyll (a + b) mg/g tissue $= 20.2\ (A_{645}) + 8.02\ (A_{663}) \times V \div 1000 \times W$
Carotenoid $= 0.0105 + 23.5366 \times A(440)$

Where A = Absorbance at specific wavelengths. V = Final volume of chlorophyll extract in 80% acetone. W = Fresh weight of tissue extracted.

### *Laboratory determination of cucumber fruits vitamin content*

The levels of vitamins (A, B9, C, and K) in water extracts from cucumber samples were assessed following the methodology outlined by Gorinstein et al. (2010). All measurements were conducted in triplicate.

### *Laboratory determination of cucumber fruits mineral element content*

Samples of cucumber fruits were systematically collected from each plot and replicate for analysis of mineral element concentrations at the Crop and Soil Laboratory of Landmark University in Omu-Aran, Nigeria. Mature fresh cucumber fruits were harvested, sliced, and subjected to 24-h oven-drying at 80 °C, followed by grinding in a Willey mill. The mineral content analysis was conducted following methods recommended by the Association of Official Analytical Chemists (AOAC (Official Methods of Analysis of the Association of Official's Analytical Chemists) 2005). Each sample, weighing one gram, underwent digestion using a mixture of $HNO_3$, $H_2SO_4$, and $HClO_4$ (in a ratio of 7:2:1 v/v/v). Calcium (Ca), Zinc (Zn), and Magnesium (Mg) contents were determined using an atomic absorption spectrophotometer. (AAnalyst 800 by PerkinElmer) while the Kjeldahl method was employed to determine the total nitrogen content.

### *Statistical analysis*

The data collected from the study were subjected to statistical analysis of variance (ANOVA) using GENSTAT discovery (GenStat 2014). The ANOVA for the two trials were similar, therefore, the means for all the parameters were calculated. The significance of treatment means was compared using Tukey's test at a 5% level of probability.

## Results

### *Initial soil properties*

The pre-cropping soil analysis findings are detailed in Table 1. The soil exhibited strong acidity in pH, very low nitrogen content, high availability of phosphorus, and low levels of exchangeable

**Table 1.** Pre-cropping physical and chemical properties of the experimental soil before amendment application.

| Parameter | 2021 | 2022 | Parameter | 2021 | 2022 |
|---|---|---|---|---|---|
| Sand (%) | 71.0 | 69.2 | Organic matter (%) | 1.98 | 2.01 |
| Silt (%) | 13.5 | 14.5 | K (mg $kg^{-1}$) | 0.13 | 0.11 |
| Clay (%) | 15.5 | 16.3 | Ca (mg $kg^{-1}$) | 1.90 | 2.00 |
| Textural class | Sandy loam | Sandy loam | Mg (mg $kg^{-1}$) | 0.29 | 0.30 |
| pH ($H_2O$) 1:2 | 5.25 | 5.35 | Available P (mg $kg^{-1}$) | 9.12 | 9.14 |
| Total nitrogen (%) | 0.15 | 0.101 | Zn (mg $kg^{-1}$) | 0.33 | 0.35 |

potassium. However, exchangeable sodium, calcium, and magnesium were all within suitable ranges. Organic matter content was found to be low. Additionally, the soil showed high sand content with relatively lower values in silt and clay, classifying it as sandy loam.

### The chemical composition of the cow dung used for the study

The results of the laboratory analyses on the cow dung used in the study are outlined in Table 2. These findings demonstrated the presence of diverse levels of macro and micro-nutrients which are crucial for enhancing soil fertility and promoting plant growth.

### Effects of the application of organic and inorganic sources of N amendments on the vine length and stem diameter of cucumber

The sole and different combinations of the application of organic and inorganic sources of N amendments showed a significant effect on the vine length and stem girth of cucumber (Table 3). Though the difference in vine length and stem diameter with the application of the amendments was not significant at 2 and 4 wk after sowing (WAS) for both parameters but at 6 and 8 WAS all treatments containing the combination of the two sources of N amendments and at all levels significantly increased both parameters. In a similar vein, the sole application of each of the amendments at different levels resulted in non-significant similar values at 6 and 8 WAS. The least values for the two parameters were recorded at the control treatment.

### Effects of applying organic and inorganic N amendments on the number of leaves and branches of cucumber

The findings on the number of leaves and branches of cucumber as influenced by the utilization of both organic and inorganic nitrogen amendments are presented in Table 4. The data revealed a non-significant effect of the amendments on the number of leaves and branches at 2 WAS but at 4 WAS only treatments with the combination of the two amendments had higher but similar

**Table 2.** Chemical composition of the organic amendments (cow dung) used for the study.

| Amendment | OC % | N % | P % | K % | Ca % | Mg % | Zn % | C:N |
|---|---|---|---|---|---|---|---|---|
| Cow dung | 25.70 | 1.84 | 0.82 | 1.98 | 0.99 | 0.54 | 0.10 | 14.78 |

**Table 3.** Mean effects of the application of organic and inorganic sources of N amendments on the vine length and stem diameter of cucumber.

| | Vine length (cm) | | | | Stem diameter (cm) | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 2 WAS | 4 WAS | 6 WAS | 8 WAS |
| $U_0CD_0$ | 5.17b | 14.67c | 79.00d | 105.33d | 0.22ab | 0.51b | 0.55c | 0.56c |
| $U_0CD_{60}$ | 6.17ab | 25.67ab | 93.72c | 135.32c | 0.24ab | 0.53b | 0.71b | 0.72b |
| $U_0CD_{12}$ | 6.00ab | 25.83ab | 96.20c | 130.45c | 0.25ab | 0.55b | 0.72b | 0.73b |
| $U_{60}CD_0$ | 6.83ab | 26.52ab | 107.71b | 160.34b | 0.26a | 0.61ab | 0.74b | 0.75b |
| $U_{60}CD_6$ | 6.83ab | 26.50ab | 144.29a | 199.52a | 0.26a | 0.62ab | 0.81a | 0.82a |
| $U_{60}CD_{12}$ | 6.83ab | 30.33a | 147.70a | 200.57a | 0.27a | 0.66ab | 0.81a | 0.85a |
| $U_{120}CD_0$ | 7.17ab | 29.72a | 130.62b | 167.44b | 0.28a | 0.68a | 0.73b | 0.76b |
| $U_{120}CD_6$ | 8.33a | 30.67a | 145.33a | 202.85a | 0.29a | 0.69a | 0.82a | 0.87a |
| $U_{120}CD_{12}$ | 7.50a | 32.50a | 147.70a | 200.01a | 0.29a | 0.73a | 0.82a | 0.87a |
| SED ± | 5.19 | 7.33 | 23.14 | 35.21 | 0.08 | 0.14 | 1.85 | 1.90 |
| SD | 0.91 | 5.22 | 27.27 | 36.65 | 0.02 | 0.08 | 0.09 | 0.10 |

There is no significant difference among means having an identical letter(s) with a certainty level of 95% according to Tukey's test. SED = Standard Error of the Difference; SD = Standard Deviation; WAS = Weeks after sowing; U = Urea; CD = Cow dung.

**Table 4.** Mean effects of the application of organic and inorganic sources of *N* amendments on the number of leaves and branches of cucumber.

| | Number of leaves | | | | Number of branches | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | 2 WAS | 4 WAS | 6 WAS | 8 WAS | 2 WAS | 4 WAS | 6 WAS | 8 WAS |
| $U_0CD_0$ | 1.67a | 3.00b | 11.33c | 17.33c | 0.00a | 0.00c | 1.00c | 2.00c |
| $U_0CD_{60}$ | 2.00a | 4.67ab | 16.33bc | 22.67b | 0.00a | 2.25b | 3.00b | 3.24b |
| $U_0CD_{12}$ | 1.67a | 4.33ab | 17.00b | 24.67b | 0.00a | 2.30b | 3.00b | 3.50b |
| $U_{60}CD_0$ | 2.33a | 4.67ab | 17.67b | 23.67b | 0.00a | 2.26b | 3.00b | 3.25b |
| $U_{60}CD_6$ | 2.00a | 5.00a | 22.33a | 34.00a | 0.00a | 2.50a | 3.35a | 4.56a |
| $U_{60}CD_{12}$ | 2.00a | 5.33a | 22.00a | 34.33a | 0.00a | 2.59a | 3.40a | 4.59a |
| $U_{120}CD_0$ | 1.67a | 4.33ab | 21.67ab | 32.00a | 0.00a | 2.30b | 3.20ab | 3.50b |
| $U_{120}CD_6$ | 2.3a | 5.67a | 23.67a | 35.67a | 0.00a | 2.62a | 3.35a | 4.60a |
| $U_{120}CD_{12}$ | 1.67a | 5.33a | 23.65a | 33.67a | 0.00a | 2.63a | 3.33a | 3.55b |
| SED ± | 0.68 | 1.80 | 6.05 | 9.00 | 0.00 | 0.20 | 0.52 | 1.25 |
| SD | 0.27 | 0.79 | 4.18 | 6.63 | 0.00 | 0.83 | 0.75 | 0.85 |

There is no significant difference among means having an identical letter(s) with a certainty level of 95% according to Tukey's test. SED = Standard Error of the Difference; SD = Standard Deviation; WAS = Weeks after sowing; U = Urea; CD = Cow dung.

**Table 5.** Mean effects of the application of organic and inorganic sources of N amendments on the flowering pattern, yield and yield attributes of cucumber.

| Treatments | Days to first flowering | Days to 50% flowering | Days to fruit maturity | Average fruit weight (kg) | Average fruit girth (cm) | Average fruit length (cm) |
|---|---|---|---|---|---|---|
| $U_0CD_0$ | 44.67a | 53.33a | 0.00c | 0.000c | 0.00c | 0.00d |
| $U_0CD_{60}$ | 43.00a | 48.00b | 51.67a | 0.242b | 15.30b | 15.53c |
| $U_0CD_{12}$ | 43.67a | 49.33b | 51.67a | 0.248b | 15.20b | 15.83c |
| $U_{60}CD_0$ | 43.67a | 49.00b | 51.00a | 0.233b | 15.33b | 14.50c |
| $U_{60}CD_6$ | 40.67b | 45.00c | 48.33b | 0.335a | 17.70a | 18.83ab |
| $U_{60}CD_{12}$ | 40.00b | 46.67c | 49.33b | 0.333a | 17.40a | 18.60ab |
| $U_{120}CD_0$ | 40.00b | 46.67c | 53.67a | 0.237b | 15.00b | 17.00b |
| $U_{120}CD_6$ | 39.33b | 43.33c | 51.33a | 0.342a | 17.83a | 19.00a |
| $U_{120}CD_{12}$ | 38.33b | 42.33c | 51.00a | 0.32a | 15.50a | 17.27b |
| SED ± | 2.320 | 2.872 | 3.269 | 0.031 | 1.338 | 1.920 |
| SD | 2.28 | 3.35 | 17.07 | 0.11 | 5.51 | 5.90 |

There is no significant difference among means having an identical letter(s) with a certainty level of 95% according to Tukey's test. SED = Standard Error of the Difference; SD = Standard Deviation; U = Urea; CD = Cow dung.

values for the number of leaves while the effects were significant on the number of branches. In contrast to the control group that produced the fewest leaves and branches, treatment $U_{120}CD_6$ produced a greater number of leaves and branches which was statistically similar to other co-applications of the two amendments at 6 and 8 WAS. The sole application of each of the amendments gave varying but lower values.

### *Effects of the application of organic and inorganic sources of N amendments on the flowering pattern, yield and yield attributes of cucumber*

Table 5 presents the effects of the application of organic and inorganic sources of N amendments on the flowering pattern, number of days to maturity, yield and yield attributes. Data presented showed that grow bags applied with $U_{120}CD_{12}$ produced the first flower and number of days to 50% flowering earlier than the other treatments and the values obtained were statistically similar to grow bags applied with $U_{60}CD_6$, $U_{60}CD_{120}$, $U_{120}CD_0$ and $U_{120}CD_6$. There was a non-significant increase in the number of days to first flowering in control grow bags and grow bags amended with sole urea and cow dung. In a similar vein, control grow bags had a delayed number of days to 50% flowering followed by grow bags amended with $U_0CD_6$, $U_0CD_{12}$, and $U_{60}CD_0$.

The effect of treatments on the number of days to maturity shows that cucumber fruits matured earlier with the application of $U_{60}CD_6$, and $U_{60}CD_{12}$. Other treatments produced a significant and similar number of days to fruit maturity. There were variations in fruit weight, girth and length when all amendments were applied with treatment $U_{120}CD_6$ producing heavier, wider and longer fruits although the values exhibited statistical similarity with other combined applications of organic and inorganic sources of N amendments except for fruit length where the application of $U_{120}CD_{12}$ was not significant.

### Effects of the application of organic and inorganic sources of N amendments on leaf and fruit chlorophyll a, b, a + b, and carotenoid of cucumber

Application of treatments indicated that there was a significant reduction in the leaf and fruit chlorophyll a, b, a + b, and carotenoid content of cucumber in the control grow bags when compared with the sole and combined application of the two sources of N amendments (Table 6). There was also a reduction in the concentration of the pigments with the sole application of the two sources of N amendments when compared with the values obtained when the combined treatments were applied. Significant and higher pigment concentrations were observed with the application of the combined sources of N when compared with the control and sole application of the two sources of N amendments though the values are statistically similar.

### Effects of the application of organic and inorganic sources of N amendments on the vitamins and minerals compositions of cucumber fruits

Vitamins and minerals compositions of cucumber fruits were generally increased with the application of the two sources of N amendments as compared to the control (Table 7). Plants subjected to a combined treatment of urea and cow dung produced significantly higher values ($p < 0.05$) for all the vitamins irrespective of the applied rates when compared with the sole application of each of the amendments. In a similar vein, higher values for all the minerals were recorded with the application of $U_{120}CD_{12}$, the value of which was statistically similar with other rates of combined application of urea and cow dung and sole application of cow dung for Zn, Mg, P and K. Applied $U_0CD_6$, $U_0CD_{12}$ and $U_{60}CD_0$ gave lower values when compared with other treatments except the control which resulted in significantly lower values.

## Discussion

The soil of the experimental site exhibited an acidic pH, with very low nitrogen content and moderate availability of phosphorus. Additionally, the exchangeable potassium was low, whereas

**Table 6.** Mean effect of the application of urea and cow dung on leaf and fruit chlorophyll a, b, a + b, and carotenoid of cucumber leaf and fruit.

| Treatment | Leaf chlorophyll a (mg $m^{-2}$) | Leaf chlorophyll b (mg $m^{-2}$) | Leaf chlorophyll a + b (mg $m^{-2}$) | Leaf carotenoid (mg $m^{-2}$) | Fruit chlorophyll a (mg $m^{-2}$) | Fruit chlorophyll b (mg $m^{-2}$) | Fruit chlorophyll a + b (mg $m^{-2}$) | Fruit carotenoid (mg $m^{-2}$) |
|---|---|---|---|---|---|---|---|---|
| $U_0CD_0$ | 0.20c | 0.19c | 0.46c | 0.17c | 0.00c | 0.00c | 0.00c | 0.00d |
| $U_0CD_{60}$ | 0.40b | 0.27b | 0.62b | 0.28b | 0.05b | 0.03b | 0.08b | 0.61c |
| $U_0CD_{12}$ | 0.44b | 0.20b | 0.65b | 0.26b | 0.06b | 0.03b | 0.85b | 0.72bc |
| $U_{60}CD_0$ | 0.45b | 0.24b | 0.59b | 0.29b | 0.06b | 0.03b | 0.08b | 0.97b |
| $U_{60}CD_6$ | 0.68a | 0.35a | 0.93a | 0.49a | 0.08a | 0.04a | 0.11a | 1.26a |
| $U_{60}CD_{12}$ | 0.69a | 0.38a | 1.20a | 0.60a | 0.09a | 0.04a | 0.11a | 1.18a |
| $U_{120}CD_0$ | 0.64a | 0.34a | 0.95a | 0.49a | 0.08a | 0.04a | 0.10a | 1.03b |
| $U_{120}CD_6$ | 0.70a | 0.38a | 0.10a | 0.59a | 0.09a | 0.04a | 0.10a | 1.07b |
| $U_{120}CD_{12}$ | 0.69a | 0.31a | 0.95a | 0.47a | 0.10a | 0.04a | 0.10a | 0.92ab |
| SED ± | 0.177 | 0.09 | 0.091 | 0.129 | 0.02 | 0.01 | 0.24 | 0.22 |
| SD | 0.306 | 0.156 | 0.158 | 0.224 | 0.035 | 0.017 | 0.416 | 0.38 |

There is no significant difference among means having an identical letter(s) with a certainty level of 95% according to Tukey's test. SED = Standard Error of the Difference; SD = Standard Deviation; U = Urea; CD = Cow dung.

**Table 7.** Mean effects of the application of organic and inorganic sources of N amendments on the vitamins and mineral compositions of cucumber fruit.

| | Vitamins (mg kg$^{-1}$) | | | | Minerals (mg kg$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | A | B9 | C | K | Ca | Zn | Mg | N | P | K |
| $U_0CD_0$ | 0.001c | 0.005d | 1.12d | 3.59d | 8.61c | 0.12b | 8.27c | 0.99c | 14.22c | 50.21c |
| $U_0CD_{60}$ | 0.003b | 0.013b | 3.20b | 9.52b | 14.24b | 0.21a | 13.33a | 0.119b | 24.86a | 74.86a |
| $U_0CD_{12}$ | 0.003b | 0.014b | 3.45b | 9.99b | 14.55b | 0.22a | 13.44a | 0.120b | 24.88a | 74.82a |
| $U_{60}CD_0$ | 0.003b | 0.010c | 2.78c | 8.25c | 13.41b | 0.13b | 10.52b | 0.119b | 18.87b | 61.50b |
| $U_{60}CD_6$ | 0.005a | 0.018a | 4.18a | 14.81a | 18.40a | 0.22a | 13.32a | 0.125a | 24.87a | 74.98a |
| $U_{60}CD_{12}$ | 0.006a | 0.019a | 4.35a | 15.10a | 18.63a | 0.23a | 13.45a | 0.127a | 25.55a | 75.80a |
| $U_{120}CD_0$ | 0.003b | 0.011c | 2.85c | 8.50c | 13.51b | 0.13b | 10.55b | 0.125a | 19.22b | 62.55b |
| $U_{120}CD_6$ | 0.006a | 0.020a | 4.23a | 15.03a | 19.22a | 0.22a | 13.42a | 0.128a | 24.85a | 75.07a |
| $U_{120}CD_{12}$ | 0.006a | 0.022a | 4.37a | 15.11a | 19.54a | 0.23a | 13.50a | 0.128a | 25.62a | 75.66a |
| SED± | 0.0015 | 0.0032 | 0.802 | 2.44 | 2.74 | 0.11 | 4.02 | 0.17 | 3.02 | 6.12 |
| SD | 0.0018 | 0.0055 | 1.065 | 4.128 | 3.650 | 0.048 | 1.930 | 0.289 | 4.091 | 9.220 |

There is no significant difference among means having an identical letter(s) with a certainty level of 95% according to Tukey's test. SED = Standard Error of the Difference; SD = Standard Deviation; U = Urea; CD = Cow dung.

the levels of exchangeable sodium, calcium, and magnesium were all within appropriate ranges. However, the soil had low organic matter content. In a similar vein, the laboratory determination of the mineral composition of the cow dung used for the study revealed that cow dung possesses diverse levels of essential macro and micro-nutrients necessary for enhancing both soil fertility and plant growth. The effects of the amendments were noticeable in all the parameters tested. This could primarily be attributed to the limited mineralizable nitrogen content as evident in the result of the laboratory physical and chemical analysis of the native soil, a consequence of their low organic matter content.

The result of this study indicated that there was an increase in the vegetative parameters (vine length, stem girth, number of leaves and number of branches) of cucumber when applied with combined urea and cow dung as compared with sole application of the two amendments. The difference in the vegetative parameters could be as a result of the combined effect of urea and cow dung. Ullah et al. (1970) proposed a comparable outcome in their research, which assessed the impacts of organic and chemical fertilizers on the growth and yield of *Solanum melongena*. Similarly, Okunlola, Adejorom, and Fakanlum (2011) discovered that the combined use of poultry and inorganic fertilizers effectively merges the characteristics of both organic and inorganic fertilizers when applied individually. The increased vegetative parameters may also be ascribed to the characteristics of the experimental soil and the favorable conditions within the screen house, which enhanced the nutrient utilization efficiency of the tested crop. This finding aligns with the research of Opiyo (2004), which suggested that soil and air temperatures affect the absorption and translocation of mineral nutrients by plants from the soil.

Adequate nitrogen nutrition enhances flowering and fruit set; however, an excess of nitrogen delays the period of fruit maturity. Early flowering and fruit maturity as observed in the study could be ascribed to the effects of moderate application of combined organic and inorganic sources of N and their capacity to boost cytokinin biological synthesis in the crop. A similar study was conducted by Ding et al. (2014) where they found that cytokinin's presence in the floral meristem induces floral buds to generate a higher number of flowers.

Crop production requires different levels of micro and macro-nutrients. Nitrogen (N), not only affects the vegetative growth of plants and yield but also plays an important role in regulating fruit quality (Yang et al. 2023). Ensuring an ample supply of nitrogen to crops is essential for optim N not only affects the vegetative growth of plants, but also plays an important role in regulating fruit quality [2,18] izing yields, yet excessive nitrogen application may lead to groundwater contamination, as highlighted by Jaynes et al. (2001). Ahmed et al. (2007) found that increased nitrogen application led to the highest measurements in fruit length, fruit weight, vine length, and cucumber yield. In a separate study, Akanni, Ojeniyi, and Awodun (2011) recommended that the joint use of organic and mineral fertilizers demonstrated superior performance in enhancing the yields of tomato, maize, and *Solanum macrocarpon* compared to the exclusive application of either type of fertilizer.

Nitrogen (N) plays a crucial role as a primary nutrient essential for the growth and development of crops, ensuring the production of agricultural products with high quality and yield (Ahmad et al. 2019). The combined application of the two sources of N used for the study had a greater effect on the yield of cucumber. Moderate and combined applied amendments resulted in higher productivity of cucumber. An increase in yield could be attributed to the availability and uptake of nutrients by plants which resulted in improved chlorophyll content and enhanced synthesis of carbohydrates which in turn, contributes to a greater accumulation of photosynthates, which are then distributed to the developing ovules (M. Singh, Khan, and Naeem 2016). The significant increase in yield and its attributes could be adduced to the continuous and slow release of nutrients to the crop as a result of the use of organic source of N which assisted the crop in the uptake and utilization of nutrients. Reports indicated that organic manure enhances the uptake of plant nutrients by acting as a buffer against undesirable pH fluctuations. Additionally, it enhances soil water availability through retention and aeration, ultimately leading to improved nutrient utilization by crops (Adediran et al. 2015). This result is also in agreement with Devi et al. (2002) who reported that different types of organic and mineral fertilizers influenced the yield of brinjal. The enhanced growth parameters, including increased plant height and leaf count, leading to a higher number of flowers per plant in fertilized plots, may account for the positive impact on fruit yield. This observation aligns with findings by Odunze (2006).

Light and nitrogen are the most important factors in crop production. The nitrogen supply has a direct impact on both photosynthetic activity and growth, ultimately influencing yield and the efficient utilization of light energy. Nitrogen serves as the fundamental element for plants, constituting a key component in various plant structures and essential to their physiological and external metabolic processes (P. Singh et al. 2022). The utilization of nitrogen has the potential to enhance various physiological functions in plants, including nutrient absorption, enzyme functionality, and the rate of photosynthesis (Guo et al. 2007). Photosynthesis stands as a fundamental physiological process crucial for the growth, maturation, and metabolic activities of plants (Brück and Guo 2006). The presence of photosynthetic pigments is crucial for the process of photosynthesis.

Photosynthetic pigments play a crucial role in absorbing solar energy and converting it into chemical energy, which is utilized for synthesizing ATP and glucose. Research has extensively documented a positive relationship between leaf nitrogen content and the concentration of photosynthetic pigments across various plant species (Fritschi and Ray 2007). Chlorophyll, a key pigment involved in photosynthesis, is essential for capturing energy from sunlight. In a study conducted on horticultural crops, Nazir et al. (2024) opined that applying nutrients to crops is crucial for enhancing both production yield, fruit quality and sustainability. This is achieved by improving essential physiological functions like nutrient uptake and photosynthetic activity. Chlorophyll is used in the medicine industry as well, for example, as a photosensitizer for cancer therapy (Mishra, Bacheti, and Husen 2012). Carotenoids exhibit highly attractive biological activities, such as antioxidant properties, anti-inflammatory effects, and the attributes of provitamin A, making them attractive for applications in medicine and the treatment of specific diseases (Muhammad et al. 2024).

This study revealed that there was significant effects of combined and different sources of N applications on the photosynthetic pigments of cucumber leaf and fruit. High N supply boosts plant growth and productivity, while also enhancing the photosynthetic capacity of leaves by increasing the levels of stromal and thylakoid proteins within them (Teixeira Filho et al. 2011).

An earlier investigation indicated a positive association between N fertilizer and photosynthetic efficiency (Luo et al. 2018).

The utilization of urea and cow dung resulted in a notable impact on the levels of chlorophyll a, chlorophyll b, total chlorophyll (a + b), and carotenoids in both leaves and fruits. The combined application of both amendments along with a high dose of urea, resulted in higher levels of chlorophyll a, b, a + b, and carotenoids on the plots. The increase in these pigments as a result of the application of the two sources of N could be because nitrogen is a constituent molecule of chlorophyll. It could also be a result of nitrogen being the main constituent of all amino acids and hence of proteins and lipids as glactolipids, acting as a structural component of chloroplast. The result of this study is in agreement with that obtained by Adelusi and Oseni (2015) where they found that as the nitrogen content increased, there was a corresponding rise in the concentrations of photosynthetic pigments and yield of tomato. The increase in chlorophyll a, b and a + b of the leaves and fruit of cucumber as a result of the application of combined organic and inorganic sources of N could be ascribed to the effects of the organic N which releases its nutrients gradually.

Improving the absorption of nutrients by plants from the soil can be accomplished by managing the overall nitrogen balance and the quantity of nitrogen reserves within the soil (Cassman, Dobermann, and Walters 2009). The increased mineral and vitamin concentrations in cucumber fruits resulting from the simultaneous use of organic and inorganic sources of N fertilizers can be attributed to the improvement of soil chemical properties. Applying organic fertilizers which are derived from animal excreta or other agricultural residues, is typically employed to enhance soil structure and stability. Additionally, it plays a crucial role in improving the yield and quality of crop plants (Marzouk and Kassem 2011). Vitamin composition of cucumber fruits varied with the application of sole and combined sources of N amendments. The result of this study indicated that all treatments with combined application of organic and inorganic N amendments improved vitamins A, B9, C and K. Vitamins and minerals are found in fruits, vegetables, and whole grains (Gil-Ch′avez et al. 2010). According to Aboyeji (2022), vegetables grown using organic methods often demonstrated higher levels of bioactive compounds in comparison to those cultivated conventionally.

Examination of cow dung in the laboratory unveiled a notable presence of mineral elements. The mineral composition of cucumber fruits displayed a noteworthy correlation with the diverse levels of sole and combined application of the two nitrogen sources employed in the study

Laboratory analysis of cow dung revealed a notable presence of mineral elements. The mineral content in cucumber fruits exhibited a significant correlation with various levels of sole and combined application of the two nitrogen amendment sources used in the experiment. An increase in Ca, Zn, Mg, N, P and K in cucumber fruits could be a result of the application of organic manure which increases the availability of the mineral elements in the soil. The introduction of organic materials into the soil substantially boosts the availability of macro and micro-nutrients when compared to the control group (Aboyeji et al. 2023). Increase in cucumber fruits mineral elements could also be a result of the presence of Zn in the cow dung which facilitated the uptake of other nutrients. Findings from H. P. Singh and Singh (2004) revealed that the application of zinc increased chlorophyll content and elevated the concentrations of zinc, calcium, magnesium, potassium, and phosphorus in tissues.

## Conclusion

Individual application of urea and cow dung did not have significant effect on the vegetative, phenology, yield, photosynthetic pigment concentration and quality of cucumber fruit. The combined application of urea and cow dung at varying levels significantly increased all the parameters measured. This study clearly showed that increased photosynthetic pigments are related to the increasing levels of N amendments. The effects of application of $U_{60}CD_6$ was more pronounced on the performance, photosynthetic pigments and quality of cucumber fruits than other combinations. Based on these findings, it is recommended that the combined application of urea and cow dung at the rate of $U_{60}CD_6$ is economical and suitable for the growth, increased photosynthetic pigments and quality of cucumber.

## Authors contributions

C. M. Aboyeji and F. O. Okunlola developed the concept, designed the experiments and wrote the entire manuscript; S. O. Adelanwa, and W. B. Akaazua, took all the field data and did the laboratory analysis; S. A. Oyekale, and G. M. Muritala, did the statistical analysis and reviewed the manuscript.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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