

## Research Article

# Influence of Abattoir Waste Blood Meal on Soil Chemical Properties, Growth and Yield of African Chili Pepper (*Capsicum Frutescens*) in Nutrient Deficient-tropical Soil

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## Abstract

The use of chemical fertilizers as soil amendment has improved crop yields in sub-Saharan Africa successfully. Unfortunately, they appear to be expensive and readily unavailable to farmers. They are also believed to cause soil acidity, eutrophication and emit greenhouse gases. This current field experiment was carried out to evaluate the effect of blood meal from abattoir blood waste on soil chemical properties (pH, organic Carbon, total Nitrogen, available Phosphorus, and exchangeable Potassium), the concentration of macro elements (Nitrogen, Phosphorus, Potassium, Magnesium, Calcium) and microelements (Copper, Zinc, and Iron) as well as the growth and yield of African chili pepper relative to chemical fertilizer. The study comprised four treatments: blood meal, conventional NPK, combination of blood meal and chemical NPK, and control with five replications in a Randomized Complete Block Design (RCBD). The result showed that blood meal significantly improved the soil pH, organic matter content, total Nitrogen, available Phosphorus and exchange Potassium, and the concentration of macro and microelements in pepper relative to chemical fertilizer and control. Also, Blood meal in combination with chemical fertilizer significantly improved the soil pH, organic matter content, total Nitrogen, available Phosphorus and exchange Potassium, and the concentration of macro and microelements in pepper compared to the chemical fertilizer and control. The study also revealed that the application of blood meal significantly resulted in 7.6%, 32.9% and 398.7% fruit yield increase relative to the combination of blood meal and chemical NPK, conventional NPK alone and control. The application of blood meal from abattoir blood waste can improve soil chemical properties, nutrient concentration, growth and yield of African Chili pepper under field conditions.

## Keywords

Blood Meal, Nutrients Concentration, Soil Chemical Properties, Fertilizer, Yield

## 1. Introduction

The world population is expected to increase from 7.7 billion in 2020 to about 9.7 billion by 2050 [1]. As a result, the global food demand is expected to double by the 2050s [2, 3].

The rate of African population growth, especially in Sub-Saharan Africa, coupled with the changes in food preferences and consumption growth, suggests that the global

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demand for food will increase for at least another 40 years [2] and that food production must more than double to meet the food needs in 2050 [4].

One of the most compelling factors jeopardizing the increase and resilience of agricultural productivity, which is also a significant threat to global food and nutrition security, is soil degradation [5, 6]. It is reported that 65% of the soil and arable land is degraded [7].

Soil fertility decline is a major problem confronting most countries, especially in the tropics, causing food and nutritional insecurity in sub-Saharan Africa [8]. To address this fertility problem, there is the need for external sources to boost and increase the nutrient value and contents of such soils in order to increase crop production.

In sub-Saharan Africa, chemical fertilizers have been extensively applied to crops by farmers to increase productivity and yield [9].

However, overuse of chemical fertilizers can result in soil acidification and compaction [10], cause declines in microbial function and diversity [11], and change microbial assembly processes [12]. These changes can adversely affect soil ecology and food production. They are also expensive and easily unavailable and can result in soil nutrient imbalance [13].

Organic fertilizers are a promising alternative to chemical fertilizers [14, 15] as they are mainly derived or composted from plant-based or animal-based materials, rich in soil nutrients, and carry beneficial microbes. Organic fertilizers could prevent the adverse effects of synthetic fertilizers in agricultural production, improving soil nutrition and microbial communities [16, 17]. However, the adverse effects of these fertilizers from different biological sources on plants and their risks to soil ecology remain poorly apprehended.

Because organic fertilizers are derived from the composting of animal manure, human excreta, household and municipal wastes, agriculture and plant waste [18], they possess a significant possibility of improving environmental cleanliness and sustainability [19].

One important unutilized organic resource available for soil fertility and crop yield enhancement is the wastes generated from the abattoir processing industry, a significant source of environmental problems. In Ghana, large quantities of this waste are generated yearly. According to Awafo & Amenorfe [20], Kumasi alone generates approximately 80,000 tons of abattoir waste (solid + liquid waste) annually.

There are problems and challenges concerning the disposal of abattoir wastes, including unavailability of landfill sites, high labour and transport costs of disposal at landfill sites, and the lack of processing methods [20, 21]. Abattoir or slaughterhouse wastes are made up basically of blood and rumen contents of animals and are an important source of organic matter which can be recycled or converted to soil amendments to improve the fertility of soils and crop yield [22]. Environmentally, the recycling of abattoir waste offers the potential to reduce the quantity of waste sent to landfill sites,

thereby reducing pressure on landfill sites, promoting greener farming, and reducing environmental pollution and employment opportunities [23].

This current study sought to investigate the impact of blood meal made from abattoir blood waste on the improvement of some soil chemical properties (pH, organic Carbon, total Nitrogen, exchangeable Potassium and available Phosphorus) and growth and yield of African Chili pepper (*Capsicum frutescens*).

A report by Ravindran et al., [24] suggested that blood meal contains high molecular weight proteins and can be considered a rich source of Carbon, C and Nitrogen, N for producing organic fertilizers. Due to its rapid mineralization rate, it is regarded as a relatively fast N releaser [25]. Kalbasi & Shariatmadari [26] stated that blood meal has a high N content, between 10-13%, and is made up of hemoglobin (globular protein) and characterized by the presence of a prosthetic group (protoporphyrin) containing iron (Fe) (about 0.2-0.3% (w/w) which may be taken up by plant roots [27]. Blood meal is also reported to have N (12% to 14%) higher than most organic fertilizers [28]. Reports by the Indonesian Ministry of Agriculture [29] put the content of N, P, and K in blood meal at 13%, 2% and 1%, respectively.

Blood meal is reported to enhance soil fertility and crop yield [26, 30].

The objectives of the study were to

1. Evaluate the growth and yield response of African chili pepper (*Capsicum frutescens*.) upon application of blood meal from abattoir blood waste
2. Assess the impact of blood meal from abattoir blood waste on some selected soil chemical properties (pH, organic Carbon, total Nitrogen, exchangeable Potassium and available Phosphorus), and
3. Determine the influence of blood meal from abattoir blood waste on the concentration of macro and micronutrients in African Chili pepper.

## 2. Materials and Methods

### 2.1. Description of the Study Area

This study was conducted at the Teaching and Research farm of the University of Cape Coast, Ghana. With 5° 7' 53.436" N latitude and 1° 16' 46.1064", the experimental site receives two rainfall periods - from late March to July and from September to early November. The annual rainfall is between 800 mm and 1400 mm per annum, with an average annual rainfall of 1100 mm. The temperatures of the area range between 24 °C and 28 °C monthly. March is the hottest month (temperature of 31 °C). The mean monthly relative humidity is generally high ranging from 60% to 85%. The soil at the experimental site is classified as a Haplic Acrisol (FAO, I. Working Group WRB, 2015) formed from Sekondian rocks [31]. Table 1 shows the chemical properties of the soil used.

## 2.2. Preparation of Blood Meal and Chemical Analyses

The fresh blood waste was poured into a tray and oven-dried at 60 °C for 48 hours [32]. The dried blood was weighed, milled, pulverized and then stored in a polythene bag.

A sample of the blood meal was then taken and analysed for the pH, organic Carbon (C), total nitrogen (N), total Phosphorus (P), total Potassium (K), total Calcium (Ca), total Magnesium (Mg), Copper (Cu), Zinc (Zn) and Iron (Fe). The remaining was used for agronomic investigations. The chemical components of the blood meal used for this study are shown in Table 2.

## 2.3. Experimental Design and Treatment

A randomized complete block design (RCBD) was used as the experimental design. The experiment was made up of four treatments with four replications as follows:

T<sub>1</sub>: Absolute control

T<sub>2</sub>: Urea, UR (261 kg ha<sup>-1</sup>) + Tripple Super Phosphate, TSP (29 kg ha<sup>-1</sup>) + Muriate of Potash, MoP (6 kg ha<sup>-1</sup>)

T<sub>3</sub>: Blood Meal, BM (354.5 kg ha<sup>-1</sup>) + UR (130.5 kg ha<sup>-1</sup>) + TSP (14.5 kg ha<sup>-1</sup>) + MoP (3 kg ha<sup>-1</sup>)

T<sub>4</sub>: BM (709 kg ha<sup>-1</sup>)

The blood meal was incorporated into the soil one week before transplanting. The TSP and MOP were applied 7 days after transplanting. In the case of urea, it was split applied (one-half of the total dose at 7 days after transplanting and the other half at 21 days after emergence). All the chemical amendments were applied using side placement buried about 5 cm deep into the soil and 5 cm away from the base of the plant. The conventional fertilizers were purchased from registered local input dealers and the N, P and K contents of urea, TSP and MOP, respectively, were gleaned from their labels.

## 2.4. Agronomic Practices and Data Collection

Seedlings of Chili pepper at 2 weeks after emergence were transplanted onto a prepared field at a planting distance of 0.9 m within rows and 0.6 m between rows, giving 18 plant stands on a 10 m<sup>2</sup> plot. The seedlings were regularly watered (every three days), and weeds were cleared manually using a hoe every fortnight. Bypel 1 was used to control pest attacks [33]. At physiological maturity (12 weeks after transplanting), data were collected on a number of leaves, branches and plant height. All the plants within the middle row were harvested. The fruits were taken, counted, and weighed and the values were recorded as fruit yield.

The fresh samples of the fruits were washed sequentially with 0.2 % liquid detergent, 0.1 M HCl solution and water to get rid of dust and other contaminants on the fruits. The washed samples of the fruits were placed in paper bags, oven-dried at 65 °C for 48 hours, and milled for laboratory

analyses.

## 2.5. Postharvest Soil and Plant Analyses

At harvest, soil samples were collected from each treatment plant, air-dried and sieved through a 2-mm mesh. The sieved soils were analysed for pH, organic C, total N, available P and exchangeable K content. Soil pH was measured in 1:2.5 soil-water suspension, organic Carbon was determined by the Walkley-Black method, total Nitrogen by micro-Kjedahl method [34] and exchangeable K by ammonium acetate extraction and AAS [35]. The Bray-1 acid and UV- vis spectrophotometer method was followed to analyse for available P content in the soil [36] and tissue [37].

## 2.6. Data Analysis

Collected data from the study were subjected to analysis of variance (ANOVA) employing the GenSTAT statistical package (Discovery, Edition 12) [38]. Post Hoc analysis of the mean values of the soil chemical properties, growth and yields, and some mineral elements were deemed statistically significant at P-values less than 0.05. Pearson correlation was carried out to determine the relationship between the nutrient concentration in the lettuce and the yield.

## 3. Results

### 3.1. Chemical Properties of Blood Meal and Soil Used

**Table 1.** Some chemical components of the blood meal prepared from the abattoir blood waste.

| Parameter                        | Value  |
|----------------------------------|--------|
| pH                               | 8.20   |
| Organic Carbon (%)               | 47.60  |
| Total Nitrogen (%)               | 16.92  |
| C: N Ratio                       | 2.8:1  |
| Total Phosphorus (%)             | 1.87   |
| Total Potassium (%)              | 0.5    |
| Total Magnesium (%)              | 0.05   |
| Total Calcium (%)                | 0.15   |
| Boron (ug g <sup>-1</sup> )      | Traces |
| Molybdenum (ug g <sup>-1</sup> ) | Traces |
| Copper (ug g <sup>-1</sup> )     | 12.94  |
| Zinc (ug g <sup>-1</sup> )       | 42.85  |

| Parameter                     | Value |
|-------------------------------|-------|
| Iron ( $\mu\text{g g}^{-1}$ ) | 272.1 |

**Table 2.** Chemical properties of the soils used for the trials.

| Parameter                                         | Value |
|---------------------------------------------------|-------|
| pH                                                | 6.3   |
| Total Nitrogen (%)                                | 0.09  |
| Organic Carbon (%)                                | 0.63  |
| Available Phosphorus ( $\mu\text{g g}^{-1}$ )     | 0.22  |
| Exchangeable Potassium ( $\text{cmolc kg}^{-1}$ ) | 0.7   |

The chemical analysis of the blood meal used (Table 1) indicates that it has a high pH (8.2), portraying its ability to reduce soil pH. It contains high N content (17%) with organic C of 47.6% and appreciable levels of Ca and Mg. It also contains an appreciable concentration of some microelements (Fe, Zn, Cu) required for plant development. This shows that blood meal can potentially improve fertility and crop yield.

The data indicates that the soil (Table 2) used was slightly acidic and had low organic C, total N, available P and exchangeable K concentrations, suggesting that the soil was low

in fertility.

### 3.2. Effect of Blood Meal and Chemical NPK on Some Soil Chemical Properties After Planting

The application of blood meal significantly ( $p < 0.05$ ) increased the soil pH, organic C, total N exchangeable K and available Phosphorus compared to the sole application of conventional NPK and the control (Table 3). Blood meal application elevated the soil pH by 0.5 and 1.1 pH units over the control and conventional NPK. Total nitrogen content was increased by blood meal by 1625%, 62% and 19% relative to control, sole NPK and combination of blood meal and NPK, respectively. Blood meal application increased organic carbon level by 226.7%, 180.7% and 6.5% compared to the control, sole NPK and combination of blood meal and NPK. Regarding available Phosphorus, there was a significant difference between the sole blood meal and the combination of blood meal and NPK, but the two improved the available Phosphorus by 26.2% and 18%, respectively, relative to sole conventional NPK application and over 1000% compared to the control. Blood meal application elevated the exchangeable Potassium by over 100% relative to the control and 48% compared to the conventional NPK.

**Table 3.** Soil chemical properties of soil as influenced by blood meal and chemical fertilizer application after planting.

| Treatment | pH    | Total Nitrogen (%) | Organic Carbon (%) | Available Phosphorus ( $\mu\text{g g}^{-1}$ ) | Exchangeable Potassium ( $\text{cmolc}^{-1} \text{kg}$ ) |
|-----------|-------|--------------------|--------------------|-----------------------------------------------|----------------------------------------------------------|
| T1        | 6.4b  | 0.08a              | 1.16a              | 0.2a                                          | 0.438a                                                   |
| T2        | 5.8a  | 0.85b              | 1.35b              | 151.8b                                        | 0.752b                                                   |
| T3        | 6.7c  | 1.16c              | 3.56c              | 178.7c                                        | 1.028c                                                   |
| T4        | 6.9d  | 1.38d              | 3.79d              | 191.6c                                        | 1.116d                                                   |
| P-Value   | <.001 | <.001              | <.001              | <.001                                         | <.001                                                    |
| LSD       | 0.11  | 0.06               | 0.10               | 13.73                                         | 0.059                                                    |

Means followed by the same letter in each column are not significantly different at  $P \leq 0.05$  using Fisher's unprotected LSD (LSD, Least significance difference).

The combination of blood meal and NPK significantly ( $p < 0.05$ ) increased the soil pH and the concentrations of N, P, K, P and K compared to the control and the sole NPK. Conventional NPK significantly reduced the pH of the soil by 0.6 units relative to the control. On the other hand, the sole application of NPK recorded higher nutrient values relative to the control.

### 3.3. Concentrations of Selected Nutrient Elements in Pepper upon the Application of Blood Meal and Chemical NPK

The concentrations of selected major nutrients (Nitrogen, Phosphorus, Potassium, Calcium and Magnesium) in the plant (chili pepper) are represented in Table 4.

Application of blood meal significantly ( $p < 0.05$ ) increased the concentrations of Nitrogen, Phosphorus, Potassium, Calcium and Magnesium in pepper. Sole blood meal application increased the concentration of Nitrogen, Phosphorus and Potassium in pepper was increased by 112%, 97% and 90%, respectively, relative to control and 36%, 49% and 33% compared to sole application of conventional NPK. Calcium and magnesium concentrations in pepper were elevated by

blood meal addition by 106% and 194%, respectively compared to control and 21% and 38% compared to the sole application of NPK. The combined addition of blood meal and NPK significantly ( $p < 0.05$ ) improved the Nitrogen, Potassium and Calcium relative to control and NPK alone. There was no significant difference between the combined application of blood meal and NPK and NPK alone with regard to the concentration of Phosphorus and Magnesium.

**Table 4.** Concentration of some major elements in pepper following the application of blood meal and chemical fertilizer (NPK).

| Treatment | Nitrogen (%) | Phosphorus (mg g <sup>-1</sup> ) | Potassium (mg g <sup>-1</sup> ) | Calcium (mg g <sup>-1</sup> ) | Magnesium (mg g <sup>-1</sup> ) |
|-----------|--------------|----------------------------------|---------------------------------|-------------------------------|---------------------------------|
| T1        | 2.936a       | 2.820a                           | 20.82a                          | 23.20a                        | 1.320a                          |
| T2        | 4.580b       | 3.740b                           | 29.84b                          | 39.60b                        | 2.820b                          |
| T3        | 5.220c       | 4.200b                           | 34.54c                          | 45.43c                        | 3.160b                          |
| T4        | 6.240d       | 5.560c                           | 39.54d                          | 47.95d                        | 3.880c                          |
| P-Value   | <.001        | <.001                            | <.001                           | <.001                         | <.001                           |
| LSD       | 0.4172       | 0.3700                           | 1.189                           | 1.361                         | 0.3079                          |

Means followed by the same letter in each column are not significantly different at  $P \leq 0.05$  using Fisher's unprotected LSD (LSD, Least significance difference).

The concentrations of some selected minor nutrients (iron, zinc and copper) in chili pepper are shown in Table 5. Iron concentration was similar for sole blood meal and blood meal in combination with NPK. The two, however, elevated the iron level significantly ( $p < 0.05$ ) compared to the control and conventional NPK. Sole blood meal and the combined application increased the iron level by 447 % and 307%, respectively, compared to the control and 51.5% and 37.5 % respectively, compared to conventional NPK. Conventional NPK also significantly ( $p < 0.05$ ) increased the iron concentration by 195% relative to the control. Regarding the zinc

concentration in pepper, there was no significant difference between sole NPK and the combined application of blood meal and NPK. However, the two were significantly different from the control treatment. Sole blood meal application significantly recorded the highest zinc level over the control, conventional NPK and the combined application with 618%, 127.2% and 72% respectively. Sole NPK application increased the copper concentration by 151% relative to control. Sole blood meal application recorded significantly higher copper concentrations, with over 400% and 98% for control and conventional NPK, respectively.

**Table 5.** Concentration of some minor elements in pepper following the application of blood meal and chemical fertilizer (NPK).

| Treatment | Iron (mg g <sup>-1</sup> ) | Zinc (mg g <sup>-1</sup> ) | Copper (mg g <sup>-1</sup> ) |
|-----------|----------------------------|----------------------------|------------------------------|
| T1        | 0.2420a                    | 0.298a                     | 0.0716a                      |
| T2        | 0.7140b                    | 0.942b                     | 0.1800b                      |
| T3        | 0.9820c                    | 1.244b                     | 0.2300c                      |
| T4        | 1.0820c                    | 2.140c                     | 0.3580d                      |
| P-Value   | <.001                      | <.001                      | <.001                        |
| LSD       | 0.0936                     | 0.3402                     | 0.02596                      |

Means followed by the same letter in each column are not significantly different at  $P \leq 0.05$  using Fisher's unprotected LSD (LSD, Least significance difference).

### 3.4. Effect of Blood Meal and Chemical NPK on Growth and Yield of Pepper

Table 6 shows the number of leaves, plant height, branches, and days to fruiting as influenced by blood meal and NPK application. Control recorded the least number of leaves per plant harvesting with the sole application of blood meal recording significantly ( $p < 0.05$ ) higher leaves number. The trend of increase followed  $T_4 > T_3 > T_2 > T_1$ . The conventional NPK recorded significantly ( $p < 0.05$ ) higher plant height with over 25% increase relative to the control. The addition of

blood meal alone and in combination with NPK increased the plant height by 4.5% and 3.1%, respectively over NPK and 26% and 24% respectively over the control. The number of branches per plant ranged from 13 to 22.2, with blood meal recording the highest and control recording the lowest. The increase was in the order of  $T_4 = T_3 > T_2 > T_1$ . The control recorded a greater number of days (over 80) to reach 80% fruiting compared to the other treatments. Blood meal alone and in combination with NPK required significantly fewer days (70) to reach 80% fruiting than the conventional NPK, which took 76 days.

**Table 6.** Growth response at harvesting upon the application of blood meal and inorganic NPK.

| Treatment | No of leaves plant <sup>-1</sup> | Plant height (cm) | No of branches plant <sup>-1</sup> | Days to 80% fruiting |
|-----------|----------------------------------|-------------------|------------------------------------|----------------------|
| T1        | 118.2a                           | 96.4a             | 13.80a                             | 80.20c               |
| T2        | 126.0b                           | 116.2b            | 17.80b                             | 76.00b               |
| T3        | 130.8c                           | 119.8bc           | 20.80c                             | 70.20a               |
| T4        | 135.8d                           | 121.4c            | 22.20c                             | 70.00a               |
| P-Value   | <.001                            | <.001             | <.001                              | <.001                |
| LSD       | 2.131                            | 3.554s            | 1.252                              | 1.556                |

Means followed by the same letter in each column are not significantly different at  $P \leq 0.05$  using Fisher's unprotected LSD (LSD, Least significance difference).

The number of fruits per plant, fruit weight, fruit length, fruit diameter and the fruit yield as affected by the addition of blood meal NPK are displayed in Table 7. There was no significant difference between blood meal alone and in combination with NPK regarding the number of fruits per plant. Nonetheless, the two increased the fruit number significantly with about 50 % and 15% compared to the control and the NPK. Sole blood meal addition significantly increased the fruit weight with 8.3%, 16% and 231.4% compared to the combined application, conventional NPK and control. The combined application and conventional NPK recorded significantly higher fruit weights with over 205% and 186 %,

respectively, relative to the control. The control treatment recorded the lowest fruit length and diameter, followed by NPK, with sole blood meal having the highest values. The order of increase for both fruit length and diameter followed  $T_1 < T_2 < T_3 = T_4$ . Compared to the combined application, conventional NPK and control, the sole addition of blood meal significantly increased the fruit yield by 7.6%, 32.9% and 398.7%. The conventional NPK also significantly increased the fruit yield by 275.3% relative to the control. The combined treatment recorded a percentage fruit yield increase of 23.5 and 363.5% relative to NPK and the control.

**Table 7.** Yield response at harvesting upon the application of blood meal and inorganic NPK.

| Treatment | No of fruit plant <sup>-1</sup> | Fruit weight (g) | Fruit length (cm) | Fruit diameter (cm) | Yield t ha <sup>-1</sup> |
|-----------|---------------------------------|------------------|-------------------|---------------------|--------------------------|
| T1        | 100.8a                          | 1.020a           | 5.040a            | 1.000a              | 1.905a                   |
| T2        | 132.2b                          | 2.920b           | 7.340b            | 1.980b              | 7.150b                   |
| T3        | 151.8c                          | 3.120b           | 8.080c            | 2.400c              | 8.829c                   |
| T4        | 152.8c                          | 3.380c           | 8.460c            | 2.600c              | 9.500d                   |
| P-Value   | <.001                           | <.001            | <.001             | <.001               | <.001                    |

| Treatment | No of fruit plant <sup>-1</sup> | Fruit weight (g) | Fruit length (cm) | Fruit diameter (cm) | Yield t ha <sup>-1</sup> |
|-----------|---------------------------------|------------------|-------------------|---------------------|--------------------------|
| LSD       | 2.513                           | 0.1586           | 0.3212            | 0.2182              | 0.4402                   |

Means followed by the same letter in each column are not significantly different at  $P \leq 0.05$  using Fisher's unprotected LSD (LSD, Least significance difference).

The correlation between yield and nutrient concentrations are presented in Table 8. There was a positive and strong correlation among the parameters. All the selected major

nutrients positively correlated with the pepper yield. Similarly, the micronutrients also showed a positive correlation with the yield.

**Table 8.** Correlation between of yield pepper and nutrient concentration in pepper.

| Parameter | N       | P       | K       | Mg      | Ca      | Cu     | Zn     | Fe      | FD      | FL      | FW      |
|-----------|---------|---------|---------|---------|---------|--------|--------|---------|---------|---------|---------|
| P         | 0.95*** |         |         |         |         |        |        |         |         |         |         |
| K         | 0.97*** | 0.94**  |         |         |         |        |        |         |         |         |         |
| Mg        | 0.94**  | 0.89**  | 0.95*** |         |         |        |        |         |         |         |         |
| Ca        | 0.94**  | 0.86**  | 0.97*** | 0.94**  |         |        |        |         |         |         |         |
| Cu        | 0.94**  | 0.96*** | 0.96*** | 0.91**  | 0.89**  |        |        |         |         |         |         |
| Zn        | 0.92**  | 0.93**  | 0.91**  | 0.86**  | 0.84**  | 0.92** |        |         |         |         |         |
| Fe        | 0.95*** | 0.87**  | 0.97*** | 0.95*** | 0.97*** | 0.91** | 0.87** |         |         |         |         |
| FD        | 0.95*** | 0.87**  | 0.95*** | 0.92**  | 0.97*** | 0.88** | 0.86** | 0.97*** |         |         |         |
| FL        | 0.92**  | 0.85**  | 0.96*** | 0.92**  | 0.98*** | 0.89** | 0.86** | 0.97*** | 0.96*** |         |         |
| FW        | 0.92**  | 0.83**  | 0.93**  | 0.91**  | 0.98*** | 0.85** | 0.81** | 0.94**  | 0.95*** | 0.97*** |         |
| FY        | 0.95*** | 0.86**  | 0.96*** | 0.93**  | 0.99*** | 0.89** | 0.84** | 0.96*** | 0.97*** | 0.98*** | 0.99*** |

N, Nitrogen; P, Phosphorus; K, Potassium; Mg, Magnesium; Ca, Calcium; Cu, Copper; Zn, Zinc; Fe, Iron; FY, Fruit yield; FD, Fruit Diameter; FL, Fruit Length; FW, Fruit Weight; \*, \*\* for 0.01 and \*\*\* for 0.001 probability level.

## 4. Discussion

### 4.1. Effect of Blood Meal and Chemical NPK on Some Soil Chemical Properties After Planting

The analytical components of the blood meal indicated that it could be a good soil amendment due to the presence of considerably high N concentration and other plant nutrients, including Ca, Mg, P and K and micronutrients [25]. Again, the elemental content of blood meal, especially for Iron, Copper and Zinc, has implications for hidden hunger control in Africa.

Application of blood meal significantly improved the soil nutrients relative to the control and the conventional NPK. The blood meal is alkaline as it contains basic forming cations (K, Ca and Mg) and may correct soil acidity when applied to

acidic humid tropical soils used in the trial.

The improvement in the pH soil by adding blood meal might be caused by the decomposition and release of the basic cations (Ca, Mg, and K) possessed by the blood meal. These cations, when released, alter the pH [39]. They also explained that at low pH aluminum toxicity, precipitation of P, decreased N mineralization and earthworm turnover occur. In contrast to their report, the increase in pH in blood meal amended soils is favourable for the availability of nutrients, macrofauna and microbial activity enhancement and reduction in aluminum toxicity to plants roots. Total N and Organic C were elevated in blood meal amended plots above that of the NPK and control. This conforms to the chemical properties of the former. The organic carbon content in blood meal-treated soil is high according to the rating of Tian et al., [40], as they stated that organic carbon content less than 1.5, 1.5-2.5 and >2.5% are classified as low, medium and high, respectively. The increase in organic C will serve as an energy source for soil microbes, helping to bind soil aggregates to

form a good soil structure and an overall driver of soil productivity [41]. Nitrogen elevations by the blood meal plots could be associated with the high total N reserves of the same. Blood meal may have slowly undergone mineralization, resulting in the steady release of plant N into the soil, though this was not considered in this experiment. Also, due to the high N reserves in the blood meal, available N restoration takes place after being used by plants. The enhanced availability of P in the blood meal-treated soils could also be associated with increased pH and possible mineralization of organic P from the blood meal. The blood meal applied contained high amounts of basic cations and may have caused the retention and exchange of K. In contrast, the NPK fertilizer with readily soluble Nitrogen, Phosphorus and Potassium were either taken up by the plants, volatilized and or leached, causing its rapid depletion from the soil. The P in the NPK-treated soil might have been precipitated by acidic cations in the experimental soil, causing reduced P availability in those soils.

Organic fertilizer enhances nutrient availability, soil pH and microbial activities [42]. Similarly, blood meal as an organic fertilizer enhances plant available nutrients and enhanced soil physical and biological properties [43]. Moreover, it is also reported that organic fertilizer can activate the nutrients in the substrate, improving the soil's physical and chemical properties [44].

## 4.2. Influence of Blood Meal and NPK Applications on Selected Macro and Micronutrients Contents in Pepper

Both macro and micronutrient concentrations (N, P, K, Mg, Ca, Fe, Cu and Zn) in the pepper fruit from the blood meal-treated soil were significantly higher than inorganic fertilizer and the control as shown in Tables 4 and 5. This increase in concentration can be attributed to the amount of nutrient reserves in the blood meal that are released steadily after decomposition, making it available and possible for plant uptake, confirming the fact that organic fertilizer has the propensity to promote the absorption of nutrients by plants and increase the plant nutrient content [44]. This aligns with the amount of nutrients stocked in the soil after harvesting [45]. Also, Zn-enriched fertilizers elevate Zn concentration in crops [46]. The microelements in blood meal are needed to curtail hidden hunger in the African population.

## 4.3. Effect of Blood Meal and Chemical NPK on the Growth of Pepper

The addition of blood meal increased the number of leaves, branches, and plant heights of pepper relative to the control and chemical NPK. The blood meal contains high N content, which may go through biochemical processes to enhance vegetative growth. Al-Fraihat & Ahmad [47] opined that Nitrogen, a fundamental cell component, plays an important

role in all living tissues of a plant and helps to develop healthy plant growth and development. Nitrogen is reported to be an essential element for onion growth through the build-up of protoplasm and proteins, which affect cell division and meristematic activities [48].

Application of blood meal resulted in the early fruiting of pepper relative to the control and the chemical NPK. This can be attributed to the improved nutrient absorption or accumulation in the pepper grown on blood meal-amended soil. These absorbed nutrients promote vegetative and reproductive growth, thereby causing early flowering and fruiting in the plant. This is in tandem with the findings of Qi et al., [49] and Negi et al., [50] who reported that organic fertilizer can provide the nutrients required for dry matter accumulation and promote vegetative growth and reproductive growth.

## 4.4. Influence of Blood Meal and Chemical NPK on Yield of Pepper

The addition of blood meal resulted in the production of more fruits and lengthy fruits relative to the NPK and control treatments. This elevation of fruit length could result from a supply of adequate plant nutrients such as Nitrogen, which may lead to more vegetative growth and dry matter accumulation, thus promoting fruit length [51] and inducing a greater number of fruits. This is evident as there was a positive correlation between the number of fruit and the fruit length (Table 8).

The effect of blood meal application increased the fruit diameter relative to NPK and the control. The presence of Nitrogen might ensure vigorous plant growth, resulting in the highest diameter and thickness of the fruits. This was in conformity with the findings of Mekuria et al., [52], who reported similar results and opined that the diameter and thickness increased with the increasing level of Nitrogen that favoured the growth of plants. The impact of blood meal on the fruit weight was significantly different from the control and inorganic fertilizer. The higher fruit weight could be attributed to the higher soil nutrients released from the blood meal, which were absorbed by the plant resulting in the increase in fruit weight. Blood meal-amended soils recorded the highest fruit yield compared to control and NPK. The observed yield increase is due to the availability of plant nutrients. This observed yield increase could be as a result of the adequate supply and availability of soil nutrients needed for the growth and development of the plant [53]. Blood meal is reported to have a good effect on crop yield and soil fertility as it increased onion yield and improved soil fertility following its application [30]. This corroborates the work of some researchers who reported on the beneficial impact of abattoir waste fertilizers (MBM) on crop yields [54, 55].

The fruit weight, diameter, and yield correlated positively with the nutrient concentrations in the pepper seed (Table 8).

## 5. Conclusion

This current work revealed that blood meal improved the soil's chemical properties (pH, OC, N, P and K), resulting in improved soil fertility. Similarly, the blood meal significantly enhanced the concentration of major nutrients such as Ca, Mg, N, P and K in the pepper fruits. Essential micronutrients such as Cu, Zn and Fe in the pepper seed were also elevated with addition of blood meal. Plant height, number of leaves and number of pepper branches were all positively affected by the addition of blood meal. Pepper yield and other yield indices (fruit length, weight, diameter and number of fruits) were all significantly improved by blood meal relative to NPK and control. Conclusively, this work revealed that blood meal had greater effects or impact on the soil fertility, growth, yield and nutrient contents of the pepper seed.

## Abbreviations

|       |                                  |
|-------|----------------------------------|
| UR    | Urea                             |
| TSP   | Tripple Super Phosphate          |
| MoP   | Muriate of Potash                |
| BM    | Blood Meal                       |
| RCBD  | Randomized Complete Block Design |
| ANOVA | Analysis of Variance             |
| LSD   | Least Significance Difference    |

## Author Contributions

**Abdul Razak Mensah Idriss:** Conceptualization, Data curation, Methodology, Writing – original draft Writing – review & editing

**Emmanuel Hanyabui:** Data curation, Validation, Visualization, Writing – review & editing

**Rita Esi Ampaw:** Formal Analysis, Investigation, Writing – original draft, Writing – review & editing

**Kwame Adjei Frimpong:** Supervision, Validation, Writing – review & editing

## Consent to Participate

Not applicable.

## Consent for Publication

Not applicable.

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## Availability of Data and Material

The datasets generated during the current study are available from the corresponding author on request.

## Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

## References

- [1] United Nations; Department of Economic and Social Affairs; Population Division. World Population Prospects 2019: Highlights; UN: New York, NY, USA, 2019; ISBN 978-92-1-148316-1.
- [2] Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S. M.; Toulmin, C. (2010) Food security: The challenge of feeding 9 billion people. *Science*, 327, 812–818. <https://doi.org/10.1126/science.1185383>
- [3] Nastis, S.A.; Michailidis, A.; Chatzitheodoridis, F. (2012) Climate change and agricultural productivity. *Afr. J. Agric. Res.*, 7, 4885–4893. <https://doi.org/10.5897/AJAR11.2395>
- [4] FAO (2017) The future of food and agriculture – trends and challenges. Rome: FAO (2017). Available at: <https://www.fao.org/3/i6583e/i6583e.pdf>
- [5] Gomiero, T. (2016) Soil degradation, land scarcity and food security: Reviewing a complex challenge. *Sustain.* 8(3): 1–41. <https://doi.org/10.3390/su8030281>
- [6] Bindraban, P.S.; Van der Velde, M.; Ye, L.; Van den Berg, M.; Materechera, S.; Kiba, D.I. (2012) Assessing the impact of soil degradation on food production. *Curr Opin Environ Sustain* 4(5): 478–88. <https://doi.org/10.1016/j.cosust.2012.09.015>
- [7] Mansourian, S.; Berrahmouni, N. (2021) Review of forest and landscape restoration in Africa. Rome, Italy: Accra. FAO and AUDA-NEPAD. <https://doi.org/10.4060/cb6111en>
- [8] Food and Agriculture Organization of the United Nations Statistics Division. FAO. (2015) FAOSTAT. (Accessed March, 2022) [http://faostat3.fao.org/download/D/\\*E](http://faostat3.fao.org/download/D/*E)
- [9] Wang, T.; Cheng, K.K.; Huo, X.J.; Meng, P.P.; Cai, Z.H.; Wang, Z.K.; Zhou, J. (2022) Bioorganic fertilizer promotes pakchoi growth and shapes the soil microbial structure. *Front Plant Sci* 13: 1040437. <https://doi.org/10.3389/fpls.2022.1040437>
- [10] Wang, C.; Zheng, M.M.; Song, W.F.; Wen, S.L.; Wang, B.R.; Zhu, C.Q.; Shen, R.F. (2017) Impact of 25 years of inorganic fertilization on diazotrophic abundance and community structure in an acidic soil in Southern China. *Soil Biol Biochem* 113: 240–249. <https://doi.org/10.1016/j.soilbio.2017.06.019>
- [11] Liang, Y.; Nin, D.; Lu, Z.; Zhang, N.; Hale, L.; Wu, L. (2020) Century long fertilization reduces stochasticity controlling grassland microbial community succession. *Soil Biol. Biochem.* 151: 108023. <https://doi.org/10.1016/j.soilbio.2020.108023>

- [12] Feng MM, Adams JM, Fan KK, Shi Y, Sun RB, Wang DZ, Guo XS, Chu HY (2018) Long-term fertilization influences community assembly processes of soil diazotrophs. *Soil Biol Biochem* 126: 151–158. <https://doi.org/10.1016/j.soilbio.2018.08.021>
- [13] Bationo A, Lungu O, Naimi M, Okoth P, Smaling E, Lamourdia T (2006) African soils: their productivity and profitability of fertilizer use: background paper for the African Fertilizer Summit 9-13th June 2006, Abuja, Nigeria.
- [14] Gouda S, Kerry RG, Das G, Paramithiotis S, Shin HS, Patra JK (2018) Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiol Res* 206: 131–140. <https://doi.org/10.1016/j.micres.2017.08.016>
- [15] Dincă LC, Grenni P, Onet C, Onet A (2022) Fertilization and soil microbial community: a review. *Applied Sciences* 12: 1198. <https://doi.org/10.3390/app12031198>
- [16] Chowdhury SP, Babin D, Sandmann M, Jacquiod S, Sommermann L, Sørensen SJ, Fliessbach A, Mäder P, Geistlinger J, Smalla K, Rothballer M, Grosch R (2019) Effect of long-term organic and mineral fertilization strategies on rhizosphere microbiota assemblage and performance of lettuce. *Environ Microbiol* 21: 2426–2439. <https://doi.org/10.1111/1462-2920.14631>
- [17] Guo S, Tao C, Jousset A, Xiong W, Wang Z, Shen Z, Wang B, Xu Z, Gao Z, Liu S, Li R, Ruan Y, Shen Q, Kowalchuk GA, Geisen S (2022) Trophic interactions between predatory protists and pathogen-suppressive bacteria impact plant health. *ISME J* 16: 1932–1943. <https://doi.org/10.1038/s41396-022-01244-5>
- [18] Chew KW, Chia SR, Yen HW, Nomanbhay S, Ho YC, Show PL (2019) Transformation of biomass waste into sustainable organic fertilizers. *Sustainability*, 11, 2266. <https://doi.org/10.3390/su11082266>
- [19] Zhou Z, Zhang S, Jiang N, Xiu W, Zhao J, Yang D (2022) Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Front. Environ. Sci.* 2022, 10, 2292. <https://doi.org/10.3389/fenvs.2022.1058071>
- [20] Awafo E. A, Amenorfe J (2021) Techno-economic studies of an industrial biogas plant to be implemented at Kumasi Abattoir in Ghana. *Scientific African*, 11, e00712.
- [21] Roy M, Karmakar S, Debsarcar A, Sen PK, Mukherjee J (2013) "Application of rural slaughterhouse waste as an organic fertilizer for pot cultivation of Solanaceous vegetables in India," *International Journal of Recycling of Organic Waste in Agriculture*, vol. 2, no. 6, <http://www.ijrowa.com/content/2/1/6>
- [22] Wang S, Jena U, Das KC (2018). Biomethane production potential of slaughterhouse waste in the United States, *Energy Convers Manag*, 173: 143-157. <https://doi.org/10.1016/j.enconman.2018.07.059>
- [23] Miezah K, Obiri-Danso K, K'ad'ar Z, Fei-Bafoe B, Mensah MY (2015) "Municipal solid waste characterization and quantification as a measure towards selective waste management in Ghana," *Waste Management*, vol. 46, pp. 15–27,
- [24] Ravindran B, Nagalakshmi C, Devi SG, Subramanian KS, Mandal AB, Sekaran G (2013) Efficiency of hydrolyzed tannery solid waste for the growth and yield potentials on tomato. *J. Plant Nutr.* 36(5): 795–810. <https://doi.org/10.1080/01904167.2012.756893>
- [25] Agehara S, Warncke DD (2005) Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil Sci. Soc. Am. J.* 69: 1844–1855. <https://doi.org/10.2136/sssaj2004.0361>
- [26] Ciavatta C, Govi M, Sitti L, Gessa C (1997) Influence of blood meal organic fertilizer on soil organic matter: A laboratory study, *J. Plant Nutr.* 20(11): 1573-1591. <https://doi.org/10.1080/01904169709365358>
- [27] Kalbasi M, Shariatmadari H (1993) Blood powder, a source of iron for plants, *Plant Nutr.* 16(11): 2213-2223. <https://doi.org/10.1080/01904169309364681>
- [28] Hartz TK, Johnstone PR (2006) Nitrogen availability from high-nitrogen-containing organic fertilizers. *HortTechnology* 16: 39–42. <https://doi.org/10.21273/Horttech.16.1.0039>
- [29] Regulation of the Minister of Agriculture Number 70 (RoMA 2011), "Regarding Organic Fertilizers Biology and Soil Improvement," Jakarta: Indonesia, 2011.
- [30] Momtaz N, Parvin A, Hossain MK, Saha B, Moniruzzaman M, Kibria A, Sarker MAM, Munshi JL (2021) Blood meal organic fertilizer application on onion yield. *Bangladesh J. Sci. Ind. Res.* 56(2), 87-94. <https://doi.org/10.3329/bjsir.v56i2.54315>
- [31] Asamoah GK (1973) Soils of proposed farm sites of the University of Cape Coast, Technical (Report No. 88). Kwadaso, Kumasi: Soil Research Institute (C.S.I.R.).
- [32] *Agriculture.Institute. Process and Uses of Blood Meal in Agriculture and Livestock Feed. Available from: https://agriculture.institute/animal-by-products-utilisation/process-uses-blood-meal-agriculture-livestock-feed/ (assessed Dec 3, 2023)*
- [33] Ngosong NT, Boamah ED, Fening KO, Kotey DA, Afreh-Nuamah K (2021) The efficacy of two bio-rational pesticides on insect pests complex of two varieties of white cabbage (*Brassica oleracea* var. capitata L.) in the coastal savanna region of Ghana. *Phytoparasitica*, 49(3), 397-406. <https://doi.org/10.1007/s12600-020-00859-8>
- [34] Rowell DL (1994) *Soil science: Methods and applications*. Singapore: Longman Publication Ltd.
- [35] Zhai Y, Cui L, Zhou X, Yin G, Fei, T, Gao W (2013) Estimation of Nitrogen, Phosphorus, and potassium contents in the leaves of different plants using laboratory-based visible and near-infrared reflectance spectroscopy: Comparison of partial least-square regression and support vector machine regression methods. *International Journal of Remote Sensing*. 34. <https://doi.org/10.1080/01431161.2012.746484>
- [36] Maghanga KJ, Kituyi LJ, Segor KE, Kisinyo P (2015) Comparison of soil phosphorous extraction by Olsen and double acid methods in acid soils of Western, Kenya.

- [37] Murphy J, Riley JP (1962) Colorimetric method for determination of P in soil solution. *Anal. Chim. Acta*, 27, 31-36.
- [38] GenStat Release 12.1 (PC/Windows Vista) 03 October 2024 01:40: 34 Copyright 2009, VSN International Ltd. Registered to: The NULL Corporation.
- [39] Weil R. R. & Brady N. C. (2017) *The Nature and Properties of Soils*. 15th Edition, Pearson, New York.
- [40] Maria RM, Yost R (2006) A survey of soil fertility status of four agro ecological zones of Mozambique, *Soil Science* 171(11): 902-914.  
<https://doi.org/10.1097/01.ss.0000228058.38581.de>
- [41] Tian Q, Jiang Y, Tang Y, Wu Y, Tang Z, Liu F (2021) Soil pH and Organic Carbon Properties Drive Soil Bacterial Communities in Surface and Deep Layers Along an Elevational Gradient. *Front. Microbiol.* 12: 646124.  
<https://doi.org/10.3389/fmicb.2021.646124>
- [42] Dinesh R, Dubey RP, Ganeshamurthy AN, Prasad GS (2000) Organic manuring in rice-based cropping system: effects on soil microbial biomass and selected enzyme activities, *Curr. Sci.* 79: 1716-1720.  
<http://localhost:8080/xmlui/handle/123456789/865>
- [43] Datt N, Sharma RP, Sharma GD, (2003) Effect of supplementary use of farmyard manure along with chemical fertilizers on productivity and nutrient up-take by vegetable pea (*Pisum Sativum Var Arvense*) and build-up of soil fertility in Lahaul valley of Himachal Pradesh, *Indian J. Agri. Sci.* 73: 266-268.
- [44] Xiao Q, Wang Q, Wu L, Cai A, Wang C, Zhang W, Xu M (2018) Fertilization impacts on soil microbial communities and enzyme activities across China's croplands: a meta-analysis [J]. *Journal of Plant Nutrition and Fertilizers*, 24(6): 1598-1609.  
<https://doi.org/10.11674/zwfyf.18241>
- [45] Botir K, Hye JY, Yejin L, Farrukh R, Thi HL, Mirjalol U, Aung BB, Kwang MC, Kee WP (2019) Impact of Organic Manure on Growth, Nutrient Content and Yield of Chilli Pepper under Various Temperature Environments Int. J. Environ. Res. Public Health 2019, 16, 3031.  
<https://doi.org/10.3390/ijerph16173031>
- [46] Joy EJ, Broadley MR, Young SD, Black CR, Chilimba AD, Ander EL, Watts MJ (2015) Soil type influences crop mineral composition in Malawi. *Science of the Total Environment*, 505, 587-595. <https://doi.org/10.1016/j.scitotenv.2014.10.038>
- [47] Bungard RA, Wingler A, Morton JD, Andrews M (1999) Ammonium can stimulate nitrate and nitrite reductase in the absence of nitrate in *Clematis vitalba*, *Plant Cell Environ.* 22: 859-66. <https://doi.org/10.1046/j.1365-3040.1999.00456.x>
- [48] Al-Fraihat H & Ahmad H (2009) Effect of different Nitrogen and sulphur fertilizer levels on growth, yield and quality of onion (*Allium cepa* L.), *Jordan J. Agri. Sci.* 5(2): 155-65.
- [49] Zhou Y, Li YM, Fan MP, Wang ZL, Xu Z, Zhang D, Zhao JX, (2020) Effects of different base fertilizer treatments on mountain red earth soil nutrition, enzyme activity, and crop yield. *Chin. J. Appl. Environ. Biol.* 26, 603-611.  
<https://doi.org/10.19675/j.cnki.1006-687x.2019.10022>
- [50] Qi Y, Bing F, Yuehua Z, Jing W, Xianju X, Hongbo M (2021) Partial Replacement of Chemical Fertilizer with Organic Fertilizer: Effects on Eggplant Yield, Quality and Soil Fertility [J]. *Chinese Agricultural Science Bulletin*. 2021, 37(34): 59-63  
<https://doi.org/10.11924/j.issn.1000-6850.casb2020-0433>
- [51] Negi SRV, Singh RV, Dwivedi GK (2004) Effect of biofertilizers, FYM, NPK and lime on pea in acidic soils of Uttarakhand Hills. *Vegetable. Science.* 31(2): 193-195.
- [52] Pramanik S (2007) Effect of Nitrogen and Phosphorus on the growth and yield of cabbage (*Brassica oleraceae* var. *capitata* L.). MSc thesis, Department of Horticulture, Sher-e Bangla Agricultural University, Dhaka, Bangladesh. 21-42 pp.
- [53] Mekuria W, Langan S, Noble A, Johnston R (2014) Soil Organic Carbon and Nutrient Contents are not influenced by Exlosures established in communal grazing land in Nile basin, Northern Ethiopia. In *International Conference on Advances in Agricultural, Biological & Environmental Sciences (AABES-2014) Oct* (pp. 15-16).
- [54] Ylivainio K, Uusitalo R, Turtola E (2008) Meat bone meal and fox manure as P sources for ryegrass (*Lolium multiflorum*) grown on a limed soil. *Nutrient Cycling in Agroecosystems* 81, 267-278. <https://doi.org/10.1007/s10705-007-9162-y>
- [55] Nogalska A (2016) Meat and bone meal as fertilizer for spring barley. *Plant Soil Environ.*, 62, 373-378.  
<https://doi.org/10.17221/270/2016-PSE>