Comparison of the effect of different organic fertilizers on the availability of some nutrients and the yield of cowpeas

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Abstract

A field experiment was conducted during the summer season of 2024 in an open farm located in Al-Tuwaitha Al-Gharbiya, near the Old Diyala Bridge in Baghdad (33°11′56″ N –44°29′30″ E), to evaluate and compare the effects of Black Soldier Fly (BSF) larvae frass with other types of organic fertilizers on the growth, yield quality, and soil nutrient availability for cowpea (Vigna unguiculata L.) grown in calcareous silty loam soil. The cowpea cultivar ‘Ramshorn’ (originating from the USA) was sown on April 2, 2024. Three types of organic fertilizers were used: BSF larvae frass, poultry manure, and cattle manure, each applied at a rate of 5 tons ha^{-1}. In addition, macronutrients (N, P, K) were applied at three levels: no addition (control), half the recommended dose, and the full recommended dose (80 kg N, 60 kg P, and 160 kg K ha^{-1}). The experiment was laid out in a factorial randomized complete block design (RCBD) with three replications.

Results showed significant differences among treatments, where BSF frass—whether applied alone or combined with the full recommended NPK dose—led to superior performance in most plant and soil parameters. The highest recorded values included leaf area (120.420 cm^2 $leaf^{-1}$), shoot dry weight (79.800 g $plant^{-1}$), pod length (16.300 cm pod^{-1}), and cumulative yield (1.670 Mg ha^{-1}). Likewise, soil fertility indicators were enhanced, showing significant increases in available nitrogen (77.000 mg N kg^{-1} soil), phosphorus (13.670 mg P kg^{-1} soil), and potassium (195.730 mg K kg^{-1} soil). The

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highest seed protein content (26.25%) was also recorded under the BSF frass treatment combined with the full NPK recommendation. Conclusion: BSF frass is one of the most innovative and efficient organic fertilizers derived from insect-based systems. Its rich nutrient content (N, P, K), fast decomposition due to prior digestion in the insect's gut, and positive influence on soil health and crop productivity make it a highly sustainable alternative to conventional fertilizers. Its use contributes to enhancing soil fertility and agricultural sustainability in calcareous soils.

Keywords: Organic fertilizers, Nutrients, cowpeas

Introduction

The use of organic fertilizers in agriculture has gained increasing importance due to their positive effects on soil fertility, crop productivity, and environmental sustainability (Al-Hlfie and Hussein, 2024; Al-Qaisi, 2020). Organic fertilizer sources vary based on availability, cost, crop type, and economic feasibility (Beesigamukama et al., 2022). Among the most innovative and emerging organic fertilizers is Black Soldier Fly (BSF) frass, which is the residue produced after BSF larvae consume biodegradable organic waste (Gärttling and Schulz, 2022; Lopes, Yong and Lalander, 2022). This frass is considered a valuable soil amendment due to its high content of nutrients—particularly nitrogen, phosphorus, and potassium—as well as organic matter and other beneficial components such as chitin (derived from larval exoskeletons) (Elissen, van der Weide and Gollenbeek, 2023; Hol, Elissen and van der Weide, 2022; Grigatti *et al.*, 2015). The BSF larvae efficiently convert organic waste into two main products: a protein-rich larval biomass used as animal feed, and frass used as an organic fertilizer (Houben *et al.*, 2020; Shaker and Rasool, 2023). BSF frass is characterized by its rapid decomposition, owing to the partial digestion of organic matter in the insect gut, and has been increasingly adopted in sustainable agriculture systems (Van der Fels-Klerx et al., 2020; Lugato et al., 2020). The addition of organic fertilizers—regardless of their source—plays a significant role in improving nutrient availability, especially in calcareous soils, which typically suffer from low nutrient mobility and availability (Isa and Sulaiman, 2020: Alwan and Mohsen, 2024). Organic amendments enhance microbial activity, promote soil aggregation, and stimulate the biological functioning of soil systems, thereby improving plant growth and yield (Al-Karghi, 2016). For instance, Sheikh Sulieman and Haddad (2020) reported improved vegetative growth and fruit yield of eggplant when organic fertilizers were applied (Ali and Abdul Razzaq Shaker, 2018). However, conventional organic fertilizers such as cattle and poultry manures may be limited by their low nutrient content, slow nutrient release rates, and high application costs (Al-Qaisi, 2020; Shaji, Chandran and Mathew, 2021; Ndambi et al., 2019). As global demand for food increases and arable land continues to decline, identifying alternative organic fertilizer sources becomes essential (Font-i-Furnols ,2023). In this context, insect-based fertilizers such as BSF frass offer a promising and sustainable solution. Cowpea (Vigna unguiculata L.), a leguminous crop belonging to the Fabaceae family, is widely cultivated in tropical and subtropical regions (Al-Saeed, 2017). It is valued for its high protein content (up to 26.61%), carbohydrates (up to 56.24%), and other essential nutrients that support human health (Oyewale and Bamaiyi, 2013; Ali, 2016; Oliwi, Jubier and Alwan, 2021). As a legume, cowpea also contributes to soil fertility through biological nitrogen fixation (Al-Jabri, 2016; Jackson, 1958; (Musyoka *et al.*, 2019; Humod Al-Ogaidi and Alwan, 2024). In Iraq, cowpea production in 2022 reached approximately 23,038 tons over 3,723 hectares, with an average yield of 6.188 tons ha^{-1} (COSIT, 2022). Therefore, this study aims to evaluate and compare the effects of BSF frass and other organic fertilizers on soil fertility and cowpea productivity in calcareous soils, and to assess the potential of BSF frass as a viable alternative to traditional organic and mineral fertilizers in sustainable agricultural systems (Jaafar and Abdulrasool, 2025; Aljassani, Alqaisi and Al-Ahbabi, 2022; Almamori and Abdul-Ratha, 2020).

Materials and Methods

Field Experiment Site

The field experiment was conducted during the 2024 agricultural season on cowpea (Vigna unguiculata L.) in a farm located in Baghdad – Old Diyala Bridge area / Al-Tuwaitha Al-Gharbiya village (N 33°11′56″ – E 44°29′30″), in a silty loam soil (Mohsen & Alwan, 2019; Page, Miller and Keeney, 1982).

Soil Preparation

Prior to planting, the soil was plowed twice using a moldboard plow in perpendicular directions and then leveled and refined using a rotary harrow. Soil samples were collected randomly from a 0–30 cm depth, mixed thoroughly to form a composite sample, air-dried, and ground for analysis of physical, chemical, and fertility properties (Al-Shammari, 2015; Schmitt and de Vries, 2020).

Table 1: Presents selected physical, chemical, and fertility characteristics of the soil before planting.

Property	Value	Unit
Electrical conductivity (1:1 EC)	2.62	dS m^{-1}
pH (1:1)	7.23	—
Cation exchange capacity (CEC)	20.75	cmol (+) kg^{-1}
Organic matter (OM)	11.3	g kg^{-1}
Carbonate minerals	265.41	g kg^{-1}
Soluble cations: Ca^{2+}	5.83	mmol L^{-1}
Mg^{2+}	3.64	mmol L^{-1}
Na^{+}	4.20	mmol L^{-1}
K^{+}	0.33	mmol L^{-1}
Soluble anions: CO_3^{2-}	Nil	mmol L^{-1}
HCO_3^{-}	1.65	mmol L^{-1}
SO_4^{2-}	4.58	mmol L^{-1}
Cl^{-}	12.30	mmol L^{-1}
Available nitrogen	36.05	mg kg^{-1}

Available phosphorus	5.97	mg kg^{-1}
Available potassium	190.50	mg kg^{-1}
Plant available water at field capacity	0.23	%
Bulk density	1.34	Mg m^{-3}
Soil separates: Sand	153	g kg^{-1}
Silt	648	g kg^{-1}
Clay	199	g kg^{-1}
Soil texture class	Silty Loam	—

In Table 1, it can be noted that the pH of the soil was nearly neutral (7.23), while the salinity was moderate (EC 2.62 dS m^{-1}), so the researched soil appeared suitable for crop growth. Additionally, soil showed adequate nutrient-holding capacity (CEC 20.75 cmol (+) kg^{-1}) and sufficient organic matter (11.3 g kg^{-1}). Basic nutrients such as N, P, and K are available in sufficient amounts. With a texture of salty loam, the soil demonstrates a good balance of moisture retention, aeration, and drainage (Table 2).

Table 2: Lists the measurement methods and instruments used for the analysis.

No.	Analysis	Unit	Method or Instrument Used
1	Electrical Conductivity (1:1)	dS m^{-1}	EC Meter
2	Soil pH (1:1)	—	pH Meter
3	Available Nitrogen	mg kg^{-1} soil	Micro-Kjeldahl Method
4	Available Phosphorus	mg kg^{-1} soil	Spectrophotometer
5	Available Potassium	mg kg^{-1} soil	Flame Photometer
6	Organic Matter Content	g kg^{-1} soil	Oxidation with Potassium Dichromate
7	Carbonate Minerals Estimation	g kg^{-1} soil	Calcimeter
8	Soluble Calcium	mmol L^{-1}	1:1 Soil Extract
9	Soluble Magnesium	mmol L^{-1}	Eriochrome Black T (EBT) Indicator
10	Soluble Potassium and Sodium	mmol L^{-1}	Flame Photometer
11	Soluble Chloride	mmol L^{-1}	1:1 Soil Extract
12	Soluble Bicarbonate	mmol L^{-1}	1:1 Soil Extract
13	Soil Particle Size Distribution	g kg^{-1} soil	Hydrometer Method

Table 3: Analytical methods and instruments used for soil property evaluation.

Type of Organic Material	Total N (%)	Total P (%)	Total K (%)	EC (dS m^{-1})	pH	Organic Matter (%)	C/N Ratio
BSF Larvae Fertilizer	4.00	2.00	1.70	11.20	6.9	78.00	8.02
Cattle Manure	1.20	1.05	1.01	27.40	7.10	52.30	13.32
Poultry Manure	1.40	1.56	1.12	22.20	7.00	60.00	11.65

The nutrient content of BSF larvae fertilizer was demonstrated to be higher than that of cattle and poultry manure (N: 4.00%, P: 2.00%, K: 1.70%). This suggests that BSF larvae fertilizer has a stronger fertilizing potential than cattle and poultry manure. BSF larvae fertilizer exhibited a near-neutral pH of 6.9 and a significantly higher organic matter concentration of 78%, which promotes soil enrichment and microbial activity. The C/N ratio of 8.02 suggests quick decomposition with faster nutrient release compared to the cattle and poultry manures, which showed lower nutrient content and closer to neutral pH values, but higher C/N ratios; therefore, they would also indicate slower mineralization and less immediate nutrient availability (Table 3).

Seedling Transplantation and Experimental Factors

Seedlings were transplanted into the field on April 2, 2024, after being sterilized to protect them from soil-borne fungal diseases. The field was arranged into planting rows, with each bed having a width of 50 cm and 30 cm between plants on one side. Each bed was equipped with a drip irrigation line, and each experimental unit consisted of 12 plants (Al-Lami, Ati and Al-Rawi, 2023). There was a 60 cm distance between experimental units (Bouras et al., 2011).

Two experimental factors were tested:

1. **Organic Fertilizer Source**:

- Three types—cattle manure, poultry manure, and BSF larvae-based compost, each applied at 5 tons ha^{-1}.

2. **Mineral Fertilizer Levels (NPK):**

- Full recommended dose (N=80, P=60, K=160),
- Half dose (N=40, P=30, K=80),
- No mineral fertilizer. (Ali, 2018).

Experimental Design

A factorial experiment was conducted using a Randomized Complete Block Design (RCBD) with three replicates per treatment. The total number of treatments was 9, resulting in 27 experimental units.

Application of Organic and Mineral Fertilizers

Organic fertilizers were applied before planting. Mineral fertilizers were applied via fertigation using irrigation water starting from the third week after planting. Urea (46% N) was used as a nitrogen source; urea phosphate (20% P, 18% N) provided phosphorus and supplemental nitrogen; and potassium sulfate (41.5% K_2O) was used for potassium (Hammadi and Alwan 2023).

Irrigation Method

Drip irrigation was used with water sourced from the Tigris River. The system was calibrated to determine the appropriate irrigation duration, maintaining soil moisture near field capacity and initiating irrigation when 40% of the available water was depleted.

Crop Management

Standard agronomic practices—including weeding, hoeing, irrigation, pest and disease control, and harvesting—were carried out throughout the growing season until the experiment was completed.

Results and Discussion

Effect of BSF Organic Fertilizer and Other Organic Fertilizers on Growth Parameters and Yield of Cowpea

Mean Leaf Area (cm^2 $leaf^{-1}$)

The statistical analysis (Table 4) showed significant differences among organic and mineral fertilizer types in their effect on leaf area of cowpea. The BSF fertilizer treatment significantly outperformed other treatments, followed by cattle manure, and then poultry manure, with mean leaf areas of 116.820, 77.780, and 58.867 cm² leaf⁻¹, respectively. An increase in leaf area was also observed with increasing levels of mineral NPK fertilizer, with the full recommendation yielding the highest mean value (87.577 cm²), followed by the half dose (85.043 cm²), and the control (80.847 cm²).

The interaction between organic and mineral fertilizer types was also significant. The combination of BSF organic fertilizer and full NPK recommendation yielded the highest leaf area: 120.420 cm² leaf⁻¹. No significant differences were observed between treatments combining organic fertilizer with half or full mineral recommendations in other sources.

Table 4: Effect of BSF and other organic fertilizers on leaf area (cm² leaf⁻¹).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	112.66	117.38	120.42	116.82
Poultry Manure	55.49	59.31	61.80	58.87
Cattle Manure	74.39	78.44	80.51	77.78
Mean	80.847	85.043	87.577	
LSD 5%			2.151	

Dry Weight of Vegetative Growth (g plant⁻¹)

Table 5 shows that BSF organic fertilizer significantly increased dry biomass compared to poultry and cattle manures, with values of 77.167, 73.533, and 71.233 g plant⁻¹, respectively. Increasing NPK levels also significantly affected this parameter, with 76.267 g under full recommendation, 73.900 g under half, and 71.667 g without addition. The combination of BSF fertilizer and full NPK resulted in the highest dry biomass: 79.800 g plant⁻¹.

Table 5: Effect of BSF and other organic fertilizers on dry vegetative biomass (g plant⁻¹).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	74.40	77.30	79.80	77.17
Poultry Manure	71.70	73.50	75.40	73.53
Cattle Manure	69.20	70.90	73.60	71.23
Mean	71.667	73.900	76.267	
LSD 5%			2.214	

Mean Pod Length (cm pod⁻¹)

Significant differences were recorded among treatments in pod length (Table 6). BSF frass recorded the highest mean value of 15.510 cm, followed by poultry manure (13.600 cm), and cattle manure (9.867 cm). Full NPK recommendation again outperformed other levels with 13.933 cm, compared to 12.967 cm and 11.077 cm for half and no addition, respectively. The highest pod length of 16.300 cm was observed under the combination of BSF and full NPK.

Table 6: Effect of BSF and other organic fertilizers on pod length (cm pod⁻¹).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	14.53	15.70	16.30	15.51
Poultry Manure	12.50	13.40	14.90	13.60
Cattle Manure	9.20	9.80	10.60	9.87
Mean	11.077	12.967	13.933	
LSD 5%			2.01	

Cumulative Yield (Mg ha^{-1})

The results in Table 7 indicate significant differences in cumulative yield among the treatments. BSF frass recorded the highest yield (12.090 Mg ha^{-1}) compared to poultry manure (10.243 Mg ha^{-1}) and cattle manure (9.197 Mg ha^{-1}). Similarly, yield increased significantly with higher mineral NPK levels: 11.790, 10.367, and 9.040 Mg ha^{-1} for full, half, and no addition, respectively. The combination of BSF fertilizer and full NPK recommendation resulted in the highest cumulative yield: 13.670 Mg ha^{-1}.

Table 7: Effect of BSF and other organic fertilizers on cumulative yield (Mg ha^{-1}).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	10.330	12.270	13.670	12.090
Poultry Manure	8.860	10.690	11.180	10.243
Cattle Manure	7.930	9.140	10.520	9.197
Mean	9.040	10.367	11.790	
LSD 5%			1.175	

Effect of BSF and Other Organic Fertilizers on Soil Nutrient Availability at the End of the Experiment

Available Nitrogen (mg N kg^{-1} soil)

Table 8 shows significant differences in soil nitrogen availability across treatments. BSF fertilizer achieved the highest value (68.443 mg N kg^{-1}), followed by poultry manure (53.777 mg N kg^{-1}) and cattle manure (47.667 mg N kg^{-1}). The full NPK dose led to higher N availability (61.500 mg N kg^{-1}) than the half dose and the control. The combination of BSF and full NPK recommendation yielded the highest nitrogen level: 77.000 mg N kg^{-1}.

Table 8: Effect of BSF and other organic fertilizers on available nitrogen (mg N kg^{-1} soil).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	61.000	67.330	77.000	68.443
Poultry Manure	50.500	52.330	58.500	53.777
Cattle Manure	42.670	48.330	52.000	47.667
Mean	51.390	55.997	61.500	
LSD 5%			1.216	

Available Phosphorus (mg P kg^{-1} soil)

As shown in Table 9, BSF frass significantly enhanced soil phosphorus availability (11.989 mg P kg^{-1}), outperforming poultry manure (8.389 mg P kg^{-1}) and cattle manure (7.700 mg P kg^{-1}). The full NPK recommendation also showed a significant increase (10.600 mg P kg^{-1}) compared to the half and control treatments. The highest value was recorded under the BSF + full NPK treatment: 13.467 mg P kg^{-1}.

Table 9: Effect of BSF and other organic fertilizers on available phosphorus (mg P kg^{-1} soil).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	10.700	11.800	13.467	11.989
Poultry Manure	7.300	8.133	9.733	8.389
Cattle Manure	6.900	7.600	8.600	7.700
Mean	8.300	9.178	10.600	
LSD 5%			0.451	

Available Potassium (mg K kg^{-1} soil)

Table 10 indicates that BSF frass again resulted in the highest potassium availability (183.710 mg K kg^{-1}), followed by poultry manure (155.577 mg K kg^{-1}) and cattle manure (145.710 mg K kg^{-1}). Full NPK recommendation produced the highest value (170.843 mg K kg^{-1}), with the combination of BSF and full NPK leading to the top reading: 195.730 mg K kg^{-1}.

Table 10: Effect of BSF and other organic fertilizers on available potassium (mg K kg^{-1} soil).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	171.600	183.800	195.730	183.710
Poultry Manure	145.600	156.930	164.200	155.577
Cattle Manure	138.800	145.730	152.600	145.710
Mean	152.000	162.153	170.843	
LSD 5%			2.517	

BSF frass and various organic fertilizers do aid in soil nutrition, overuse or usage of them inappropriately near water bodies can contribute to nutrient runoffs in water systems, primarily nitrogen and phosphorus. This runoff can lead to over-nitrification and algal blooms in aquatic ecosystems, resulting in oxygen depletion. But BSF frass often has a slower nutrient release profile than synthetic fertilizers, and is less likely to create a water pollution problem. Buffer zones and application rates can also help mitigate potential insect rearing impacts to aquatic ecosystems.

Effect of BSF and Other Organic Fertilizers on Cowpea Seed Quality

Protein Content (%) in Cowpea Seeds

According to Table 11, BSF fertilizer significantly improved seed protein content, reaching 23.37%, compared to 20.38% for poultry manure and 20.09% for cattle manure. Protein levels also increased with mineral fertilizer addition, reaching 24.27% under full NPK, followed by 22.92% (half) and 20.64% (control). The highest protein content (26.20%) was recorded with the BSF + full NPK treatment.

Table 11: Effect of BSF and other organic fertilizers on protein content in cowpea seeds (%).

Organic Fertilizer Type	No Fertilizer	Half NPK	Full NPK	Mean
BSF Frass	20.99	23.58	26.20	23.37
Poultry Manure	19.00	20.99	22.88	20.38
Cattle Manure	18.30	20.52	22.40	20.09
Mean	20.64	22.92	24.27	
LSD 5%			1.30	

Conclusion

BSF frass is considered one of the most recent and promising types of insect-derived organic fertilizers. As the BSF larvae feed on organic waste, their excreta become rich in essential macronutrients such as nitrogen, phosphorus, and potassium, and are more rapidly decomposed due to prior digestion in the insect’s gut. Its increasing use in sustainable agriculture contributes to enhancing soil fertility and improving its efficiency. BSF frass's inclusion aids in reducing pollution to the environment, by repurposing organic waste materials from landfills and providing alternative pathways to reduced greenhouse gas emissions. The nutrient recycling effect decreases nutrient runoff into waterways, which will help to improve water quality and help to safeguard aquatic ecosystems. This circular approach is a demonstration of circular bioeconomy concepts and assists climate-smart agricultural practices. This study demonstrated that BSF frass significantly increased the availability of N, P, and K in calcareous soil and improved vegetative growth, yield quantity, and seed quality of cowpea when applied alone or in combination with full mineral NPK fertilization. The frass treatment outperformed poultry and cattle manures across most evaluated parameters. These results support the potential of BSF frass as a viable substitute or supplement to traditional organic and mineral fertilizers, helping to achieve sustainable soil management and environmentally responsible agricultural practices.

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