

HAWASSA UNIVERSITY, SCHOOL OF GRADUATE STUDIES



**COMPARATIVE EFFECTS OF BLACK SOLDIER FLY FRASS, BIOSLURRY
AND CHEMICAL FERTILIZER ON MAIZE AND SWISS CHARD AGRONOMIC
PERFORMANCE AND SOIL PROPERTIES IN HAWASSA, SIDAMA REGION,
ETHIOPIA**

MSc THESIS

EMABET ASEFA

HAWASSA, ETHIOPIA

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ETHIOPIA**

EMABET ASEFA

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF
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MAJOR ADVISOR: YADESSA GONFA (PhD)

CO ADIVSIOR: GETACHEW SIME (PhD)

HAWASSA, ETHIOPIA

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SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

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I declare that this thesis is my work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate

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Place: College of computational science, Hawassa University, Hawassa, Ethiopia.

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DECLARATION

I hereby declare that this thesis proposal titled “**COMPARATIVE EFFECTS OF BLACK SOLDIER FLY FRASS, BIOSLURRY AND CHEMICAL FERTILIZER ON MAIZE AND SWISS CHARD AGRONOMIC PERFORMANCES AND SOIL PROPERTIES IN HAWASSA, SIDAMA REGION, ETHIOPIA**” It is submitted to Hawassa university Biology department in partial fulfillment of the requirement for qualification of Master of science in Botanical Sciences. This is my independent work and has not been previously submitted for any degree or examination at any higher education institution. All references are well-indicated and properly acknowledged.

Name: Emabet Asafa

Signature.....

Date

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TABLE OF CONTENTS

CONTENTES

PAGE

STATEMENT OF THE AUTHOR	i
DECLARATION	ii
ACKNOWLEDGMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURE	viii
LIST OF APPENDIX	ix
LIST OF ACRONMYS	x
ABSTRACT	xi
1. INTRODUCTION	1
1.1. Back Ground of the Study	1
1.2. Statement of the Problem.....	4
1.3. Objectives of the study	6
1.3.1. General objective	6
1.3.2. Specific objective.....	6
1.4. Research question	7
1.5. Significance of the study.....	7
1.6. Scope of the study.....	7
1.7. Limitation of the Study	8
1.8. Operational definition term.....	8
2. REVIEW OF RELATED LITERATURE	10
2.1. Maize	10
2.1.1. Origin, distribution and botany of maize	10
2.1.2. Climate and growth requirement of maize	11
2.1.2.1. Nutrient requirement and deficiency in maize.....	13
2.2. Origin, Distribution Botany and Importance of Swiss chard.....	16
2.2.1. Growth requirement of Swiss chard	17
2.2.2. Nutrient requirement and deficiency in Swiss chard	18
2.2.3. Swiss chard production in Ethiopia	19
2.3. Black soldier fly (BSF) and life cycle	20

2.4. Black soldier fly frass (BSFF) in agriculture.....	23
2.4.1. Properties of frass	23
2.4.2. Nutrient content and pH.....	25
2.4.3. Frass as soil amendments and as a source of bioactive compounds.....	26
2.4.4. Maturity, stability and heavy metal contents of frass	29
2.4.5. BSFF for improving soil quality	31
2.4.6. Effect of BSFF on crop growth performance, yield and quality	35
2.5. Black soldier fly farming in Ethiopia and the challenges	37
3. MATERIALS AND METHODS	38
3.1. Description of the Experimental Site.....	38
3.2. Agro-climatic Conditions of Hawassa City	38
3.3. Experimental Materials.....	39
3.3. Treatments and Experimental Design.....	40
3.4. Seedbed Preparation and Seed Sowing.....	41
3.5. Soil, Organic Fertilizer (BSFF and BS) Sample Collection and Preparation	41
3.5.1. Soil sampling and analysis.....	41
3.5.2. BSFF and BS sampling and analysis	43
3.6. Data Collection	43
3.6.1. Maize	43
3.6.2. Swiss chard	44
3.8. Statistical Analysis.....	45
4. RESULTS AND DISCUSSION	46
4.1 Properties of Pre-Experimental Soil and Organic Fertilizers	46
4.1.1. Physicochemical Properties of BSFF and Bioslurry.....	48
4.2. Effects of Different Fertilizers on the Soil Physicochemical Properties	48
4.2.1. Properties of the soil after harvesting maize.....	48
4.2.2. Properties of the soil after harvesting Swiss chard	53
4.3. Effects of Different Fertilizers on Germination and Growth of Maize	56
4.3.1. Effects on seedling emergence and plant vigorsity and uniformity.....	56
4.3.2. Effects on plant height and ear height of maize.....	58
4.3.3. Effects on tasseling and silking and maturity	59
4.4. Effects of Fertilizers on Stand Count, Total Biomass, Stalk Weight and Grain Yield.....	60

4.4.1. Stand count at harvest, total biomass yield and stalk weight.....	60
4.4.2. Effects on number of ears, ear weight and cob length of maize	63
4.4.3. Grain yield	64
4.5. Effects of Various Fertilizers on Growth Parameters and Yield of Swiss chard.....	66
4.5.1. Effect on plant vigor and uniformity	66
4.5.2. Plant height	67
4.5.3. Leaf length and leaf width	69
4.5.4. Leaf number	71
4.5.5. Leaf area	71
4.5.6. Effects on relative growth rate in height.....	72
4.5.7. Effects on leaf fresh weight	74
5. CONCLUSION AND RECOMMENDATION	76
5.1. Conclusion	76
5.2. Recommendation	76
REFERENCE.....	77
ANNEX	107

LIST OF TABLES

Table 1. Treatments, fertilizer types and rates of fertilizers.	40
Table 2. Field layout of the experiments.	40
Table 3: Selected physicochemical properties of pre-experimental soil and organic fertilizers.	47
Table 4. Physicochemical properties of the soil after harvesting maize.	49
Table 5: Physicochemical properties of post-experiment soil after Swiss chard harvest	55
Table 6. Effects of different fertilizers on maize seedling emergence and plant growth. ...	57
Table 7. Effect of fertilizer on days to tasseling, silking and maturity of maize	59
Table 8. Effect of fertilizer on yield and yield components of maize	62
Table 9. Effects of different fertilizer on seedling vigorsity and uniformity for Swiss chard	67
Table 10. Effects of different fertilizer on growth parameters of Swiss chard.....	68

LIST OF FIGURE

Figure 1: The life cycle of Black soldier fly (Maglangit et al., 2021).....	23
Figure 2. Map of the experimental area (Lolam <i>et al.</i> , 2023).....	38
Figure 3. Monthly average rainfall and maximum and minimum temperatures of the experimental site during 2007-2022. (Data source: National Metrology Service Agency /NMSA, Hawassa Branch, 2022).....	39
Figure 4. Pattern of growth in plant height for various treatments.....	69
Figure 5. Pattern of growth in leaf length for various treatments.....	70
Figure 6. Pattern of growth in leaf width for various treatments.....	70
Figure 7. Pattern of growth in leaf Number for various treatments.....	71
Figure 8. Pattern of growth in leaf area.	72
Figure 9. The relative growth rate in height of Swiss chard plants treated with different fertilizers.	74
Figure 10. Effects of different treatments on the marketable yield of Swiss chard.....	75

LIST OF APPENDIX

Annex 1. Measuring of organic fertilizer

Annex 2. Prepared plot area (left) and maize seed sowing (right)

Annex 3. Agricultural practice and pesticide

Annex 4. Picture of the experimental field during vegetative growth of maize plant

Annex 5. Seedling on seed bed (left) and transplanting (right)

Annex 6. Picture of the experimental field during vegetative growth

Annex 7. Picture during data collection of growth parameters and fresh weight yield

Annex 8. Picture during harvesting of Swiss chard

LIST OF ACRONYMS

BS	Bioslurry
BSFF	Black Soldier Fly Larvae Frass
BSFL	Black Soldier Fly Larvae
CEC	Cation Exchange Capacity
EC	Electrical Conductivity
GY	Grain Yield
ICIPE	International Center Insect of Physiology and Ecology
NPS	Nitrogen, Phosphorous and Sulfur fertilizer
PH	Plant Height
TBM	Total Biomass
TN	Total Nitrogen

ABSTRACT

In Ethiopia, soil fertility and crop production are influenced by various agronomic practices. However, increasing crop production without disrupting the environment is one of the main challenges. Application of organic fertilizers such as manure, compost, bioslurry and frass can be an alternative solution for sustainable farming. This study evaluated the comparative effects of black soldier fly larvae frass (BSFF), bioslurry (BS) and chemical fertilizer (CF) on maize and Swiss chard agronomic performances and soil properties. Maize and Swiss chard were used as test crops. The treatments were 7.5 t ha⁻¹ BSFF and BS, 100 kg ha⁻¹ CF and the control for maize and 10.3 t ha⁻¹ BSFF and BS, 100 kg ha⁻¹ CF and the control for Swiss chard. The treatments of both experiments were arranged in a randomized complete block design with three replications. Data related to agronomic parameters of both crops were collected and analyzed using SAS software. Physicochemical properties of BSFF, BS, and pre and post experimental soil samples were analyzed. Results showed that the application of all fertilizer improved the agronomic performance of both crops. The application of BSFF to maize reduced the average number of days to reach tasseling, silking and physiological maturity. It also resulted in significantly ($p < 0.05$) larger maize plant height (218 cm), total biomass (20.4 t ha⁻¹) and larger grain yield (4 t ha⁻¹) compared to the control. Moreover, the BSFF treatment resulted in significantly ($p < 0.05$) larger Swiss chard plant height (72 cm) and leaf fresh weight (125 t/ha⁻¹) compared to the BS, CF and the control. BSFF and BS improved soil pH, bulk density and porosity. Soil organic matter, soil organic carbon, total nitrogen, available phosphorus and cation exchange capacity of the soil were improved with the applications of BSFF and BS. Overall, the results of the study demonstrated that BSFF is an effective organic fertilizer for maize and Swiss chard production and soil health. However, since the experiment was done only for one season and at one study site, similar experiments should be carried out for over several seasons and locations to make a more conclusive recommendation.

Keyword: bioslurry, black soldier fly frass, maize, soil fertility, Swiss chard

1. INTRODUCTION

1.1. Back Ground of the Study

The United Nations predicts that the current global population of 8 billion will increase to 9.8 billion by 2050 (UNDESA, 2023). Consequently, it becomes crucial to discover effective methods for ensuring sufficient food access for all people (Kleyn and Ciacciariello, 2021). To meet the demands of this larger population it is crucial to improve and increase food production (Searchinger *et al.*, 2019; Kaburagi *et al.*, 2020). This requires transforming agricultural systems to ensure both food security and environmental sustainability (Eigenbrod and Gruda, 2015).

The agriculture sector is a vital source of income for millions of people around the world suffering from poverty and contributes significantly to the economic growth of nations (Getaye Gizaw, 2020; Liu *et al.*, 2023). It provides with all our food but also serves as the raw material supplier for various agrobased industries, offering significant opportunities for populations in developing countries (Getachew Diriba, 2020). Ethiopia, as one of the developing countries, heavily relies on agriculture (Gebeyanesh Zerssa *et al.*, 2021; Alefu Chinasho *et al.*, 2023). The agricultural sector plays a central role in the lives and livelihoods of the majority of Ethiopians (Stellmacher and Kelboro, 2019; Benyam Tadesse *et al.*, 2021). In the Ethiopian economy, agriculture accounts for 40% of GDP, 75% of employment, and 80% of exports (USAID, 2023). Despite its importance, the agricultural sector in Ethiopia has underperformed in comparison to the rapid population growth, primarily due to limited utilization of improved inputs and backward agricultural practices (Zerssa *et al.*, 2021; Belete *et al.*, 2022)

According to Kopittke *et al.* (2019), the agricultural industry is facing persistent demands to produce larger quantities of food due to the expanding global population. The use of inputs such as fertilizers and pesticides was needed for agricultural development to boost crop production to keep people fed and healthy (Ngoune and Mutengwa, 2019; Giordano *et al.*, 2021). In the past, farmers have relied on expanding land area and chemical fertilizers for maximum productivity (Jaja and Barber, 2017; Umesha *et al.*, 2018). However, the long-term sustainability of these practices is now being questioned (Borkent and Hodge, 2021), posing a threat to future food production due to soil degradation. To ensure food security, a new sustainable approach is necessary (Farooq *et al.*, 2019).

Restoring soil quality through nonchemical fertilizers and pesticides is recommended in sustainable agriculture, with organic fertilizers gaining interest for their potential benefits (Ali *et al.*, 2021; Poveda, 2021).

The recent trend in agriculture is the mainstreaming of organic farming, which involves the use of locally available and environmentally friendly sources of nutrients (Libutti and Rivelli, 2021; Nakayiwa, 2022). Organic fertilizers are derived from natural sources, and their utilization can have a positive impact on environmental pollution, as well as serve as effective strategies for restoring soil health and promoting carbon storage in soils (Naher *et al.*, 2019). Applying organic fertilizers becomes a means of supporting both long-term food security and environmental preservation (Cen *et al.*, 2020).

Various organic materials, including animal manure and other organic wastes, can be used as the basis for making compost and solid fertilizers. One potential organic fertilizer that has emerged recently is a by-product of insect farming (Borkent and Hodge, 2021). In recent years, the larvae of the black soldier fly (*Hermetia illucens* L.) have demonstrated efficient conversion of organic waste, making them a promising option for waste management (da Silva and Hesselberg, 2020). In this insect-based treatment, biodegradable waste is transformed into two primary products: nutrient-rich larval biomass that can be used in animal feed (Wang and Shelomi, 2017) and frass as the main by-product (Lalander *et al.*, 2019; Siddiqui *et al.*, 2022). This process's main output, globally recognized as a promising and hygienic organic fertilizer (Lalander *et al.*, 2015; Wu *et al.*, 2023), has great potential for improving soil and crop productivity (Kagata and Ohgushi, 2012; Menino *et al.*, 2021).

BSFL frass can be characterized as a slightly alkaline, nutrient-rich compound fertilizer (Gärtling and Schulz, 2019), which falls within the optimum range for promoting plant growth (Surendra *et al.*, 2020) and providing a conducive environment for beneficial bacterial communities (Choi and Hassanzadeh, 2019). Due to this the residue of BSFL can be used as an organic fertilizer (Kawasaki *et al.*, 2020; Lopes *et al.*, 2022). Kebli and Sinaj (2017) confirmed that the application of frass improves soil fertility by providing essential plant nutrients. Therefore, the use of insect frass as fertilizer could help reduce the need for agrochemicals and contribute to the development of sustainable agriculture (Poveda, 2021). This technology aligns with the principles of a circular bio-economy, where waste

from one process becomes a resource for another (Slorach *et al.*, 2019). Currently, most frass fertilizers are marketed as garden fertilizers, particularly in organic agriculture and horticulture, as there is a high demand for high-value organic fertilizers (Gärttling *et al.*, 2020).

Ethiopia is a country with varied terrain and agro-ecological climate ranging from temperate in the highlands to tropical in the lowlands. Due to the heterogeneity of topography, climatic conditions and soil types, the country is able to grow a wide variety of crops, including cereals and various horticultural crops for domestic consumption and foreign markets (Urgessa Tilahun, 2014; Selamawit Ketema and Tesfaye Tadesse, 2019). Maize (*Zea mays* L) is one of the worlds' three primary cereal crops (Cai *et al.*, 2023). Maize holds a unique position in the world agriculture as a food; feed for livestock and as a source of diverse, industrially important products (Abdulfeta Tariku and Aseged Walelign, 2020). It Plays a critical role in ensuring food and nutritional security, and livelihoods of millions of resource constrained smallholders (Bekele Shiferaw *et al.*, 2011; Erenstein *et al.*, 2022), and being used as source of income for many populations in developing countries (Ngoune and Mutengwa, 2019).

In Ethiopia, maize owns a success story as it has become a strategic food security crop, produced and consumed on a large scale by smallholder farmers, next to teff in terms of area (Tsedeke Abate *et al.*, 2015). Because of these efforts, maize has become the major cereal staple crop in terms of production and productivity (Moti Jaleta *et al.*, 2018). Swiss chard (*Beta vulgaris* L.) is a horticultural crop belonging to the Chenopodiaceae family (Getaneh, 2022). Its cultivation is highly valued for its nutritional properties and flavor, year round availability, low cost and wide use in many traditional dishes (Dumani *et al.*, 2021; Mroczek *et al.*, , 2021). In Ethiopia, Swiss chard was produced under both irrigated and rainy conditions in urban and periurban areas compared to lettuce and cabbage (Gebremedhin Hailay and Awgchew Haymanot, 2019). This vegetable has nutritional benefits that can have a significant positive impact on improving food security and it will contribute to the country's economic growth (Selamawit Ketema and Tesfaye Tadesse, 2019). Despite the fact that vegetable crops are vital to the Ethiopian economy, public research on vegetable crops has been negligible and limited attention has been given to the sector (Aliyi *et al.*, 2021).

Previous studies have demonstrated the potential of BSF frass for improving plant health, crop yield, and soil fertility (Zahn and Quilliam 2017; Anyega *et al.*, 2021; Tanga *et al.*, 2021) and frass fertilizer applications significantly increased soil organic matter (OM), nutrient availability, and enzyme activity (Wu *et al.*, 2023). However, due to lack of information, particularly in Ethiopia, there is insufficient knowledge regarding the effect of BSFF on the growth performance and yield of maize and vegetables. The purpose of the current study is to compare the effects of black soldier fly frass, composted bioslurry and chemical fertilizer on the agronomic performance of maize and the Swiss chard and soil properties.

1.2. Statement of the Problem

Depletion of soil fertility is a main problem to sustain agricultural production and productivity in many countries (Tesfaye Burju, 2018; Bekele *et al.*, 2021). In Ethiopia, soil erosion and declining of soil fertility are two of the main problems that affect agricultural productivity and crop yields (Tilahun Gisila *et al.*, 2022). The primary causes of declining in soil fertility are loss of organic matter, macro and micronutrient depletion, acidity, topsoil erosion and deterioration of soil physical properties (Fanuel Laekemariam and Gifole Gidago, 2013; Zeleke *et al.*, 2022).

Fertilizers are substances used in soil to give plants the vital nutrients they need for growth and higher crop yields. They can be either organic or inorganic and play a crucial role in supporting plant development and maximizing productivity (Shahena *et al.*, 2021). For food selfsufficiency, growth in crop productivity is critical to spur growth in other parts of the economy (Stewart and Lal, 2018). Increasing soil fertility through fertilization is the common way of modern agricultural practice (Kadigi *et al.*, 2020) and addition of different soil amendments in response to declining soil fertility has been studied (Syuhada *et al.*, 2016; Jjagwe *et al.*, 2020). The main challenge in agricultural is increasing crop yield without disrupting the environment and to maintain production sustainably by minimizing the negative influences of agrochemicals on crop and soil properties (Hajnal-Jafari *et al.*, 2020; Chen *et al.*, 2020),

An inorganic fertilizer improves crop yield and increased nutrient availability, while using organic fertilizer, leads to improved soil conditions for longer periods of time, particularly with continuous maize cultivation (Oladele *et al.*, 2019). Globally, Maize is commonly

referred to as the queen of grains due to its high genetic yield potential compared to other grains (Kumar *et al.*, 2013; Kannan *et al.*, 2013) and absorbs large quantity of nutrients from the soil during different growth stages (Detebo Orebo *et al.*, 2021). However, maize yield in the tropical rainfed environments is generally low due to combinations of several factors which include poor soil fertility and limited access to fertilizers (Ngoune and Mutengwa, 2019; Murad Mohammed, 2021). Increasing maize yield and reducing the yield gap are essential to ensure future food security in Ethiopia (Van Dijk *et al.*, 2020). Ethiopia will need to sustain the current upward trend in cereal yield, with maize being the predominant crop, to maintain its current self-sufficiency rate of 95% by 2050 (Ittersum *et al.* 2016; van Dijk *et al.*, 2020).

Increasing the yield and production of horticultural crops is also very important to ensure food security in Ethiopia (Selamawit Ketema and Tesfaye Tadesse, 2019). Fertilizer plays an important role for growth of vegetables. Among the horticulture crops suitable for cultivation with organic amendments is included the Swiss chard (Libutti and Rivelli, 2021). In the country Swiss chard related to limited information and lack of research based information concerning fertilizer requirements under various ecologies and lack of research based information and agricultural extension services (Fekadu *et al.*, 2022; Lolamo *et al.*, 2023).

In developing countries including Ethiopia, there has been a lack of emphasis on developing fertilizer products that are both cost-effective and environmentally friendly, with the aim of enhancing vegetable growth and maximizing yield (Anyega *et al.*, 2021). Important causes for the increased productivity include increased availability and use of modern inputs (such as improved varieties and fertilizers), better extension services and increasing demand (Tsedeke Abate *et al.*, 2015). Getachew Sime *et al.* (2018) also stated that the agricultural productivity depends on the use and availability of better agricultural technologies and practices.

Organic fertilizers such as manure, compost, bioslurry and BSFF contain plant or animal materials that are either a byproduct or an end product of naturally occurring processes (Shaji *et al.*, 2021; Mannaa *et al.*, 2023). They are primarily cost effective, easily available from local products than chemical fertilizers (Solomon, *et al.*, 2012). They have the potential to address both crop and soil quality issues (Tsegaye Terefe *et al.*, 2018) while being environmentally friendly (Worku Ajema, 2021; Boudabbous *et al.*, 2023).

Using organic fertilizers such as animal manure, compost, bioslurry and black soldier fly frass (BSFF) as fertilizer crop cultivation could be a way of efficiently returning plant nutrients in organic waste to the food chain to increase agricultural productivity. Additionally, it is essential for organic farming development to identify new and better organic fertilizers that both minimize crop yield losses and enhance soil quality.

In Ethiopia, using BSFF as organic fertilizer is relatively new technology compared to animal manure, compost and bioslurry. However, some studies have investigated the use of BSFF as a soil amendment for enhancing crop growth in other regions of Africa and other country, which may provide some useful insights. For instance in Kenya Beesigamukama et al. (2020) and Tanga et al. (2021) report that the application of BSFF led to higher maize growth and yield and improve nutritional quality of maize or comparable with chemical fertilizer. Similarly Anyega et al., (2021) report frass has an effective fertilizer on French beans, tomato and kales in Sub-saharan Africa, Dzepe et al., (2022) on Lettuce and Abiya et al., (2022) on Kale and Swiss chard.

As BSFF is relatively a new product and information on its importance in terms of its effects on growth and yields of some common cereal and vegetable crops, particularly its effects on the on growth and yields maize and Swiss chard are largely unknown. There is also limited literature on the effect of BSFF growth and yields crops in the Ethiopia context. Therefore, the present study compared the performance of black soldier fly frass, composted bioslurry and chemical fertilizer in improving the agronomic performance of maize and Swiss chard and the soil physicochemical properties.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this study is to evaluate the effects of frass of black soldier fly larvae, bioslurry and chemical fertilizer on agronomic performance of maize and Swiss chard, and soil physicochemical properties.

1.3.2. Specific objective

1. To evaluate the effects of black soldier fly frass, bioslurry and chemical fertilizer on the growth performance of maize and Swiss chard.

2. To compare the effects of black soldier fly larvae frass, bioslurry and chemical fertilizer on the yields of maize and Swiss chard.

3. To determine the effects of black soldier fly larvae frass on the soil physicochemical properties compared to bioslurry and chemical fertilizer.

1.4. Research question

1. What are the effects of black soldier fly larvae frass, bioslurry and chemical fertilizer on the on the growth performance of maize and Swiss chard?

2. How does black soldier fly larvae frass, bioslurry and chemical fertilizer are influence the yield of maize and Swiss chard?

3. What are effect of black soldier fly larvae frass on the soil physicochemical properties compared to the application of bioslurry and chemical fertilizer?

1.5. Significance of the study

No study has been conducted on the effect of BSFF on cereal and vegetable production in Ethiopia. As there is lack of clear information and accessible extension services regarding the uses of Black soldier fly frass (BSFF) as an organic fertilizer in Ethiopia, field experiments were conducted to compare this fertilizer with bioslurry and chemical fertilizer in terms of crop agronomic performance and soil properties. These studies provide valuable insights into the effectiveness of BSFF as an organic fertilizer and aim to reduce dependence on chemical fertilizers. The results of this study will primarily benefit small farmers, maize and vegetable growers, researchers, the agricultural sector, and others.

1.6. Scope of the study

The study was limited to determining the performance of the insect based organic fertilizer (BSFF) as compared with bioslurry and chemical fertilizer on the agronomic performance of maize, the marketable yield of Swiss chard and the soil properties at the main campus of Hawassa University, Sidama region.

1.7. Limitation of the Study

The study had certain limitations concerning maize. Firstly, the experiment was conducted for only one season and with only one variety. Additionally, the fertilizer application relied on a single rate of dose for both crops. Furthermore, there were limitations regarding the exploration of soil parameters, including microbial biomass, nutrient use efficiency, heavy metals, and phytotoxicity, which were not measured. These limitations were primarily attributed to the unavailability of necessary laboratory equipment, budget constraints, and time shortages.

1.8. Operational definition term

Black soldier fly (BSF): is a common and widespread fly of the family Stratiomyidae, *Hermetia illucens* L. species.

Black soldier fly larvae (BSFL): from life stage BSF which have proven to convert organic waste into high quality nutrients for fish and poultry feeds.

Insect frass fertilizer: Frass often refers to a mixture of primarily BSFL faeces, substrate residues, and shed BSFL exoskeletons. A second byproduct obtained from the feeding of BSFL on a substrate made of food waste and vegetable waste used as organic fertilizer for crop production.

Bioslurry: The residue of manure digestion can be used as fertilizer for crop production.

Maize: *Zea mays* L is the most abundantly produced cereal in the world belongs to Poaceae family, leafy stalk whose kernels have seeds inside.

Swiss chard: Swiss chard (*Beta vulgaris* L) is a green leafy vegetable belonging to the *Chenopodioideae* family, has broad, thick white midribs and petioles, with heavily crinkled, dark green leaves.

Soil fertility: refers to the ability of soil to sustain agricultural plant growth, i.e. to provide plant habitat and result in sustained and consistent yields of high quality.

Randomized complete block design (RCBD): is the standard design for agricultural experiments where similar experimental units are grouped into blocks or replicates.

2. REVIEW OF RELATED LITERATURE

2.1. Maize

2.1.1. Origin, distribution and botany of maize

Maize or corn (*Zea mays* L.) is a plant belonging to the tribe Maydeae of the grass family (Poaceae) (Ram, 2011). The genus *Zea* consists of four species of which *Zea mays* L. is economically important. Maize is believed to have evolved from a wild grass in central Mexico 7000 years ago and Native Americans transformed into a better food source. Maize is a versatile crop grown over a range of agroclimatic zones (Doebley, 1990). Now it is cultivated around the world, with the United States, China and Brazil the three largest maize producing countries in the world (Ranum *et al.*, 2014) and is the third most important cereal crop in the world after wheat and rice (FAO 2020).

In recent years, there has been tremendous increase in its acreage and production because of its usage in both food as well as nonfood industrial products. In addition to various nonfood uses, it is a flexible multipurpose crop that is predominantly used as a feed across the globe. However, it is also significant as a food crop, particularly in sub-Saharan Africa and Latin America (Erenstein *et al.*, 2022). The diverse industrial uses of maize also generate by-products that provide important additional feed resources and nutrients for the livestock industries (Kumar *et al.*, 2013; Loy and Lundy, 2019). For instance, bioethanol production from maize grain generates distiller's dry grains as a co-product, a valuable animal feed with high nutritional value (Wallington *et al.*, 2012).

Globally, maize is predominantly used for feed (56% of production), 13% for food, and 5% for other uses. These use categories undervalue the role that maize plays in human food and nutrition when taken at face value (Erenstein *et al.*, 2022). Thus, maize contributes in a variety of ways to the global agrifood systems and the security of food and nutrition and there has been a rise in interest in agri-food systems (Shiferaw *et al.*, 2011; Grote *et al.*, 2021; IFAD, 2021). In comparison to rice and wheat, maize has a lower protein level and has an energy density of 365 Kcal/100 g thanks to its 72% starch, 10% protein, and 4% fat content (Nuss and Tanumihardjo, 2010). However, it is a good source of fiber, many B vitamins, and important minerals including calcium, iron, and folate, but it is deficient in other vitamins and nutrients like vitamin B12 and vitamin C.

The number of chromosomes in *Zea mays* is $2n=20$. Maize is a tall, determinate, and monoecious plant, annual plant, produces large, narrow, opposite leaves borne alternatively along the length of stem (Chahar *et al.*, 2014). The plant has separate staminate and pistillate flowers on the same plant. Maize being a highly cross-pollinated crop requires special efforts to maintain its genetic purity. All maize varieties follow the same pattern of development, although specific time and interval between stages and total number of leaves developed may vary between different hybrids, seasons, time of planting and location (Beis *et al.*, 2011; Kumar *et al.*, 2013).

The separation of different rainfed maize mega-environments based on growing season maximum temperature and rainfall has been made as a result of the variety of agro-ecological environments where maize is grown (e.g., from wet to dry; from low to mid-altitude to highland) (Bellon *et al.*, 2005). As stated by Huffnagel (1961) maize arrived in Ethiopia slightly later, around the late 17th century and was mainly grown as a subsistence crop in the mid-altitudes (1500–2000 m above sea level) in southern, south-central, and southwestern parts of the country (Abate *et al.*, 2015).

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions typically under rain-fed production (Jaleta *et al.*, 2018; Abdulfeta Tariku and Aseged Walegn, 2020). The wide adaptability of the crop and the potential to produce more calories and food per area of land cultivated than all major cereals grown in Ethiopia were important factors in considering maize as part of the national food security strategy (Abate *et al.*, 2015; Orebo *et al.*, 2021). The expansion and productivity change in maize production in Ethiopia is attributable to multiple factors. These include; increased availability of modern varieties; increased commitment to enhance farmer access to and use of modern inputs through better research-extension linkages; wider adaptability of the crop and modern varieties; better production conditions and low production risks and growing consumption demand and market access for producers to support market based production to absorb surplus supply (Abate *et al.*, 2017).

2.1.2. Climate and growth requirement of maize

An appropriate type of fertilizer application at an appropriate crop growth stage is also another main focus to increase maize productivity.

The crop yield fluctuates significantly from year to year, mainly because of the variable distribution of rainfall (Zerihun Abebe and Hailu Feyisa, 2017). Maize requires large amounts of rainfall to ensure good harvests. Maize receives high external inputs mainly fertilizers, insecticides, and herbicides (Gorfu and Ahmed, 2012). Maize is a type of plant that is more suited to higher temperatures than other types of plants. However, Maize is well adapted to well drained soils but sensitive to water stress (Araya *et al.*, 2015) and when it is exposed to cold temperatures, it can experience problems with growth and productivity. This can cause issues with the size of the leaves, stem growth, root development, and the ability to take in nutrients and water.

The two most important environmental factors that affect the kind of crops that can be cultivated in a particular area are probably temperature and water availability (Awika, 2011). Maize yield-reducing factors yields can include water shortage, inadequate nutrient management, insufficient or improper application of labor or mechanization, lack of technical expertise and damage due to pests, weeds and disease (Giller *et al.*, 2011). However, limiting factors to production are region-specific and depend on socioeconomic and agroecological location (Lobell *et al.*, 2009; Eash *et al.*, 2019).

Climate change is set to gradually shift rainfed maize mega-environments, including abiotic (e.g., heat, drought, waterlogging) and biotic stresses (e.g., diseases and insect-pests) in the subtropical environments (Kindie Tesfaye *et al.*, 2015; Prasanna *et al.*, 2021). Erratic precipitation and increase in temperature due to climate change have been projected to have the greatest effect on maize production and productivity (Lobell *et al.*, 2011). While drought negatively affects all stages of maize growth and production, the reproductive stage, particularly between tassel emergence and early grain filling, is the most sensitive to drought stress. Heat stress alone, and in combination with drought, is becoming another major constraint to maize production (Cairns *et al.* 2013).

Frequent spells of high temperatures (often above 35 °C) along with moisture stress are a common phenomenon in most of the tropical semi-arid maize-growing regions, affecting especially the reproductive growth of maize (Lobell and Burke 2010). Unless frequently irrigated for maintaining high humidity to offset the effect of physiological drought, crop plants like maize will face compounded effects of heat and drought stress, leading to high yield losses

Temperature impacts the rates of photosynthesis, respiration, and grain filling. Crops with a C₄ photosynthetic pathway (e.g. maize and sugarcane) have higher optimum Temperature for photosynthesis than C₃ crops (e.g. rice and wheat) (Farooq et al., 2009), but even C₄ crops see declines in photosynthesis at high Temperature (Crafts-Brandner and Salvucci, 2002). Warming during the day can increase or decrease net photosynthesis (photosynthesis-respiration), depending on the current temperature relative to optimum, whereas warming at night raises respiration costs without any potential benefit for photosynthesis (Prasanna *et al.*, 2021).

Soil waterlogging frequently affects the total maize production (Zaidi et al., 2010; Cairns *et al.*, 2012). Maize is highly susceptible to waterlogging at almost all the crop stages, especially between tassel emergence and early grain filling (Kuang et al., 2012). Drought stress during this period, resulting in a significant reduction in grain yield, is generally attributed to the separation of male and female flowering organs in the maize plant, and consequent effects on male–female flowering synchronization, and reduction in grain setting and kernel size (Bolaños *et al.*, 1993).

Ear size, kernel rows and potential ovule numbers are starting to be determined by leaf stage, drought stress can reduce these components. However, if adequate moisture occurs by pollination, the corn plant probably will recover and yield losses can be reduced. Fertilized ovules develop into kernels and the first stage of this development following pollination is the blister stage. Dry conditions during this stage could result in aborted kernels (Koliai *et al.*, 2012). Water is a key component to kernel weight gain. Dry weather during the dough and/or dent stages will reduce final kernel weight and reduce yields. Dry weather will reduce yields more during the dough stage than during the dent stage

2.1.2.1. Nutrient requirement and deficiency in maize

For optimum plant growth, nutrients must be available in sufficient and balanced quantities. Nutrient management plays an important role in improving fertilizer efficiency and increasing yield. Fertilizer application rates are largely dependent on soil nutrients; however, there is substantial variability in soil indigenous nutrient supply and crop responses to nutrients in different fields as a result of differences in crop-growing conditions, soil and crop management, and climate (Chung *et al.*, 2013, He *et al.*, 2015).

Fertilizer nutrients applied to soils will be eventually absorbed by plants and can be reflected by crop yield increase. Maize plants are precisely intensive feeders and even soils need to be very fertile to fully supplied nutrients as the plant develops (Sabri *et al.*, 2020). Nitrogen (N) is essential for life sustainability. Some morphological, developmental and reproductive phenomena such as flowering, growth, senescence, oxidation, reduction and allocation of photosynthesis in a plant are regulated by the availability of N (Prinsi *et al.*, 2009). Therefore nitrogen is an integral component for many elements like chlorophyll and many enzymes necessary for plant physiological processes (Arif *et al.*, 2011). Generally, both the form and the source of nitrogen fertilizers affect grain yield by regulating nitrogen transformations, changing nitrogen loss patterns and influencing NUE (Abbasi *et al.*, 2013).

In maize, approximately half of the total dry matter at maturity is accumulated between planting and silking and the other half during the reproductive period (Ning *et al.*, 2013). At the whole plant level, improvement of crop yield may be obtained through increasing carbohydrate production in source leaves (Wang *et al.*, 2015) and/or enhancing the utilization of photo assimilates in sink organs (Sosso *et al.*, 2015). Improvement of crop yields involves enhanced allocation of assimilates from source to sink, which is regulated by a complex signaling network encompassing sugars, phytohormones, environmental factors, etc. (Yu *et al.*, 2015). N plays a fundamental role in both source and sink establishment (Hawkesford *et al.*, 2012). To meet the high N demand of grain filling, large amounts of N are progressively remobilized from vegetative organs during reproductive growth (Masclaux Daubresse *et al.*, 2010). Therefore nitrogen is a fundamental element regulating plant growth and development of maize (Adhikari *et al.*, 2023).

In the absence of fertilizer application, limited N can stifle photosynthesis in source leaves and/or limit the utilization of assimilates in sink organs and thus constrain yield (Ning *et al.*, 2017). Nitrogen deficiency has a broad range influence on the metabolism of the leaf and root, causing a reduction in a number of organic and amino acids and increases in the level of various carbohydrates, phosphoesters and several secondary metabolites (Ganie *et al.*, 2020). And N deficiency decreased grain yield and plant weight. For instance limits yield in maize through reduced kernel number (DeBruin *et al.*, 2018).

Phosphorus (P) is an essential nutrient required for crop growth and production; therefore, it plays a fundamental role in soil fertility (Battisti *et al.*, 2023). It is the main element involved in energy transfer for cellular metabolism and it is a structural component of cell membranes, nucleic acids, and other critical materials (Abolfazli *et al.*, 2012). Application of phosphorus (P) fertilization is a commonly used agronomic practice to optimize seed yield and crop composition (Xie *et al.*, 2022). Plants have evolved strategies to enhance their ability to access and utilize available P for the production of viable seed. Crops require an adequate P supply during the early stages of growth to optimize crop yield (Grant *et al.*, 2005).

Phosphorus supply to the crop is affected by soil P, fertilizer management and by soil and environmental conditions influencing P phytoavailability and root growth. Optimum yield potential requires an adequate P supply to the crop from the soil or from P additions. Where early-season P supply is low, fertilization may improve P nutrition and crop yield potential (Grant *et al.*, 2005). By properly managing P fertilization, maize growers can maximize the leaf area index at beginning of silking and net photosynthetic rate and thereby attain high grain yields without applying excessive phosphorus (Banaj *et al.*, 2006). Phosphorus stress early in the growing season can restrict crop growth, which can carry through to reduce final crop yield. P deficiency significantly diminished maximum relative elemental growth rate and shifted its location closer to the leaf base. A shorter zone of cell division with lower cell production rates along most of its length was the regulatory event that decreased cell production, and ultimately leaf elongation rates, in P-deficient maize plants (Assuero *et al.*, 2004).

Plants require sulfurs (S) for the production of functional, structural and storage proteins and for the synthesis of various essential cellular metabolites during all stages of growth and development (Anderson, 2005). Plants acquire sulfate from the soil, then transport it to sites where it is reduced and assimilated. Availability of sulfur has a major impact on crop yield and quality influencing secondary sulfur compound content and storage protein accumulation and composition (Haneklaus *et al.*, 2007). Sulfur nutrition in agricultural crops is one key factor stimulating the nutritional physiological, sensory, and technical physical quality of plants and food quality (Haneklaus *et al.*, 2008). It was observed that not only the yield and quality of agricultural crops were negatively affected by sulfur deficiency but also their health status (Bloem *et al.*, 2007). Leaves that are sulfur deficient

begin to develop chlorosis that starts at the leaf's edge, spreading over intercostal areas; can be observed throughout the vegetation period and on all plant parts (Haneklaus *et al.*, 2008).

Micronutrients represent those trace elements, which are essential for the normal physiological development, growth and reproduction of plants, animals and humans. Globally micronutrient deficiency creates serious human health problems, largely in countries of the developing world, linked mainly to low quality and quantity of agriculture products in these countries (Oliver and Gregory, 2015; Cakmak and Kutman, 2017). Currently, maize and maize-based food represents a major dietary source of calories, protein and micronutrients for humans worldwide (Nuss and Tanumihardjo, 2010). Therefore, the concentrations of micronutrients in maize grains must be increased to promote the intake of these micronutrients in the human body and alleviate deficiencies in sensitive populations in low-income regions (Zhao *et al.*, 2020). Maize is extremely sensitive to micronutrient deficiency, especially Zn and Fe. Micronutrients such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) possess a multitude of biological functions and play an essential role in the normal growth, development and reproduction of crops, animals and humans (Zhao *et al.*, 2020).

2.2. Origin, Distribution Botany and Importance of Swiss chard

Swiss chard (*Beta vulgaris L.*) is a biennial leafy vegetable belonging to Chenopodiaceae family. Swiss chard is recognized as valuable leafy vegetable species with short growing period suitable for cultivation (Kołota and Czerniak, 2010). Swiss chard has been cultivated since 300 B.C and the roots of wild chard were used as medicine. The wild form of Swiss chard is found in the Canary Island, Mediterranean region and East to South Asia (Rana and Rani, 2017).

Green leafy vegetables are exceptionally low in energy but also relatively high in micronutrients and phytochemicals, which recommend for consumption in everyday diet (van Jaarsveld *et al.*, 2014). Swiss chard is a highly nutritious crop frequently grown in rotation with other crops (Smith *et al.*, 2001). It has large, fleshy, dark green leaves and broad leaf stalks are usually white, but sometimes red or orange in ornamental forms (van Wyk, 2005). Swiss chard, as one of the Green leafy vegetables, is known to be a nutritional powerhouse vegetable packed with minerals, vitamins and health benefits

(Rana & Rani, 2017). It's rich in phytopigments such as chlorophyll and carotenoids. Phytopigments improve immune, detoxication and antioxidant systems of the human body, thus indirectly helping the prevention of disease (Ferruzzi and Blakeslee, 2007; Fiedor and Burda, 2014). As reported by Ninfali and Angelino, (2013), bioactive molecules from Swiss chard extracts have anti diabetic, anti-inflammatory, anti-oxidant and anti-cancer activities.

Swiss chard is very low in saturated fat and cholesterol contents and is a very good source of dietary fiber, vitamins A, C, E, K, B2, B6, thiamin, folate, calcium, iron, magnesium, potassium, copper, phosphorus, zinc and manganese (Gamba *et al.*, 2020). Today, when we are facing global problems such as hunger and micronutrient deficiency, especially in developing countries and coexisting obesity and related chronic diseases in developed ones (Frison *et al.*, 2006), the cultivation of Swiss chard should be encouraged because it is an excellent source of nutrients and various phytochemicals, and at the same time a cheap food crop (Ninfali and Angelino, 2013).

2.2.1. Growth requirement of Swiss chard

Factors such as climate, environmental conditions, applications of different rates of fertilizer, the time of harvesting, germination, plant physiology state, all affect nutritional properties and phytochemical content of the food crops (Miceli and Miceli, 2014). Chard is a desirable food crop because it adapts to environments with elevated saline concentrations, and it can grow in soils with scarce availability of water (Kolota *et al.*, 2010; Ninfali and Angelino, 2013). Furthermore, Swiss chard is tolerant to conditions of low light and both cold and hot weather (Kolota *et al.*, 2010). Swiss chard plants are most often cultivated at lower air temperatures, ranging from 13 to 21°C (Rana & Rani 2017). Good irrigation (and drainage) facility to avoid random drought stress or excessive moisture/ waterlogging during trial (Ivanović *et al.*, 2019).

The adequate water supply is essential for crops' growth, as well as the adequate applications of fertilizers (Ertek and Kara, 2013; Mogren *et al.*, 2016). Swiss chard has a moderately deep root system and can be grow on any type of soil having sufficient fertility and proper drainage system but sandy loam or loam soil are ideal for its cultivation (Rana & Rani, 2017). The optimum soil pH is between 6 and 7 (Ninfali and Angelino, 2013). High levels of organic matter in the soil are desirable and help to ensure adequate moisture

supply. It requires frequent irrigation because of its succulent behavior to ensure that the soil is not dry out to less than 50% of available water (Shah *et al.*, 2016).

2.2.2. Nutrient requirement and deficiency in Swiss chard

Swiss chard is a very nutritive demanding species. The content of mineral elements, total quality and yield are influenced by the amount, frequency and method of fertilization (Miceli and Miceli, 2014). Fertilization must be sufficient to provide an optimal final yield and the desired product quality (Boussadia *et al.*, 2010). Nitrogen is essential in many of the process needed to carry out growth, it is also vital to chlorophyll and significant component in amino acids, so it is required for virtually every physiological process in plants (Ivanović *et al.*, 2019). Nitrogen is recognized as one of the major factors influencing yield of vegetables and quality of the crop. Sub optimal supply of this nutrient can lead to delays in maturity and cause a high reduction of the yield (Kołota and Czerniak, 2010). Plant growth and leaf development of Swiss chard was positively influenced by nitrogen application and also nitrogen application promoted linear increase in total and marketable yield (Gebremedhin Hailay and Awgchew Haymanot, 2019).

Potassium helps regulate plant metabolism and Phosphorous is involved in the metabolic process responsible for transferring energy from one point to another in the plant and it is critical in flowering (Hüner, 2014; Ivanović *et al.*, 2019). Phosphorus is essential at all developmental stages, ranging from germination to maturity (Malhotra *et al.*, 2018). It is crucial for supporting early seedling growth and improving seedling vigor at the time of germination (Zhu, 2001). These growth parameters include plant height, leaf area, leaf number, and shoot dry biomass. Phosphorus plays an important role in cell division and cell enlargement (Assuero *et al.*, 2004) and is responsible for increasing the total above-ground mass and marketable yield (Li *et al.*, 2010).

Therefore, plants often encounter the problem of nutrient deficiency in agricultural fields, particularly in vegetable production. For instance, under low phosphorus conditions, plants display stunted growth, dark green foliage, and reduced leaf surface area (Malhotra *et al.*, 2018). The limited availability of phosphorus negatively affects leaf expansion, resulting in smaller leaves due to reduced cell division and enlargement. Furthermore, phosphorus limitation has a detrimental impact on crop yield and quality

2.2.3. Swiss chard production in Ethiopia

Most of the soil type in the country ranges from light clay to loam, favorable weather, altitude, adequate water and availability of suitable soils, the potential to develop horticultural crops, such as fruits, vegetables, root crops and diversified agro-ecology are well suited for horticultural production in the country (Amsalu Mitiku, 2014). The major producers of horticultural crops are small scale farmers, production being mainly rain fed and few under irrigation. Shallot, garlic, potatoes and chillies are mainly produced under rain fed conditions. Tomatoes, carrots, lettuce, beetroot, cabbage, spinach and Swiss chard are usually restricted to areas where irrigation water is available (Alemayehu *et al.*, 2010).

Vegetables are important for economic, nutrition, health, smallholder farming system sustainability and attract foreign direct investment (Amsalu Mitiku, 2014). Vegetables are also used as a source of raw material for the local processing industry. For example Melge Wondo, Gondar, Merti and Green Star food processing factories produce tomato paste and canned vegetables both for local and export markets thus creating job opportunity and generating foreign currency (Emana *et al.*, 2015; Tabor *et al.*, 2016).

According to Emana *et al.* (2015), the area cultivated to vegetables has been increasing over the years due to increasing consumer demand; average yields are far below potential. The lag in productivity is mainly due to lack of technological advancements in research and production such as traditional way of production, unavailability of high yielding germplasm, infestation due to pests, poor agronomic practices and other (Tabor *et al.*, 2016).

Swiss chard is highly appreciated for its nutritional properties, year-round availability, low cost, and wide use in the central highlands of Ethiopia (Hailay and Haymanot, 2019). While Swiss chard has been produced in urban and peri-urban areas, limited information is available about it. As stated by Hantalo *et al.* (2023), it ranks fourth among cool-season leaf vegetables in terms of area coverage and production in quintals, following Ethiopian cabbage, head cabbage, and lettuce. This vegetable offers nutritional advantages that can significantly contribute to improving food security, especially in reducing malnutrition. Increasing the yield and production of horticultural crops is crucial for ensuring Ethiopia's food security (Ashinie and Tefera, 2019).

However, little research effort has been made to enhance Swiss chard's productivity, and there is a lack of widely available information on its nutritional potential (Fekadu *et al.*, 2022). The crop has been neglected in terms of research. Furthermore, the potential yield that can be obtained from these vegetables, particularly Swiss chard, using different available organic fertilizers and under different agro-ecologies, has not been thoroughly studied (Hailay and Haymanot, 2019; Hantalo *et al.*, 2023).

2.3. Black soldier fly (BSF) and life cycle

As recognized by the Food and Agriculture Organization (FAO, 2013), one of the key advantages of insect farming is their high feed conversion efficiency. Notably, throughout their larval life stages, insects have a comparative advantage in converting inputs into high-quality products (such as protein, fat and fertilizer) especially due to their ability to adapt to the ambient temperature. Insects are incorporating the nutrients into their bodies and reducing the amount of waste material in the process and play an important role in the recycling of organic matter in nature (Čičková *et al.*, 2015).

Salam *et al.* (2022), Suggest as solve the poor waste management which leads to serious environmental issues at the local and global levels. Therefore, the development such technology becomes important because they are increasingly considered an attractive, viable, and sustainable alternative to animal and plant protein sources (Van Huis, 2013; Makkar *et al.*, 2014; Henry *et al.*, 2015). The use of insects to treat organic waste and create usable products is one field of current research (Van Huis, 2013; Gabler and Vinneras, 2014) and good rather than already well-established processes such as digestion and composting. It describes the fairly novel approach of biowaste conversion by insect larvae, using the example of the Black Soldier Fly (BSF), *Hermetia illucens*, an approach that has obtained much attention in the past decade (Dortmans *et al.*, 2017).

The black soldier fly, *Hermetia illucens*, is a true fly (Diptera) of the family Stratiomyidae. Though originally native to the Americas, it now occurs worldwide in tropical and temperate regions (Sheppard *et al.*, 1994; Čičková *et al.*, 2015; Salomone *et al.*, 2016) due to its ability to tolerate a wide selection of environmental conditions (Sheppard *et al.*, 1994; Barragan-Fonseca *et al.*, 2017). Black soldier fly undergoes five main stages in its life cycle the eggs, larvae, prepupae, pupae, and adults stages (da Silva and Hesselberg,

2020). The longest phase of its life cycle is spent in the larval and pupa stages, whereas egg and adult stages are relatively short.

The egg starts a BSF life cycle: Females lay between 500 and 900 eggs close to decomposing organic matter, into small, dry, sheltered cavities (Dortmans *et al.*, 2017; Julita *et al.*, 2020). On average, the eggs hatch in four days and vary with season, region, and temperature. Shortly after having laid the eggs, the female dies (da Silva and Hesselberg, 2020). The closeness of the eggs to the decomposing organic matter ensures that the larvae have their first food source nearby after hatching (Dortmans *et al.*, 2017). The emerged larvae from the eggs initiate feeding immediately on different types of organic matter, will search for food and start feeding on the organic waste nearby (Dortmans *et al.*, 2017; Liu *et al.*, 2019).

The larval phase consists of six instars, with the larvae progressing through five larval stages before reaching the final stage known as the prepupa (Liu *et al.*, 2019; da Silva and Hesselberg, 2020). As the larvae transform into prepupae, they undergo changes such as replacing their mouthparts with a hook-shaped structure and darkening in color to a shade of brown or charcoal grey. Utilizing this hook, they easily move away from their food source and seek a nearby dry location for pupation (Dortmans *et al.*, 2017). This self-harvesting behavior minimize the need for manual separation of the prepupae and their feed (Diener *et al.*, 2011; Gabler and Vinnerås, 2014; Gold *et al.*, 2018; Singh and Kumari, 2019). Pupation denotes the process of transforming from a pupa into a fly. This stage takes around approximately two to three weeks and ends when the fly emerges from its pupa shell (Dortmans *et al.*, 2017). The emerging process is a very short and once the fly emerges, it has a lifespan of about one week. During this short life, it will search for a partner, copulate and (for the female) lay eggs (Dortmans *et al.*, 2017)

As a fly, BSF do not feed (Nguyen *et al.*, 2012). Only a source of water or a humid surface is required to stay hydrated (Dortmans *et al.*, 2017). Adult stage (Sheppard and Tomberlin, 2002) of BSF are neither pest nor disease vector or harmless to humans because they do not have stingers, and their mouth parts or digestive organs only allow them to drink water. Therefore, they consume diets with the greatest fat content during larval stages to build up a fat body necessary to complete development and survive as adults long enough to mate and lay eggs (Tomberlin *et al.*, 2002). Unlike many pests that consume waste, black soldier

fly larvae do not carry bacteria or diseases and are capable of inactivating *Escherichia coli* and *Salmonella* (Erickson *et al.*, 2002). Dempster *et al.* (2022), also suggest BSF are non-invasive, non-biting, non-pest fly species that support several potentially profitable sustainable products.

Under optimal conditions with ideal food quality and quantity, the growth of the larvae will require a period of 14-16 days (Gabler and Vinnerås, 2014). The larval stage is the only stage during which the BSF feeds. They can feed and grow on different types of organic waste, including decaying fruits, vegetable waste, animal manure, municipal organic waste and human food waste (Nguyen *et al.*, 2013; Cickov *et al.*, 2015; Rehman *et al.*, 2017; Meneguz *et al.*, 2018). They can also grow on or including waste from the agro-food industry and agricultural processes, zootechnical waste, and urban wet waste. Larvae of BSF can convert these organic waste streams to useful nutrients, and reduction of organic solid matter up to about 42–56% (Li *et al.*, 2011; Diener *et al.*, 2011; Kalova & Borkovcova, 2013; Salomone *et al.*, 2017; Diener *et al.*, 2022).

The use of BSFL for waste management can lead to nutrient recycling, waste reduction, and value addition, which can significantly contribute to economic viability, competitiveness, and strategic development in environmental management and agriculture (Matheka *et al.*, 2022). Similarly another study found that the use of BSFL for organic waste treatment can also reduce the environmental impact of waste disposal and the study results revealed that BSFL can improve the quality of the final product (Diener *et al.*, 2011; Lalander *et al.*, 2013; Salam *et al.*, 2022). BSFL is unique in that it can convert organic wastes and its popularity links to the promising opportunities of using the harvested BSFL as a source of protein for animal feed, thus, providing a valuable alternative to conventional feed (Dortmans *et al.*, 2017; Amrul *et al.*, 2022). BSF larval bioconversion can recycle nutrients in organic wastes into larval biomass and frass. The second by-product generated in a large quantity in BSFL composting is frass, while the frass has been commonly marketed as a soil amendment (Tan *et al.*, 2021; Schmitt and de Vries 2020).

The benefit of frass as a by-product of insect larvae production can increase the profitability of this burgeoning industry in developing countries, and provide employment opportunities and self-sufficiency in the nutrient supply chain by integrating organic waste management and insect farming into peri-urban agro-food systems (Quilliam *et al.*, 2019).

These characteristics, linked to a short production cycle, make BSFL very good candidates for intensive production (Chia *et al.*, 2019). Considering the large volume of organic waste generated daily, composting organic waste using BSFL is strongly recommended for all regions, including residential areas and universities (Kabir *et al.*, 2021).

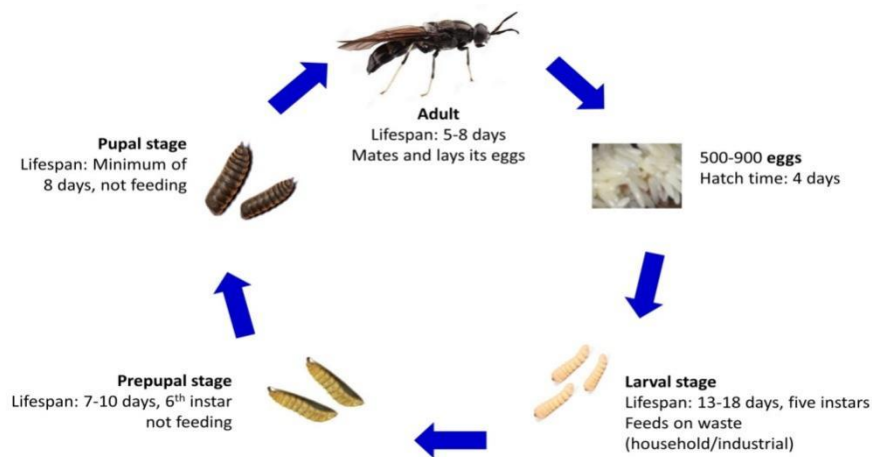


Figure 1: The life cycle of Black soldier fly (Maglangit *et al.*, 2021)

2.4. Black soldier fly frass (BSFF) in agriculture

The diversity of diets that BSFL can eat means that the frass composition can also be diverse. The frass is a mixture of uneaten feed materials, insect derivatives, such as skins and feces (Green and Popa, 2012; Klammsteiner *et al.*, 2020; Diener *et al.*, 2022), and a microbial population which carries out fermentation. This variety of components results in a material that can supply nutrients and organic matter to soil, modify the micro flora in the soil, and manipulate plant behavior (Schmitt and de Vries, 2020). The BSFF exhibits multiple features making it attractive for use in our strained agricultural system. It has application potentials as a soil fertilizer similar to existing products but with a lower environmental impact (Smetana *et al.*, 2019; Gärtling and Schulz, 2019). Specific components of the frass as insect byproducts, such as exuviae are used as biostimulants for plants that come in contact with them (van de *et al.*, 2019; Schmitt and de Vries, 2020).

2.4.1. Properties of frass

The reuse of insect by products a focus on the promising contribution of insect frass to agriculture while these products are the main outputs of insect farming activities, quantitatively speaking, and insect frass represents the highest share of the total outputs

(Poveda *et al.*, 2019). Importantly, after insects have been harvested the remaining by product, frass, has the potential to be used as a biofertiliser amendment (Kovačik *et al.*, 2010; Alattar *et al.*, 2016; Quilliam *et al.*, 2019). Frass fertilizer for organic farming have gained momentum worldwide (Liu *et al.*, 2017; Schiavone *et al.*, 2017; Lalander *et al.*, 2019). On the other hand, the organic fertilizer generated from the BSF rearing process would play an essential role in soil fertility replenishment and reduce the constant reliance on mineral fertilizer inputs for crop production (Beesigamukama *et al.*, 2020).

High input agricultural systems that supply only major nutrients to the crop may suffer from a lack of secondary nutrients (e.g., Ca, Mg, and S) and micronutrients (e.g., Fe, Cu, and Zn), which can impact yield and nutritional quality of harvested products (Davis, 2009). The amount of organic matter, essential macronutrients like phosphorous, nitrogen, and potassium, as well as micronutrients like copper, zinc, and manganese, is high in organic residues (Gabler and Vinneras, 2014).

In order to conserve resources and ensure that the world's population continues to grow properly over the coming decades, nutrients must be reused more frequently. To close the nutrient loop and improve stressed soils, it is preferable to repurpose organic leftovers as fertilizer (Newton *et al.*, 2005). The frass contains substantial amounts of nutrients essential in crop production (Lalander *et al.*, 2014; Beesigamukama *et al.*, 2020). That could be useful in crop production as an alternative organic fertilizer if converted into organic fertilizer. However, since frass quality may be affected by the type of insect substrate (Kagata and Ohgushi, 2012).

Studies on the quality of BSFF as organic fertilizer revealed a significant increase in NPK concentrations and a considerable reduction in heavy metals to the acceptable levels set by the regulatory authorities (Attiogbe *et al.*, 2019; Sarpong *et al.*, 2019). Due to its high nutritional and labile C content, it is well known that frass deposition to soil has a significant impact on soil fertility under natural circumstances (Frost & Hunter, 2004; Kagata & Ohgushi, 2012). Frass has potential as an organic fertilizer for several agricultural applications and this application increases circularity in the agrifood sector (Elissen *et al.*, 2023). Because of this, a number of businesses have already made the decision to market frass as fertilizer (Gortari & Hours, 2013; Payne, 2016; Dicke *et al.*, 2018 ;Derrien & Boccuni, 2018; Dempster *et al.*, 2022).

Several authors state that as BSFF contains many other nutrients that can affect plant and soil and chitin in the BSF frass likely benefits resistance to plant pathogens. Smetana et al. (2016), found that frass derived from BSFL production using sustainable feed streams and efficient facilities has a lower impact than conventional fertilizers on many impact categories. For example, in the event that biostimulant properties of insect byproducts in the frass are conclusively shown to improve plant resistance to pests, then the reduction in our reliance on pesticides could have important consequences for biodiversity. Applying frass also introduces organic material, not included in chemical fertilizers (Schmitt and de Vries, 2020).

2.4.2. Nutrient content and pH

Organic fertilizer inputs are one of the promising pathways for sustainably improving soil and crop productivity (Vanlauwe *et al.*, 2014). Organic fertilizers are an ingredient of stable soil aggregates and are known for improving soil pH, soil organic matter, levels of secondary and micronutrients (Vanlauwe *et al.*, 2015; Musinguzi *et al.*, 2016; Grigatti *et al.*, 2017), as well as nutrient availability, uptake, and utilization (Wortmann *et al.*, 2019). Soil pH is an indicator for soil acidity or soil alkalinity and it is important for crop cultivation because many plants and soil organisms have a preference for slight alkaline or acidic conditions and thus it influences their vitality (Kelbesa, 2021). In addition, soil pH directly impacts the availability of most plant nutrients which are needed for proper plant growth and development (Kelbesa, 2021; Sarhat, 2022).

In the context of BSF rearing and as BSF production is expanding, the valorization of BSF frass as organic fertilizer is gaining importance. However, in contrast to established organic fertilizers, little is known on the properties and variation of this by-product, which is essential for assessing possible application purposes (Gärttling and Schulz, 2021). However composition of the BSF frass is strongly dependent on the feed substrate and as such there is no universal BSF frass composition (Kagata and Ohgushi, 2012; Elissen *et al.*, 2023). Results from one study or product may not translate directly to another (Bosch *et al.*, 2019; Gärttling and Schultz, 2019). Based on average compositions BSFF has resemblances to cow manure, pig slurry, poultry manure and compost by (C/N ratio, N content, P content, DM, K content and DM) (Elissen *et al.*, 2023).

It can generally be described as having high organic matter and available nutrient content including nitrogen (N), phosphorus (P) and potassium (K), and a narrow ratio of carbon (C) to N (Poveda *et al.*, 2019). In nutrient analyses of BSF frass, it was classified as compound NPK fertilizer with 3.4% N, 2.9% P₂O₅, and 3.5% K₂O on average (Gärttling and Schulz, 2019). BSF frass has a higher pH value than most comparable fertilizers. Ma *et al.* (2018) , stated that the maximum growth performance of BSF larvae can be reached on substrates with pH 6.0 or higher, while the larvae adjusted the substrate pH in these treatments to values from 8.0 to 8.5. Gärttling and Schulz (2019) reported a mean pH of 7.75 which neutral to alkaline when averaging frass analyses from different sources. The pH shift during the processing of the feeding substrate, which typically carries lower pH values, can be explained through the incorporation of organic acids by the larvae and rising NH₄⁺ contents due to the decomposition of organic nitrogen compounds such as uric acid and allantoin in the frass (Green and Popa, 2012).

Chemical characterization of compost derived from food waste bioconversion process by BSFL showed a good potential for this material to be used as a fertilizer. The analysis reported a low humidity value, pH value and a good balanced nutrient amount of NPK with average content comparable with other organic manures. The physical quality of the product could allow easy storage, packing and transport without any further transformation or stabilization process (Salomone *et al.*, 2016). Frass may be employed as a long-term fertilizer (Gärttling and Schulz, 2021). Usually the frass is relatively high in P content, which may require extra N fertilizer addition (Elissen *et al.*, 2023). Ramadhani *et al.*, (2017) suggest solid fertilizers produced by BSFL may allow plants to fulfill their requirements of nutrient.

2.4.3. Frass as soil amendments and as a source of bioactive compounds

Beneficial soil microorganisms can contribute to biocontrol of plant pests and diseases, induce systemic resistance (ISR) against attackers, and enhance crop yield. Using organic soil amendments has been suggested to stimulate the abundance and/or activity of beneficial indigenous microbes in the soil (Barragán-Fonseca *et al.*, 2022). Residual streams from insect farming contain chitin and other compounds that may stimulate beneficial soil microbes that have ISR and biocontrol activity. Additionally, changes in plant phenotype that are induced by beneficial microorganisms may directly influence

plant pollinator interactions, thus affecting plant reproduction (Barragán-Fonseca *et al.*, 2022).

Adding BSFF to the soil in agricultural settings is beneficial to the plant or insect ecosystem (Schmitt and de Vries, 2020) and has improved the organic matter quality of intensively cultivated soils (Bortolini *et al.*, 2020). Frass may serve as a valuable fertilizer and did not impair the hygienic properties of soils (Klammsteiner *et al.*, 2020). Bioactive compounds include a set of substances, such as peptides, amino acids, humic substances and phytohormones, as well as a diverse group of microorganisms (Du Jardin, 2015; Yakhin *et al.*, 2017; Xu and Geelen, 2018). When applied in the soil, these substances stimulate the natural processes of the soil-rhizosphere medium and enhance plants' metabolism, thereby improving growth as a whole.

Frass as a source of bioactive compounds in addition to the macro and micronutrients, organic fertilizers are usually a good source of growth promoting compounds that in recent years have gained great attention, namely bioactive compounds. These biologically active compounds are responsible for another lesser-known aspects of plant nutrition (e.g. signaling), other than the provision of mineral nutrients as building blocks for structural growth (Yakhin *et al.*, 2017). Based on the knowledge existing on the processing residues of other invertebrates, frass could also be an abundant source of bioactive compounds that can be harvested and used in sustainable agriculture practices (Wong *et al.*, 2020; Poveda, 2021).

Chitinous materials have attracted special attention for their control of nematodes and soil borne fungal diseases because chitin is present in nematode egg shells as well as in the cell walls of most plant-pathogenic fungi (Oka, 2010). The BSF larva undergoes multiple developmental stages, passing through larval instars (Tomberlin *et al.*, 2002; Gligorescu *et al.*, 2018; Wang *et al.*, 2020). At each instar, the larvae molt and their chitinous exuvia remained in the frass. Chitin is known to display disease suppressive functions in the soil; for examples, plant-parasitic fungi (postma and schilder, 2015) and nematodes. Thus, when chitin-rich materials are added to the soil, it could lead to an increased number of chitinolytic microorganisms in the soil enhancing the inactivation of fungi and nematodes (Oka, 2010). Insect frass often contains chitin, which is known to have several beneficial effects on plant growth and health (Hadwiger 2013, Sharp 2013, Debode *et al.*, 2016,

Quilliam *et al.*, 2020). In this result functions as a nematicide and fungicide, and promotes mycorrhization, but in some cases appears to be phytotoxic (Sharp, 2013).

Also, BSF frass is reported to have insecticidal and insect-deterring properties (Vickerson *et al.*, 2013). Additionally, it potentially contains microbes which promote plant growth by the release of plant hormones or suppression of pathogens (Gold *et al.*, 2018; Poveda *et al.*, 2019). Furthermore, if the frass has not been sterilized, through thermal treatment. On the other hand, Kawasaki *et al.* (2020), identified in non sterilised black soldier fly frass a high relative abundance of Xanthomonadaceae, a bacterial family containing a plant-pathogenic genus. BSFF should also be studied in terms of the formation of substances like humic and fulvic acids, phytohormones, short-chain proteins, and amino acids, among others, given the significant attention that bioactive substances and beneficial microorganisms in organic materials have received in recent years.

It is yet unknown whether BSF larvae frass contains biostimulants or rhizobacteria and fungus that encourage plant growth (Lopes *et al.*, 2022). The biocontrol of plant diseases through biostimulants has been extensively reviewed (Naseem and Bano, 2014; Cortleven *et al.* 2019; Ahmad *et al.*, 2020; Hamid *et al.*, 2021; Critchley *et al.*, 2021). According to the European biostimulants industry council (EBIC), the definition of biostimulants is substances and/or microorganisms whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress and crop quality.

BSFF is rich in microorganisms Gold *et al.*, (2020) some of which may have biostimulatory capacity. For instance, multiple species of *Bacillus* spp. produce phytohormones with beneficial traits for plants, such as auxins (promotes growth and increases drought tolerance), cytokinins (stimulate root exudation), jasmonic acid (induce salinity stress tolerance), gibberelins (increases seed germination, enhance nutritional metabolites, regulates endogenous phytohormones, induce thermotolerance), among others (Poveda and Gonzalez-Andres, 2021). The plant disease suppression ability of frass could be attributed to the presence of certain biostimulants (bioactive compounds and certain microorganisms) and chitin-rich compounds. Schmitt and De Vries (2020) highlighted that finding biostimulants/biocontrol properties in BSFF could reduce the world's reliance on unsustainable pesticides.

2.4.4. Maturity, stability and heavy metal contents of frass

Due to insufficient biodegradation of organic matter, the application of undecomposed wastes or compost without stabilization to land may result in phytotoxicity (Maria and Abdalla, 2017). Addition of high C/N residues will deplete the soil's supply of soluble nitrogen, causing plants to suffer from nitrogen deficiency (Brady and Weil, 2016). To make more effective organic residue should decomposed to form stable C/N. During the composting process, the C/N ratio of organic materials in the pile decreases until a fairly stable ratio, in the range of 10:1–20:1, is achieved (Brady and Weil, 2016). Composted organic material is being applied on agricultural fields as an amendment to provide nutrients and also to enhance the organic matter content and improve the soil properties of the cultivated soils (Mohammed *et al.*, 2004). Application of organic amendments with low C/N ratios is also effective in acidic soils for the control of soil borne diseases and nematodes (Oka, 2010).

Heavy metals can negatively affect microorganisms in various ways, for instance inducing enzymatic dysfunction or causing membrane and DNA damage (Bruins *et al.*, 2000). Heavy metal inputs to soils may come from natural atmospheric deposition or anthropogenic inputs such as application of sludges and phosphate fertilizers to agricultural land. High application rates and frequent use of these can effect heavy metal accumulation as they may contain zinc (Zn), cadmium (Cd), nickel (Ni) and copper (Cu) as impurities (Alloway, 2013; Wuana and Okieimen, 2011). Heavy metals are ubiquitous in the environment, as a result of both natural and anthropogenic activities, and humans are exposed to them through various pathways (Khan *et al.*, 2008).

The higher nutrient concentrations and lower C/N ratio associated with BSF composted organic fertilizer highlight the high efficiency of BSF larvae in nutrient recycling, which has been previously reported (Lalander *et al.*, 2015; Beesigamukama *et al.*, 2021). Organic fertilisers with lower C/N ratios, such as the BSF frass fertiliser are associated with faster nutrient release for crop production (Palomba, 2016; Tanga *et al.*, 2021). However, high frass application rates can lead to growth inhibition (Newton *et al.* 2005, Temple *et al.* 2013, Alattar *et al.*, 2016) and yield reduction, which often is attributed to NH₄ + -N toxicity. This could be a reproducible phenomenon at high application rates.

Negative effects of frass on plant growth and germination were found for other insect species as well (Silander *et al.*, 1983; Kagata and Ohgushi 2012) but were associated to allelopathic effects. To make more effective organic residue for better agricultural production it should be decomposed to become stable humic substances (below 30:1 C: N) (Worku *et al.*, 2021). There are several studies indicating the potential of BSF larvae frass to increase yield, while others reported negative growth associated with plausible phytotoxicity of the frass. BSF larvae frass is a biologically unstable product, due to the rapid composting process and the presence of substances with potential phytotoxic properties. In order to enhance the compatibility of this product as a fertilizing amendment, frass likely has to undergo some sort of post-treatment for stabilization (Lopes *et al.*, 2022). Alternatively, one could consider mixing the frass with another fertilizer product to achieve better matrix stabilization while enhancing the combined fertilizer efficacy (Sani and Yong, 2022).

Early studies on BSFL frass have always focused on only NPK and micronutrients content to analyse BSFL as organic fertiliser. However, upon testing BSFL frass on several types of plants, stunted plant growth and reduced biomass production in the plants was observed. According to Diaz *et al.* (2007), compost quality and maturity are controlled using chemical parameters, such as pH, ammonia, C/N, as well as plant growth, germination tests, and microbial tests, Plant growth.

Within a short period of BSFL rapid composting (two weeks to a month), organic wastes fed by the BSFL may not be properly composted (Kawasaki *et al.*, 2020; Song *et al.*, 2020). In this cause composting process must also stop when the larvae reach the prepupae stage, as a result, producing impartial compost and immature compost. Referring to Diaz *et al.* (2007), maturity of compost can be referred to compost's level of phytotoxicity. Luo *et al.*, (2018) stated that immature compost basically has a high level of phytotoxicity and will tend to have more growth inhibitors for plants than mature compost. Phytotoxins, such as heavy metals, phenolic components, organic acids, and salt accumulation are common in immature compost (Luo *et al.*, 2018).

Meanwhile, the stability of compost can be identified when one that is no longer undergoing rapid decomposition and whose nutrients are tightly bonded. On the other hand, unstable compost, may either release nutrients into the soil owing to additional decomposition or tie up nitrogen from the soil (Diaz *et al.*, 2007).

Few other studies found negative effects of BSF frass and other commercially available frass on soil quality and plant growth (Alattar *et al.*, 2016; Watson *et al.*, 2021) and excessive nitrite accumulation in soil (Watson *et al.*, 2021). These contrasting effects can be attributed to the differences in substrate composition and the feeding rate of the substrate to the larvae. This could increase the ratio of the undigested substrate in the frass (Diener *et al.*, 2009; Gold *et al.*, 2018). A previous study reported the impact of substrate composition on the quality of mealworm frass and its effect on plant growth (Poveda *et al.*, 2019). A substrate with high fiber content has also been reported to reduce the performance of the biowaste conversion process, as it is likely that BSFL do not have enzymes for the decomposition of fibers (Gold *et al.*, 2018). The digestibility of the substrate can significantly impact the suitability of the BSF frass as a biofertilizer and soil amendment (Gebremikael *et al.*, 2020).

BSFL are accumulating heavy metals in their tissues, however leaving their frass with low concentration of heavy metals. Previous studies show that large quantities of mercury have been added to the BSFL feedstock to be observed in a 13-day experiment and resulting in low mercury levels in the BSFL frass and were noted to be below the European Union's (EU's) threshold values of 0.7–10 mg Hg/kg (Attiogbe *et al.*, 2019).

Salomone *et al.* (2017) also measured the concentrations of toxic and essential metals in BSFF fed with food waste substrates and found that the concentrations of both toxic and essential metals were below the limits stated in the Italian regulation for fertilizer. The low concentrations of heavy metals in BSFL frass can be attributed to the ability of BSFL to reduce and accumulate various forms of heavy metals during the treatment process. Sarpong *et al.* (2019) found, in their assessment of heavy metal contents in BSF frass, a considerable removal of As, Cd, Pb, and Fe, with values that comply with the maximum allowable levels for heavy metals in organic fertilizer.

2.4.5. BSFF for improving soil quality

The soil quality indicators are measurement tools that provide information about the properties, processes and characteristics of the soil (Bremer and Ellert, 2004). These soil quality indicators are measurable attributes that reveal the response of the productivity or functionality of the soil to the environment, and indicate whether the quality of the soil improves, remains constant or decreases over time (Ghaemi *et al.*, 2014).

In Ethiopia soil erosion and declining of fertility is a serious problem to agricultural productivity and economic growth (Gete *et al.*, 2010). The contribution of inorganic fertilizer to enhance crop growth and yield cannot be ignored, but on the other hand their indiscriminate use is causing deterioration of the soil structure and soil acidity (Eleduma *et al.*, 2020). Organic fertilizers are an alternative environment friendly approach with multi-advantages over chemicals (Kelbesa, 2021). According to Vanlauwe *et al.* (2014), organic fertilizer inputs are one of the promising pathways for sustainably improving soil and crop productivity. Organic fertilizers are an ingredient of stable soil aggregates and are known for improving soil pH, soil organic matter, levels of secondary and micronutrients as well as nutrient availability, uptake, and utilization (Vanlauwe *et al.*, 2015; Grigatti *et al.*, 2015; Musunguzi *et al.*, 2016; Wortmann *et al.*, 2019).

Due to soil fertility problems, crops yields often decrease and the crops are more susceptible to pest and disease because they are in bad condition (Madeleine *et al.*, 2005). On the other hand, adding artificial fertilizer alone is not sufficient to retain a sufficient level of soil fertility (Getachew *et al.*, 2014). In addition, the using of organic fertilizer such like compost can solve the problem faced on farmers with decreasing fertility of their soil (Kelbesa, 2021). BSFL frass could be used as organic fertilizer because of high content in major nutrients such as nitrogen (N), phosphorus (P), and potassium (K) and application of this input improved soil fertility by providing essential plant nutrients Vickerson, (2017; Kebli and Sinaj, 2017). However Plant nutrient content for example N in frass depends on the nature of the organic wastes consumed by the BSFL and the stabilization during the degradation process which involved biological, physical, and chemical factors (Schmitt and Vries, 2020).

Soil organic matter is of crucial importance for maintaining soil quality by improving biological, physical and chemical soil conditions (Haile, 2017) and its often considered the most important indicator of soil fertility (Johnston *et al.* 2009). It contributes to each of fertility's three dimensions: the physical (structure, aeration, and water retention), the biological (biomass, biodiversity, nutrient mineralization, disease suppression) and the chemical (nutrient supply) dimension. On this basis, maintaining SOM is an important strategy to maintain crop productivity (Lal, 2004). Long term cultivation without organic fertilizers usually leads to a decrease in SOC and total N contents and in crop yields (Bhandari *et al.*, 2002, Regmi *et al.*, 2002).

Agriculture will need organic fertilizers that provide the soil with enough organic material to maintain the SOC levels (Nest *et al.*, 2014). SOC levels is closely tied to soil health (Liptzin *et al.*, 2022) because the use of organic fertilizers is considered to be an effective way of increasing soil organic carbon (SOC) sequestration and supplying micronutrients to crops in comparison with the use of mineral fertilizers only (Lal, 2009). Most essential nutrients in compost are in organic forms which are released slowly and are less subject to leaching compared to inorganic fertilizers (Larney *et al.*, 2008). The incorporation of compost derived from biogenic household and garden waste to soils increases soil carbon and total nitrogen concentrations (Mylavarapu and Zinati, 2009).

Frass is valuable for improving soil quality but should be applied with readily available N sources, to prevent nutrient shortage during crop growth (Gebremikael *et al.*, 2022). Guo *et al.* (2021), report in his study as frass application increased N-NO₃, P available, K available and OM in soil and also according to Menino *et al.* (2021), frass increased crop production as well as soil OM, P, K. It is possible that compost and BSF frass as organic fertilizer have acted several things to benefit the soil; it could add organic matter, which improved soil physical properties like the way water interacts with the soil and the soil with vast numbers of beneficial microbes (Agustiyani *et al.*, 2021).

Furthermore, soil fertility is linked with mineralization of nutrients contained in organic matter and their release in plant- available form to the soil solution. Mineralization is the result of normal biological cycles within the soil and can be stimulated by the addition of appropriate quality compost and cultivation (Paulin and Peter, 2008). Because mineralization occurs over extended periods it can make important contribution to plant growth and to minimizing the impact of leaching associated with rainfall and excess irrigation (Paulin and Peter, 2008). The atmospheric nitrogen cannot be directly assimilated by plants, which is why there must be a nitrogen fixation process by bacteria to make the nitrogen available for plant uptake.

Frass also contains nitrifying bacteria and nitrogen-fixing bacteria, which partake in the nitrogen cycle and assist in the plants' uptake of nitrogen (Behie & Bidochka, 2013; Alattar, and Popa, 2016; Zahn, 2017). It has been shown that there are more greenhouse gases, like nitrous oxide, in areas where more synthetic fertilizer is applied to the soil (Hawkinson, 2005), whereas BSFF can store carbon and nitrogen in the soil (Lovett *et al.*,

2002). BSFL frass also prevents atmospheric loss of nitrogen and groundwater contamination through the nitrogen fixation by the bacteria (Lovett *et al.*, 2002).

A large suite of soil organisms are involved in organic mineralization (Bridgham and Lamberti, 2009). Soil invertebrates are particularly important in the fragmentation of detritus and in soil food web interactions. Nitrifying bacteria convert the most reduced form of soil nitrogen, ammonia, into its most oxidized form nitrate. In itself, this is important for soil ecosystem function, in controlling losses of soil nitrogen through leaching and denitrification of nitrate (prosser, 2005). During N mineralization, organic N is catabolized to release NH_3 , which is subsequently protonated in the soil solution to become the cation NH_4^+ . Because NH_4^+ is most often released, mineralization is frequently referred to as ammonification (Poffenbarger, 2018). This assimilation of nitrate to plant roots makes soils more resilient to floods, droughts, and land degradation processes.

Frass also consists of safer chemicals for human exposure, whereas synthetic fertilizers often are composed of harmful substances such as cadmium, uranium, and arsenic, all of which are carcinogens as well as triggers for developmental problems in children (Sharma and Singhvi, 2017). Synthetic fertilizer application has also been a contributor to increased nitrous oxide emissions (Sanders, 2012). A novel solution is using BSFL frass as organic fertilizer (Choi and Hassanzadeh, 2019). In addition to all these beneficial components, if BSFF possesses defensive properties for plants, it could be a viable alternative to chemical fertilizers for plant growth (Choi and Hassanzadeh, 2019).

Microbes play a key role in black soldier larvae production whereby larvae and microbes (usually) symbiotically break down feed materials. This has consequences for the properties of the frass. An abundance of beneficial microbes improves soil health and these can be present in high quantities in frass (Xiao *et al.*, 2018; Chia *et al.*, 2019) have shown that the addition of the microbe *Bacillus subtilis* BSF-CL can improve the organic fertilizer properties of the BSFL frass of insects fed on chicken manure. Fertilization plays an important role in changing soil microbial diversity, which is essential for determining crop yields. Organic amendments also increased microbial functionality and crop yields (Shu *et al.*, 2022). Chitin also induces improvements in the soil microbiome, thus improving soil fertility. As also reported by Quilliam *et al.* (2020), that the plots with the addition of BSFL frass have significantly fewer dead plants than the plots with synthetic NPK

fertilisers, where the cowpea crop has suffered severe Fusarium wilt (*Fusarium oxysporum*) outbreak.

2.4.6. Effect of BSFF on crop growth performance, yield and quality

Crops require a combination of resources for survival such as carbon dioxide, mineral nutrients, heat, and light (Swiader and Ware, 2002). The most important mineral nutrients include nitrogen, phosphorus, and potassium. These are abundant on earth in their elemental forms, but must be present in bioavailable forms in order to be absorbed and utilized during the vegetative growth of plants. Unfortunately, bioavailable nutrients are considerably more limited and sparse within our biosphere. Because of this cultivated food crop production requires special soil fertility management in order to meet nutritional needs (Swiader and Ware, 2002; Chavez and Uchanski, 2021).

Although several organic fertilizers, from long ago, have been used in agriculture, there is yet a paucity of experimental data on the evaluation of the fertilization potential of BSF larvae frass. Chavez and Uchanski (2021), conduct frass is a combination of insect manure that is rich in nitrogen, minerals and chitin. Therefore this left-over product has the potential to be utilized as a biofertilizer for high value crop production. There are also reports that the high chitin content in BSFL frass contributors to improvements in plant health and disease resistance (Quilliam *et al.*, 2020). Other benefits to using organic fertilizers in general includes a higher nutrient retention thus reducing excessive nutrient runoff as well as containing secondary nutrients and microbes that can improve soil quality in the long-term (Yadav *et al.*, 2019).

The common synthetic fertilizer's ability to increase nitrate levels is mitigated by the leaching of nitrate into aquatic ecosystems and waterways; this contamination eventually causes eutrophication and pollutes groundwater (Dubey and Townsend, 2004). Synthetic fertilizer application has also been a contributor to increased nitrous oxide emissions (Sanders, 2012). Frass contains nitrifying bacteria and nitrogen-fixing bacteria, which partake in the nitrogen cycle and assist in the plants uptake of nitrogen (Lovett *et al.*, 2002; Behie & Bidochka, 2013; Alattar and Popa, 2016). While other nitrifying bacteria make nitrogen within the soil accessible to plants for photosynthesis (Zahn, 2017).

However monitoring the dietary inputs of industrially reared insects may be the best way of mitigating the potential negative impacts of frass application, such as increased electrical conductivity and heavy metal toxicity (Chavez and Uchanski, 2020).

In the experimental study, the researcher focus the composition of the BSFL frass produced with different substrates is different and there is a need to investigate how it can affect crops production under open field condition or greenhouse pot trial. Newton et al. (2005), were done experiments with basil and sorghum; were with asparagus bean; onion (Zahn, 2017), lettuce and ryegrass (Kebli and Sinaj, 2017). Although inconclusive in terms of consistency as far as concerns the positive effect that is intended with the use of these type of entomocompost as organic fertilizer. Working with onion, to assess the effect of BSFF (from larvae fed with avocado, banana and avocado wastes) predicated that the frass may positively affect plant growth, through the increase of OM, N and P in the soil, although he failed in finding significant effect of BSFF on yield (Zahn, 2017).

Similarly Under the experimental conditions, Menino *et al.*, (2021) conducted the results showed a significant effect of BSFF on the overall ryegrass production, in concerns with sustainability of soil productivity. Indeed, research has shown that BSFL frass can lead to similar plant growth compared to inorganic fertilizers (Klammsteiner *et al.*, 2020; Chirere *et al.*, 2021) or even greater production (Agustiyani *et al.*, 2020; Beesigamukama et al., 2020). BSFF has been found to enhance maize growth and yield compared to other fertilizers. Studies by Beesigamukama *et al.* (2020) and Tanga *et al.* (2021) demonstrate that maize treated with BSFF showed taller plants, higher chlorophyll concentrations, and increased grain yields. These findings suggest that BSFL frass can serve as a promising and sustainable alternative to commercial fertilizers, contributing to improved soil fertility, crop yield, and food security

Composted BSFL frass, as highlighted by Anyega *et al.* (2021), demonstrated positive performance on various vegetables. Similarly, Abiya *et al.* (2022) recommended soil amendment with BSFF for higher leaf yields in Kale and Swiss compared to NPK and control treatments. The increased growth and yield observed in vegetables treated with BSFF can be attributed to its maturity, stability, and better nutrient supply compared to conventional compost and commercial fertilizers. The high release of nutrients from BSFF due to its rapid mineralization rate (Yéton *et al.*, 2019) likely contributed to improved nutrient synchrony and higher yields.

2.5. Black soldier fly farming in Ethiopia and the challenges

Black soldier fly farming is emerging as a new farm enterprise in Kenya poised to provide high-quality and affordable alternative protein sources for animal feed production (Chia *et al.*, 2019; Mutuku *et al.*, 2021) and currently, done at a small scale in east African countries like Uganda, and Tanzania. In 2021 through ICIPE's capacity building efforts, progress has been made in commencing research and development activities on black soldier flies, and by extension insects for feed, in Ethiopia. At Hawassa University, researchers underwent training at ICIPE, focusing on various components such as trapping black soldier flies from the wild, mass production in the laboratory, processing the insects, and formulating feed for poultry and fish.

The black soldier fly technology is highly efficient in biologically decomposing various types of biodegradable wastes in sub-tropical environments. Many people around the world utilize black soldier fly larvae for the decomposition of biodegradable materials, particularly in tropical regions and developing nations. However, in Ethiopia, there is a lack of comprehensive information regarding the presence, current situation, abundance, and distribution of black soldier flies, as well as their potential for managing organic waste and utilizing their excrement (frass) as organic fertilizer

In Ethiopia, it is crucial to identify black soldier flies (BSF) on a national level, establish intensive insect rearing, and implement large-scale production using organic waste. This will enhance poultry production, increase productivity, and utilize the frass produced by BSF larvae as organic fertilizer. Achieving this goal requires the active participation and shared responsibilities of various stakeholders. To mitigate environmental pollution and soil infertility, the government should raise awareness about establishing black soldier fly rearing farms that utilize local BSF species and bio-waste. Collaboration with governmental and non-governmental organizations is essential. The use of BSF frass as organic fertilizer is a new concept, and its adoption in Ethiopian farming systems necessitates information on its performance in terms of crop growth, yield, nutrient uptake, and use efficiency when compared to existing fertilizers.

3. MATERIALS AND METHODS

3.1. Description of the Experimental Site

The field experiment was conducted at research farm located in Hawassa University main campus in Hawassa city. Hawassa city is located at 273 km to the south of Addis Ababa at $07^{\circ}03'53.8''$ N latitude and $038^{\circ}28'59.2''$ E longitude with an altitude of 1694m above sea level. It receives a mean annual rainfall of 952 mm with mean minimum and maximum temperatures of 11.2°C and 29.9°C , respectively (Hawassa Meteorological Centers, 2022). The type of soils around Lake Hawassa in general is Andisols (Alshalati, 2021) Major crops grown in the study area are maize, common bean, cabbage, wheat, enset, beat root, lettuce, sweet potato, Swiss chard and chilli (Musse *et al.*, 2020).

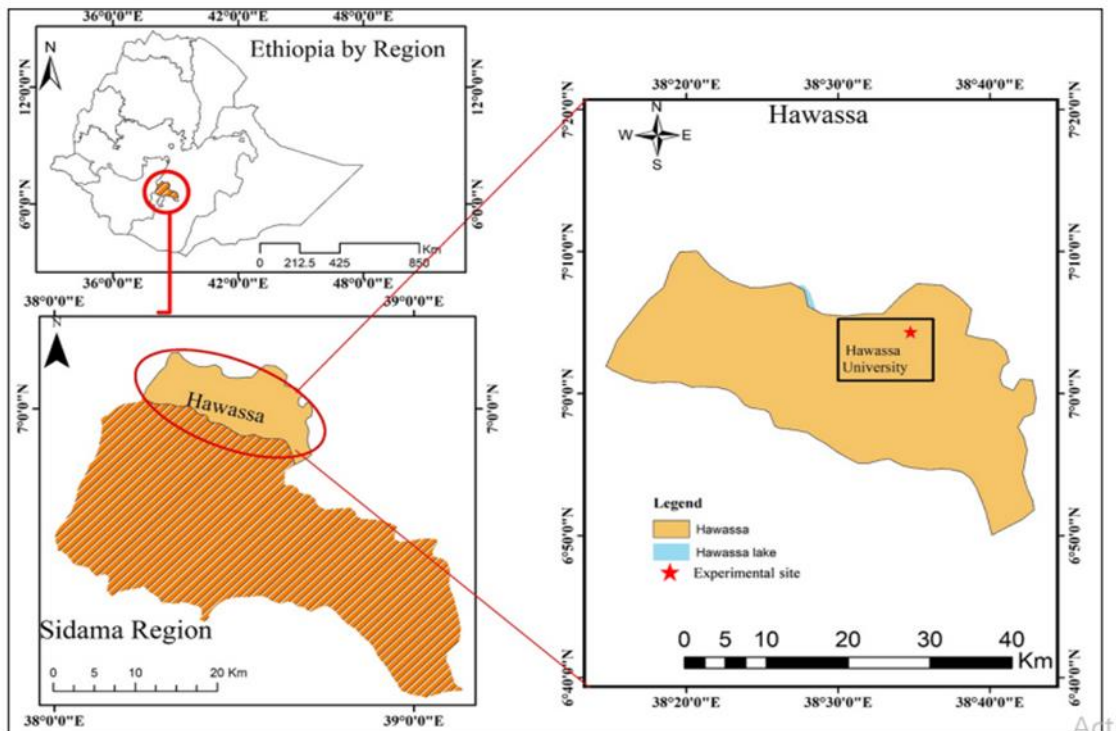


Figure 2. Map of the experimental area (Lolam *et al.*, 2023)

3.2. Agro-climatic Conditions of Hawassa City

Hawassa city has sub-humid climate with bimodal rainfall. The period of main rainfall extends from June to September with mean annual rain fall of 119.7 mm, and the second rainfall season extends from March to May with mean annual rain fall 72.16 mm. The mean annual temperature is 20.3°C with January, February, April, May and December having the highest temperature ($27.5\text{-}29.5^{\circ}\text{C}$) whereas June, July, August and September

having the lowest temperature (11.2-14°C (Figure 3). The mean maximum and minimum temperature of the study area were 29.5 and 11.2°C, respectively.

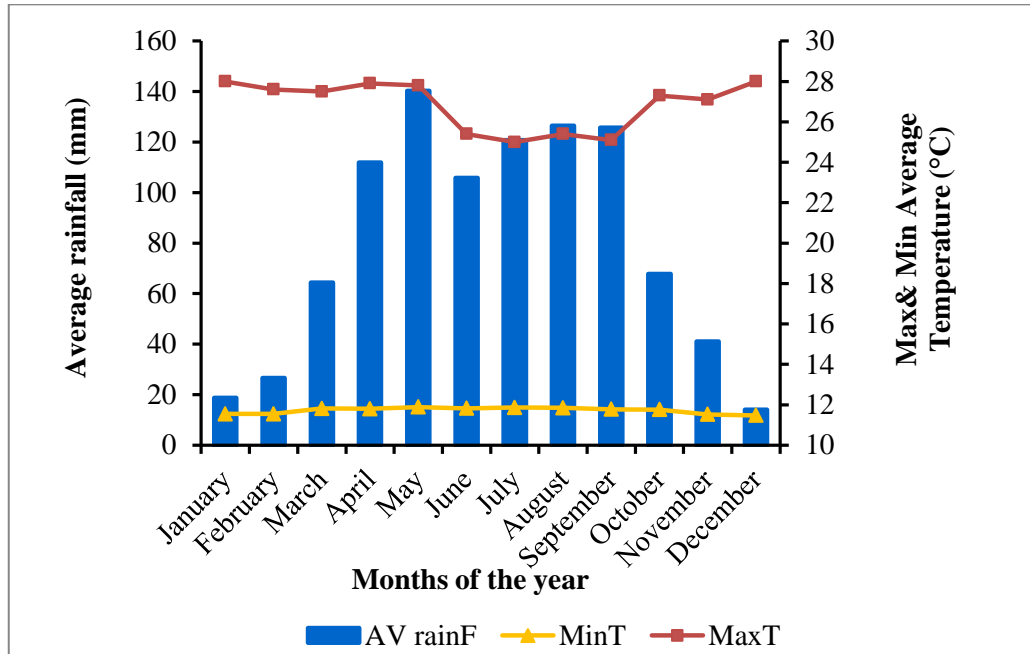


Figure 3. Monthly average rainfall and maximum and minimum temperatures of the experimental site during 2007-2022. (Data source: National Metrology Service Agency /NMSA, Hawassa Branch, 2022).

3.3. Experimental Materials

Maize (*Zea mays* L. var. Melkassa-1) and Swiss chard (*Beta vulgaris* L. var. Ford hook Giant), was used as test crop for the study. Black soldier fly frass (BSFF), composted bioslurry (BS) and chemical fertilizer (CF) were the fertilizers used for experiment. Maize seed was obtained from South Seed Supplier Enterprise whereas the Swiss chard seed was purchased from a vegetable seed supplier in Hawassa city. Composted bio-slurry was purchased from a model farmer in Wando Genet District. The compost was prepared from bio-slurry of cow dung, leaves and agricultural residues and used as organic fertilizer after it was well matured and stabilized. Chemical fertilizer was purchased from a local supplier in Hawassa city. The BSFF was obtained from frass produced by BSFL feeding on food leftover and vegetable wastes in the Laboratory of Fishery and Aquaculture, Hawassa University, following the procedures described by Beesigamukama *et al.* (2020).

3.3. Treatments and Experimental Design

This study involved four treatments; treatments with black soldier fly larvae frass (BSFF), bioslurry (BS), chemical fertilizer (CF) and the control or treatments with no fertilizer (C). Similar rates of BSFF and BS (7.5 t ha⁻¹) were used for maize (Beesigamukama *et al.*, 2020). NPS was applied to maize at 100 kg ha⁻¹ at planting while urea top dressing was done 40 days after planting (Kebede *et al.*, 2022). For Swiss chard, BSFF and BS were applied at the rate of 10.3 t ha⁻¹ (Abiya *et al.*, 2022) while the NPS rate used was 100 kg ha⁻¹ (Hailay and Haymanot, 2019). No fertilizer was applied to the control treatment. For both crops, BSFF and BS were applied one week before sowing the maize and transplant Swiss chard (Anyega *et al.*, 2021; Menino *et al.*, 2021). Table 1 show types of fertilizers and rates used.

Table 1. Treatments, fertilizer types and rates of fertilizers.

Treatment codes	Description of treatments	Fertilizer rate (t/ha)	
		For maize	For Swiss chard
C	Control (no fertilizer)	0	0
BSFF	Black soldier fly frass	7.5 t ha ⁻¹	10.3 t ha ⁻¹
BS	Bioslurry	7.5 t ha ⁻¹	10.3 t ha ⁻¹
CF	Chemical fertilizer	100 kg ha ⁻¹	100 kg ha ⁻¹

Both the experiments, experiments with maize and Swiss chard, were carried out under controlled field conditions. Each experiment was laid out in randomized complete block design (RCBD) with four treatments and each with three replications (Table 2) Randomization is needed as there may be a slight variation in soil fertility and drainage differences in a field due to spatial effects in field (Grant, 2010).

Table 2. Field layout of the experiments.

Replication 1		Replication 2		Replication 3	
Plot No.	Treatments	Plot No.	Treatments	Plot No.	Treatments
1	T4	1	T4	1	T1
2	T1	2	T2	2	T4
3	T3	3	T1	3	T3
4	T2	4	T3	4	T2

The experimental plot sizes were 4.5m × 2.5m, with a total of 11.25m² plot area; and six rows in each plot having 75 cm distance between rows, 25 cm within rows (between plants) and 1m between blocks for maize (Kebede *et al.*, 2022). The total population was 53,333 plants ha⁻¹ for maize and total plot size is measured 2m wide and 2.8m length (5.6 m²) having 1 m space between plots and between blocks. The spacing between (intra) row 40cm and the spacing between plant intervals (inter) 40cm based on Hailay and Haymanot (2019) recommendation. Total of 12 plots and 5 rows and 7 plant in each plot which 35 plant with each plot for Swiss chard.

3.4. Seedbed Preparation and Seed Sowing

Before setting up the experimental design, the land was cleaned, plowed, and sampled for physico-chemical analyzes. The plot was prepared manually with hoes; the crop was sown on well prepared seed bed. Two seeds were planted per hill on 7/18/2022 and at the three to four leaf stage; the maize seedlings were thinned to maintain the optimum plant population by uprooting. While before the experiment, Seeds of Swiss chard were sown in nursery trays on 2/17/2023 and watered every day until transplanting. 40 day-old Seedlings with four to five true leave (Miceli and Miceli, 2014) were transplanted on 3/29/2023 into experimental plots and 2 weeks after transplanting thinning was performed to get one plant per hill. During the experiments, all important agricultural practices (like weeding, hoeing and pesticide (only for maize) which are necessary for the production of both crops were undertaken uniformly for all experimental plots and supplementary irrigation was employed when there was shortage of rain.

3.5. Soil, Organic Fertilizer (BSFF and BS) Sample Collection and Preparation

Soil, BSFF and BS samples were transferred to the laboratory of Wondo Genet College of Forestry and Natural Resources for physicochemical analyses.

3.5.1. Soil sampling and analysis

Pre-experimental soil sampling, preparation, and analysis were conducted. A surface soil (0–20 cm) sample was collected randomly from 10 spots of the experimental field using the zigzag method. Augers and core samplers were used to collect the soil samples. Bulk density was determined from the collected soil samples.

The composite of samples were then used for the analysis of physicochemical properties of soil texture, pH, organic carbon (OC), organic matter (OM), total nitrogen (TN), available P, and exchangeable bases (Ca, K, Na and Mg), Cation exchange capacity (CEC) and Electrical conductivity (EC). In the same way, soil samples were collected from each treatment (BSFF, Bio-slurry, Chemical fertilizers) from eight spots within the inner four rows of each plot just after harvest. The subsamples were homogenized to obtain representative samples. The physicochemical analysis was carried out according to the standard protocols applied in the laboratory (Bekele and Sertsu, 2000).

The soil samples were air dried and ground to pass through 2.0 mm sieve before laboratory analyses. However, for total nitrogen and organic carbon content analyses, the soil samples were prepared using 0.5 mm sieve. The Soil organic carbon was determined by the chromatic acid oxidation method (Walkley & Black, 1934). SOM was calculated by multiplying organic carbon content with the factor of 1.72 (Pribyl 2010). Total nitrogen was determined according to Micro-Kjeldahl method and determination of available phosphorous was carried out according to the methods of Olsen et al., (1945). The pH of the soil was determined by glass electrode pH meter using a suspension of 1:2.5 soils to water ratio as described by Jackson (1973). Cation exchange capacity (CEC) was measured after saturating the soil with 1 N ammonium acetate (NHOAc) (Chapman, 1965). Electrical conductivity (EC) was measured from the saturated soil extract using an EC meter and was multiplied by a correction factor corresponding to the temperature reading taken during the EC reading time. Bulk density was determined by the ratio of oven dry mass of the soil to the total volume (volume of the core sampler) (Equation 1).

$$\rho b = \frac{Wd}{Vtpb} \dots \dots \dots (1)$$

Where ρb is the bulk density (gcm^{-3}), Wd is the weight of dry soil (g) and $Vtis$ the volume of the bulk soil (cm^3).

The total soil porosity was calculated from the bulk density and particle density values using Equation 2 (Bekele and Sertsu, 2000).

$$f = \left(1 - \frac{\rho b}{\rho s}\right) * 100 \dots \dots \dots (2)$$

Where f is the total porosity (%), ρ_b is the bulk density (gcm^{-3}) and ρ_s is the particle density.

3.5.2. BSFF and BS sampling and analysis

BSFF and BS were analyzed in the laboratory for its chemical properties analysis including parameters (pH, total nitrogen, available phosphorous, SOC and OM, CEC, EC and exchangeable base (Ca, K, Na and Mg). Approximately 0.5 kg of BSFF and bioslurry sample was taken to the laboratory for analysis and determined using the methods specified for soil analysis.

3.6. Data Collection

Maize and Swiss chard plants of different treatments were observed and different morphological and observable physiological characteristics were assessed regularly. Accordingly morphological and physiological characteristics such as seedling emergence (for maize), seedling establishment (for Swiss chard), general colors test plants, uniformity and vigority of both maize and Swiss chard plants were collected based on the predetermined time of growth. Measurements of growth parameters, recording days to maturity stages and recording of yield and yield components were carried on predetermined time bases. Accordingly, relevant data were collected for both crops as depicted below.

3.6.1. Maize

For maize plants, the data of seedling emergence was recorded by daily counting the seedlings emerged from the soil starting from the day of sowing to the day on which 50% seedling emergence reached, and the day on which 50% seedling emergence reached was named as day to 50% seedling emergence. When the seedling reached at the knee height, seedling vigority and uniformity were recorded. By regularly following up the plants in the field during the growing period, and when the reproductive structures started to form, the number of plants that produced silk and tassel were counted and recorded. Accordingly, the days to 50% tasseling and 50% silking, respectively were recorded by counted from the date of seed sowing. Days to 75% maturity was also recorded as the numbers of days from the date of seed sowing to the date when 75% of the plants in each plot reached physiologically maturity for harvest.

At physiological maturity, five maize plants were randomly selected and marked from each treatment for determination of growth parameters from four middle rows of all treatment. Plant height and ear height were measured by randomly selecting 5 plants, using a measuring stick and their mean heights were computed and used for comparison. During harvest from the net plot area (11.25 m²), maize plants were manually harvested to determine the above-ground biomass, stalk weight, ear weight and then converted into t ha⁻¹. The stalk weight were measured after the mature ears or cobs were removed from each plant of the net plot area and sundried in a standing position until attaining constant weight, and then weighed for the final data.

Hundred kernels weight (g) was determined by counting 100 seeds from a bulk of shelled grains from a net plot and weighed using sensitive balance. The grain yield was harvested from the net plot and the measured values of the seeds were adjusted to the standard moisture content of 12.5% and then multiplied by the seed weight to determine the adjusted yield of the plot on a hectare basis (Abera *et al.*, 2017; Mosisa *et al.*, 2022) using the following formula.

$$\text{Adjusted yield (AY)} = \frac{(\text{annual yield weight})(100 \text{ measured moisture content})}{100 - 12.5}$$

$$\text{Converting yield to hectare} = \text{yield t plot}^{-1} \frac{10,000 \text{ m}^2}{\text{net plot size (m}^2\text{)}}$$

3.6.2. Swiss chard

Starting from 30 days after transplanting, growth parameters including plant height, leaf length, leaf number, leaf width, leaf area and leaf fresh weight were also recorded from 15 plant selected from the net plot areas for each treatment & plot by lottery method and tagged. Parameters listed above were measured by every 7 days interval up to harvest and the mean values were computed and used for analysis.

Plant height

Plant height of Swiss chard was determined by measuring the plant from the soil level to the top of the longest leaf.

Leaf length

The length of three leaves was selected and measured from the leaf apex to the end of the leaf petiole by ruler and the averages of them are obtained for LL

Leaf width

The leaf width also measured using ruler from three leaves at the middle part of the leaves and the average was obtained for determination of leaf width.

Number of leaf

Number of leaves (visible leaves including the new ones) per plant determines by hand counting.

Leaf area

Leaf area is an important indicator of photosynthetic capacity in plant and were can be simply calculated by multiplying the product of recorded leaf length (L) and width (W) by a constant 0.68 (He *et al.*, 2020).

Relative growth rates in height

From the five consecutive plant height measurements, relative growth rates in height (RGR) were calculated. The value of RGR over a period of time t_1 to t_2 could be calculate using Equation 3 (Hoffmann and Poorter, 2002).

$$RG = \frac{\ln Ht_2 - \ln Ht_1}{t_2 - t_1} \dots \dots \dots (3)$$

Where, **ln** is the natural logarithm, Ht_2 and Ht_1 are the mean heights of the Swiss chard plants at times t_2 and t_1 , respectively. RGR obtained by the above formula was expressed in $cm\ cm^{-1}\ day^{-1}$. At the end of the experiment crop was ready for harvest at sixty (60) days after planting (DAP) (Dumani et al., 2021) the Swiss chard plants were harvested by treatment, weighed for total fresh leaf weight.

3.8. Statistical Analysis

The growth and yield data were tabulated correctly and then subjected to one-way analysis of variance (ANOVA) using the JMP Pro 13 Procedure of SAS software. In case of significant difference, the Tukey’s HSD (honestly significant difference) post hoc test was performed. Significant differences between means of treatments were determined at the 5% significance level ($p < 0.05$).

4. RESULTS AND DISCUSSION

4.1 Properties of Pre-Experimental Soil and Organic Fertilizers

Pre-experimental soil, BSFF and BS were sampled and analyzed for various physical and chemical parameters. Table 3 shows the physicochemical properties of the pre-experimental soil and the organic fertilizers used for the experiments. The analysis of pre-experimental soil revealed that the texture of the soil consisted of sand (44%), silt (34%) and clay (22%), which is categorized into the loam textural class. The soil had a bulk density of 1.26 (g cm⁻³), which is ideal for plant growth as the value is <1.4 gcm⁻³ and it's the textural is a loam soil (USDA- NRCS, 2013). However, the bulk density of the experimental soil was higher compared to the typical bulk density value (< 1.0) for topsoil with high organic matter (Soane, 1990).

The result of soil analysis also showed that the pH of the experimental soil was 6.5 (Table 3). According to Hazelton and Murphy (2007), soils with pH range from 5.6–6.0 are classified as moderately acidic, 6.1–6.5 (slightly acid), 6.6–7.3 (neutral), 7.4–7.8 (slightly alkaline), 7.9–8.4 (moderately alkaline), 8.5–9.0 (strongly alkaline) and pH > 9.0 are very strongly alkaline. Based on this classification, the pH (6.5) of the experimental soil was slightly acid and it was good enough for the cultivation of maize and Swiss chard. Soil pH ranges of from 5.5–7.3 is suitable for maize production while pH ranges from 6–7.2 and below 5.5 are optimal and unsuitable, respectively (Yara, 2021; Alefu Chinasho, *et al.*, 2023). Moreover, Swiss chard plant prefers well-drained loam soil with pH level of 6 to 7 similar to most vegetables (Ninfali and Angelino, 2013).

SOM, SOC, TN, available P, EC and CEC of the experimental soil were also 1.62%, 0.94%, 0.065%, 25.96 mg·kg⁻¹, 73.24μS cm⁻¹ and 26.84meq/100 g, respectively (Table 3). The TN (0.065%) content of the soil was low compared to the TN rating suggested by Hazelton and Murphy (2007), where TN <0.05, 0.05–0.15, 0.15–0.25, 0.25–0.50 and >0.5% rates as very low, low, medium, high and very high, respectively. The SOM content of the pre-experimental soil was 1.62% and it was in the low range (<2%) (Francis Abuye and Mitiku Haile, 2021). SOC of the experimental soil (0.94%) was low compared to the rating suggested by Hazelton and Murphy (2007) where the soil SOC of <0.4, 0.4–0.6, 0.6–1, 1.–1.8, 1.8–3 and >3% were rated as extremely low, very low, low, moderate, high and very high, respectively. Generally the experimental soil was low in SOM, SOC and

TN. Therefore, the experimental soil requires organic fertilizer amendment to improve its SOM, SOC and TN for sustaining crop production.

Available phosphorus in cropland ranges with <5 , $5-10$, $10-17$, $17-25$ and >25 mg kg^{-1} were classified as very low, low, moderate, high, very high (Hazelton and Murphy 2007; Haque *et al*, 2013). Based on this classification, the available phosphorus of the present experimental soils ($25.96 \text{ mg}\cdot\text{kg}^{-1}$) was rated as very high. The CEC of the soil ($26.84 \text{ meq}/100\text{gm}$ soil) was in the high range ($25-40 \text{ meq}/100\text{gm}$ soil) as suggested by Landon (1984), and the EC ($73.24\mu\text{s}/\text{cm}$) of the soil revealed that it is strongly saline as the value greater than $16 \mu\text{s}/\text{cm}$ (Muhr *et al.*, 1963).

Table 3: Selected physicochemical properties of pre-experimental soil and organic fertilizers.

Parameter	Values of the analyses results		
	Pre soil	BSFF	BS
Sand (%)	44	32	36
Clay (%)	22	48	12
Silt (%)	34	20	52
Textural class	Loam	Clay	Silt loam
Bulk density(g/cm^3)	1.26	-	-
Porosity (%)	53	-	-
pH (soil water ratio 1:2.5)	6.5	7.79	8.6
SOM (%)	1.62	48.62	10.25
SOC (%)	0.94	28.21	5.95
TN%	0.065	2.75	1.23
Aval. P (mg kg^{-1})	25.96	94.6	82.04
EC ($\mu\text{S cm}^{-1}$)	73.24	20.42	3.76
CEC($\text{meq}/100\text{gm}$)	26.84	86.98	47.95
EXNa($\text{meq}/100\text{gm}$)	2.05	19.3	12.1
EXK($\text{meq}/100\text{gm}$)	2.895	36.105	22.21
EXCa($\text{meq}/100\text{gm}$)	6.28	4.81	23.75
EXMg($\text{meq}/100\text{gm}$)	8.99	1.88	13.82

Where SOC- Soil Organic Matter, SOC- Soil organic carbon, TN- Total nitrogen, Aval. P- Available Phosphorus, EC-Electrical conductivity, CEC- Cation Exchange Capacity, Exchangeable base (EX N, K, Ca, Mg).

4.1.1. Physicochemical Properties of BSFF and Bioslurry

Chemical properties of black soldier fly larvae frass (BSFF) and bioslurry (BS) utilized as organic source of soil in the study are also presented in Table 3. The soil analysis results revealed that BSFF and BS had pH of 7.79 and 8.6, respectively, and both organic fertilizers were moderately alkaline. According to Filipović et al. (2023), for compost and vermicomposting, pH from 6.5-8.4 was suggested as a threshold for soil amendment depending type of the soil. Moreover, organic amendments with pH ranges of 6.0–8.5 are suggested in several legislations (such as Italy, Belgium and Spain) to ensure compatibility with most plants (Hogg et al., 2002). Therefore, it is possible to use both organic fertilizers as soil amendments for both test plants.

According to the NFU 44 051 standard for organic fertilizers, the following parameters must be taken into consideration when producing organic fertilizers: OM \geq 20, OC \geq 10 and TN $<$ 3%. For the present study, BSFF was respected all these parameters. However in BS SOM and OC content were under standards according to NFU 44 051. This indicates that the BSFF obtained is mature and stabilized for use as a soil amendment thus; its contribution to improving agricultural yield will be higher. However, the physicochemical properties of frass were influenced by the larval diet (Surendra *et al.*, 2020).

4.2. Effects of Different Fertilizers on the Soil Physicochemical Properties

4.2.1. Properties of the soil after harvesting maize

Table 4 shows the results of physicochemical analysis of soil samples collected from the plots treated with BSFF, BS and CF after cultivation of maize. The application of BSFF, BS and CF affected the physicochemical properties of the soils. Although slight changes were observed to the textural composition of some post experimental soils due to applications of various fertilizers compared to the control, no textural class changed occurred (Table 4).

The post experimental soil analysis showed that the pH of soils treated with BSFF, BS and CF were 7.2, 7.4 and 6.81, respectively whereas pH of the control was 6.5. These results demonstrated that although the pH of the soils treated with different fertilizers slightly increased, no such much change in the pH class occurred.

Accordingly, the pH of the soil treated with BS increased from 6.5 (slightly acid) to 7.4 (slightly alkaline) whereas pH of soils treated with BSFF and CF were increased to 7.2 and 6.81, respectively which were neutral (Hazelton and Murphy, 2007). Compared to CF, more increment in pH was observed in the soils treated with BS and BSFF (Table 4). This may be attributed to higher pH of the amended BS and BSFF (Table 3). This result is supported by the findings of Geremew Biramo *et al.* (2019) where more pH increasing occurred when bioslurry applied to the soil compared to equivalent application of chemical fertilizers. Increment in pH of the soil after organic fertilizers amendment could be due the decomposition of organic matters that release basic cations (Das and Dkhar, 2012; Neina, 2019).

Table 4. Physicochemical properties of the soil after harvesting maize.

Parameters	Treatments			
	Control	BSFF	BS	CF
Sand (%)	44	42	48	48
Clay (%)	22	22	22	20
Silt (%)	34	36	30	32
Textural class	Loam	Loam	Loam	Loam
Bulk density(g/cm ³)	1.26	0.92	0.93	0.95
Porosity (%)	53	66	65	64.1
pH (soil water ratio 1:2.5)	6.5	7.2	7.4	6.81
SOM (%)	1.62	2.65	2.34	2.31
SOC (%)	0.94	1.54	1.36	1.24
TN (%)	0.065	0.16	0.19	0.14
Aval. P (mg kg ⁻¹)	25.96	30.48	26.4	27.12
EC (μS cm ⁻¹)	73.24	87.5	57.5	43.5
CEC (meq/100gm)	26.84	30.74	29.87	29.43
EX Na (meq/100gm)	2.05	2.21	2.57	2.51
EX K (meq/100gm)	2.895	5.66	4.95	3.44
EX Ca (meq/100gm)	6.28	21.49	19.35	12.97
EXMg (meq/100gm)	8.995	15.35	16.14	13.33

Where SOC- Soil Organic Matter, SOC- Soil organic carbon, TN- Total nitrogen, Aval. P- Available Phosphorus, EC-Electrical conductivity, CEC- Cation Exchange Capacity, EX- Exchangeable bases (N, K, Ca, Mg)

In the plots treated with BSFF, BS and CF the soil bulk density improved (reduced) from 1.3 g cm⁻³ in the control to 0.92, 0.93 and 0.95 g cm⁻³, respectively. The current result is in agreement with the result reported by Berihu *et al.* (2021) where soil bulk density was reduced from 1.38 to 1.31 g cm⁻³ as a result of bio-slurry application. The changes in the soil aggregates may be due to the application of bio-slurry as the amendments of organic fertilizers normally improve soil structure and physiochemical properties. Bio-slurry and other organic fertilizers often improve the soil structure, increases porosity and decrease the bulk density, thus provide a healthy soil environment (Carrizo *et al.*, 2015; Bassouny & Abuzaid, 2017).

The porosity values of the soils treated with BSFF, BS and CF were recorded found to be 66, 65 and 64.1%, respectively compared to that of the pre experimental or control soil (53%). These findings suggested that the application of BSFF, BS and CF have positively influenced the soil structure by reducing bulk density and increasing porosity. In line with the present results, Brown and Cotton (2011) have found decreasing in soil bulk density and increasing of porosity with increasing in the rate of compost. The authors suggest that the organic fraction is much lighter in weight than the mineral fraction in soils and increases in the organic fraction decrease the total weight and bulk density of the soil. According to Bot and Benites (2005), the amendment of organic fertilizers contributes indirectly to soil porosity (via increased soil faunal activity). It improves surface infiltration by optimizing soil aggregations and stability, pore continuity and stability and the soil surface conditions.

The soil fertility indicators such as SOM, SOC, TN, Aval P and CEC increased due to the application of organic fertilizer and chemical fertilizer (Table 4). The SOM content in the soil treated with BSFF, BS and CF increased to 2.65, 2.34 and 2.13% respectively compared to organic matter content (1.62%) of the soil of the control treatment. This study has demonstrated that application various fertilizers increases the SOM compared to the control. Particularly, amendment of BSFF and BS increased the SOM by about 63.58 and 44.44%, respectively compared to the soil of the control plots. These findings are in agreement with the results reported by Frost and Hunter, (2004) and Wu *et al.* (2023) where the application of BSFF substantially improved the soil organic matter in the cultivations of maize, and it was suggested that frass deposition to in soil has a great impact on soil fertility due to its high nutrient and labile carbon content.

Similarly Menino *et al.* (2021) suggest that application of BSFF highly increased SOM when ray grass was used as a test plant. In line with the present results, Yan and Gong (2010) reported that organic fertilizer application increased SOC than chemical fertilizer input. This may be due to direct input of carbon to the soil during the application of organic fertilizers, which can be stabilized through physical, chemical, and biochemical mechanisms and contributing to long term storage of C in soil (Yan and Gong, 2010; Kelbesa *et al.*, 2021). Moreover, Mucheru-Muna *et al.*, (2007) reported that total soil carbon and nitrogen contents increased with the application of organic residues and manure after maize harvesting. Furthermore, the increment in SOC through the application of organic fertilizer was attributed to the high content of SOM, which serves as the primary source of organic carbon (Charman and Roper, 2000).

The addition of BSFF, BS and CF increased the TN of the soil to 0.16, 0.19, and 0.14%, respectively compared to 0.065% of the control. This means the application of BSFF, BS and CF increased the TN of the soil by about 146.15, 192.3 and 115.3%, respectively compared to the TN content of the control. According to Ashenafi Nigussie *et al.* (2021), application of compost and nitrogen fertilizers significantly improved the TN content in soil after maize cultivation. Organic fertilizers are a good source of nitrogen, which is one of the most limiting soil nutrients for agriculture and they improve soil microbial activities and provide macronutrients necessary for the growth of crops (Tully *et al.*, 2015; Islam *et al.*, 2017). In line with the current result, previous studies demonstrated that TN content of the soil was more maintained by the application of organic fertilizers such as compost and bioslurry compared to the control (Geremew Biramo *et al.*, 2019; Tsehaye Kebede *et al.*, 2022) and inorganic fertilizers (Tsegaye Terefe *et al.*, 2018).

The available P content in the soil treated with BSFF, CF, and BS was found 30.48, 27.12 and 26.4 mg kg⁻¹, respectively while it was 25.96 mg kg⁻¹ for the soil from the control plots (Table 4). These values represent an increase of 17.4, 4.46 and 1.69 %, respectively compared to the control treatment. These results demonstrated that applications of all fertilizers increased the available P of the soil compared to the control although the increased values varied for different fertilizers. In line with the current results, previous studies reported that the application of bio-slurry (Berihu, 2021) and manure based compost (Paulin and Malley, 2008) significantly contributed to the increasing of available P of the soil.

As it can be seen from Table 4, the highest available P was found from the soil treated with BSFF which was 12.38% and 15.45% higher than CF and BS, respectively. The highest available P in the soil treated with BSFF may be attributed to its higher value in the applied BSFF (94.6 mg kg⁻¹) compared to that of BS (82.04 mg kg⁻¹). The increment of soil available P due to application of BSFF was supported by the results of Wang *et al.* (2022) and Boudabbous *et al.* (2023), who found that the application of insect frass remarkably increased the soil available P after cultivation of maize and durum wheat, respectively. It is suspected that black soldier frass is included in the category of humic acid (Reswita *et al.*, 2022) which could increase the availability of P in the soil. Increasing of the available P due to application of BS is in agreement with the result reported by Islam *et al.* (2016) where soils treated with bioslurry resulted in higher available P compared to the control. The release of more P from the decomposition of bio-slurry in the soil medium might result in higher available P value in soils.

The CEC the soils treated with BSFF, BS and CF were 30.74, 29.87, 29.43meq/100gm respectively where as it was 27.81meq/100gm for the control plot (Table 4). As it can be observed from Table 4, the CEC of the soil increased due to the applications of various fertilizers. The soil treated with BSFF and BS more increased the CEC value of the soil compared with CF. It is well known that the application of organic amendment increased CEC due to the colloidal nature of organic matter (Ibrahim *et al.*, 2023). According to Selassie *et al.* (2015) and Fanuel Laekemariam and Kibebew Kibret (2020), the main determinants of CEC are clay and organic matter because both have negative charges which are strong enough to attract the positively charged cationic elements for exchange (Tsegaye Terefe *et al.*, 2018; Aprile and Lorandi, 2012).

EC is a measure of the soil's ability to conduct electrical current, which is related to the concentration of dissolved salts in the soil. The result of soil analysis revealed that soil treated with BSFF resulted in highest EC value (87.5 $\mu\text{s cm}^{-1}$) compared to the soil treated with BS (57.5 $\mu\text{s cm}^{-1}$), CF (43.5 $\mu\text{s cm}^{-1}$) and the control (73.24 $\mu\text{s cm}^{-1}$). In line with the current result, Zhan and Quilliam, 2017 reported that BSFF application to the soil resulted in higher EC compared to inorganic fertilizers and traditional composts and the author suggested that this was due to higher salt content in diet of the larvae of black soldier fly.

In the present study, important exchangeable bases in the soil such as Na^+ , K^+ , Ca^{2+} and Mg^{2+} were increased by the application of all types of fertilizers (Table 4). These results demonstrate that the application both organic fertilizer and chemical fertilizer increased the availability of extendable base (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) in the soil compared that of the soil from the control treatment. Moreover the application of BSFF more increased the exchangeable K^+ and Ca^+ compared to other treatments (Table 4). Similarly, BS more increased the exchangeable Mg^+ compared to BSFF and CF treatments. The increment of exchangeable bases in the present study due to application of different fertilizer was in line the results reported by Houben *et al.* (2020) where insect frass increased the soil exchangeable basis. According to Elnasikh and Satti, (2017), organic fertilizers act as a reservoir of plant nutrients and prevent nutrient leaching by maintaining a high CEC. Moreover applications of organic fertilizers to the soil increase both macro and micro nutrients.

4.2.2. Properties of the soil after harvesting Swiss chard

Table 5 shows the results of physicochemical analysis of soil samples collected from the soils treated with BSFF, BS and CF after cultivation of Swiss chard. The pH of post experimental soil after Swish chard harvesting had found to be 7.6, 7.62 and 6.62 for the soil treated with BSFF, BS and CF, respectively and the pH of the soil from the control plots was 6.5 (Table 5). These results demonstrated that application of BSFF and BS changed the pH of the soil from 6.5 (slightly acidic) to 7.6 and 7.62, respectively (slightly alkaline) and to pH of 6.62 (about neutral) for soil treated with CF based on the soil pH classification by Hazelton and Murphy (2007).

In the present study, the pH of soil after Swiss chard cultivation was increased, particularly in the soils treated by BSFF and BS compared with compared to the control. The increment of pH values may be attributed to the alkalinity the applied organic fertilizers. According to Dzepe *et al.* (2022), one of the common properties of organic fertilizers is improving soil cation availability and increasing the pH of the soils. pH increment for the soil treated with BSFF in the current study is also agreement with the results reported by Menino *et al.*, (2021) where frass from black soldier fly larvae increased the pH in the cultivation of ryegrass. Basri *et al.* (2022) suggested that the pH rise due to BSFF application could be due to ammonia generation via ammonification and organic nitrogen mineralization via microbial activity.

The soil analysis results after cultivation of Swiss chard showed that applications of all types of fertilizers increased the soil SOM, SOC, TN, Aval P, EC and CEC. The SOM of the post experimental soil for BSFF, BS and CF were 8.84, 4.32 and 2.65% respectively compare to 1.62% of the control (Table 5). The application of different fertilizers increased the SOM compare to the soil from the control and BSFF was superior in increasing the SOM of the soil (Table 5). Previous studies also demonstrated that application of BSFF to the soil increased the SOM in the cultivation of onion (Zahn and Quilliam, 2017) and lettuce (Esteves *et al.*, 2021) compared to mineral fertilizer.

The SOC content of the soil treated with BSFF, BS and CF was found to be 5.13%, 2.51% and 1.54% respectively. These findings indicate that the application of different treatments increased the SOC compared to the control treatment, which had a SOC of 1.05% (Table 5). Increment of SOC with the application BS in present study in line with the results reported by Geremew Biramo *et al.* (2019) and Lolamo *et al.* (2023). Moreover, Praeg and Klamsteiner (2023) suggested that the amendment of soil with frass derived from different fly types resulted in a significant increase in the SOC.

TN contents of soils treated with BSFF, BS, and CF were found to be 0.46, 0.26 and 0.34%, respectively while it was 0.065% for the control (Table 5). Based on these values, it was suggested that application of all fertilizers increased the TN of soil compared the control. Relatively larger TN in the soil treated with BSFF may be related its higher SOM (48.62%) and total nitrogen content (2.75%) (Table 3). In line with the current result, Houben *et al.*, (2020) found more increase in TN contents of the soil after barley cultivation by incorporation of mealworm frass into the soil. In the present study, BS also showed better performance in maintaining TN in soil compared to CF and the control. Similarly Islam *et al.* (2016) report that bioslurry increased TN content of the soil from 0.09% to 1.69% after spinach cultivation.

Table 5: Physicochemical properties of post-experiment soil after Swiss chard harvest

Parameters	Treatment			
	Control	BSFF	BS	CF
pH (soil water ratio 1:2.5)	6.5	7.6	7.62	6.62
SOM (%)	1.62	8.84	4.32	2.65
SOC (%)	1.05	5.13	2.51	1.54
TN (%)	0.065	0.46	0.26	0.34
Aval. P (mg kg ⁻¹)	25.96	37.52	34.75	32.58
EC (μS cm ⁻¹)	73.24	117	97	107
CEC (meq/100gm)	25.84	35.56	30.10	26.42

Where SOC- Soil Organic Matter, SOC- Soil organic carbon, TN- Total nitrogen, Aval. P- Available Phosphorus, EC-Electrical conductivity, CEC- Cation Exchange Capacity.

According to Ros *et al.* (2020) and McDowell *et al.* (2023), after nitrogen, phosphorus is the second most limited nutrient and is not available to plants despite the abundant phosphorus reserves in the soil. In the present study, available P of the soil treated with BSFF, BS and CF were 37.52, 34.75 and 32.58 mg kg⁻¹, respectively (Table 5) whereas it was 25.96 mg kg⁻¹ for the control treatments. The results indicate that the application of BSFF, BS, and CF increased the available P levels in the soil by about 44.53%, 33.85%, and 25.5%, respectively.

Furthermore, the application of BSFF and BS demonstrated more effectiveness in increasing the available P levels in the soil by 15.16% and 6.66%, respectively, compared to CF. This result is in agreement with findings of Kumar *et al.* (2008) who report that green manure and other organic fertilizers increased the available P in the soil relatively for longer period compared to CF in rice-wheat cropping system. According to Praeg and Klammersteiner (2023), P fertilization associated with frass is consistently beneficial in all cases and supports the replacement or reduction of CF which is a major goal in a sustainable agriculture.

CEC is one of the most important indicators of soil fertility, especially for nutrient retention, as a high adsorption capacity prevents nutrient cations from leaching into the groundwater. The CEC the soil treated with BSFF, BS and CF were 35.59, 30.10 and 26.42 meq/100gm, respectively while it was 25.84 meq/100gm for the control. The result of present study showed that all fertilizer increased the CEC of the soil compared the control

(25.87 meq/100gm). Similar to the present result in the comparable studies of compost amendments using maize and tomato as test crops, Zeleke *et al.* (2022) found more improvement in soil CEC using compost compared to CF and the control. This may be attributed to higher organic matter contents of organic fertilizer which contribute much to the improvement of the CEC of the soil

The EC of the soils treated with BSFF, BS and CF were 117, 97 and 107 $\mu\text{S cm}^{-1}$ respectively compare to 73.24 $\mu\text{S cm}^{-1}$ for the control (Table 5). These results revealed the application of all types of fertilizers during Swiss chard cultivation increased the EC of the soil compared to the control. The largest increment in EC (117 $\mu\text{S cm}^{-1}$) in case of BSFF application is in line with the results reported by Praeg and Klammsteiner, (2023) where EC increased in frass treated soils. EC is a potential estimator of soil properties such as pH, SOM, CEC and solute concentration (Peralta and Costa, 2013) and soil fertility (Zeleke *et al.*, 2022).

4.3. Effects of Different Fertilizers on Germination and Growth of Maize

4.3.1. Effects on seedling emergence and plant vigorsity and uniformity

Table 6 shows the effects of different fertilizers on maize seedling emergence and plant growth performance. As it can be seen from Table 6, there were significant differences ($p \leq 0.05$) in the number of days to 50% seedling emergence among the soil treated with BSFF (about 8 days), BS & CF (about 11 days each) and the control (13 days). The treatment with BSFF showed shorter average number of days (8.3 days) to reach 50% seedling emergence. The 50% seedlings emergence (13 days) of the control treatment was significantly longer compared to other treatments. Days to 50% seedling emergence for BS and CF treatments were comparable, and significantly shorter (11 days) compared to that of the control.

The reduction in the number of days to reach 50% seedling emergence in the organic fertilizer treatments compared to the control may be attributed to the improvement of soil physicochemical and microbiological properties resulting from the use of these fertilizers. According to this Olaniyi *et al.* (2010) mentioned that temperature, aeration, and moisture as the factors needed for seed germination. Particularly, organic fertilizers increase soil organic matter which improves soil structure; increases air spaces in the soil and water retention, as well as sustains beneficial microorganisms that help release nutrients to the

soil (Sisay Assefa and Sisay Tadesse, 2019). Similarly Soro *et al.* (2015), report that Poultry manure it has significant effect on the soil fertility by essential nutrients as well as soil organic matter which improve moisture and nutrient retention which in turn enhance seed germination and seedling emergence of maize over control.

Table 6. Effects of different fertilizers on maize seedling emergence and plant growth.

Treatment	Days to 50 % Vigorsity emergence (Days)	Uniformity	PH (cm)	EH (cm)	
C	13±0.44 ^c	1.96±0.07 ^c	2.2±0.1 ^c	199.6±0.71 ^c	83.1±0.55 ^c
BSFF	8.3±0.44 ^a	4.0±0.07 ^a	4.26 ±0.1 ^a	218.46±0.71 ^a	102±0.55 ^a
BS	11±0.44 ^b	3.53±0.07 ^b	3.5±0.1 ^b	205±0.71 ^b	98.06±0.55 ^b
CF	11±0.44 ^b	3.73±0.07 ^{ab}	4.03±0.1 ^a	205.47±0.71 ^b	83.13±0.55 ^c

BSFF = Black soldier fly frass, BS= Bioslurry, CF =chemical fertilizer, C=control, PH= plant height, EH= ear height

Different letter in the column show significant differences among the means of the respective parameters (P<0.05).

The application of different fertilizers significantly affected plant vigorsity and uniformity (P≤0.05) (Table 6). Both BSFF and CF applications had a significant effect (p≤0.05) on plant vigor and uniformity compared to the plots treated with BS. Similarly, BS application resulted in plants with higher vigor and uniformity, which were significantly different from the control treatment. The present study demonstrated that the application of organic or inorganic fertilizers led to better plant vigor and uniformity. This improvement can be attributed to providing plants with balanced nutrition through appropriate fertilization is crucial for their vigor and uniform growth. Nutrient deficiencies or imbalances can lead to stunted growth, reduced vigor, and uneven development. The higher nutrient content in BSFF and BS (Table 3) contributed to the enhancement of these growth parameters. This result was in line with Eleduma *et al.* (2020) found that maize with manure application affects nutrient availability for plant and promoting vigorous plant growth through efficient photosynthesis.

Plant vigor encompasses the overall health, strength, and vitality of a plant. To enhance both plant vigor and uniformity, several factors should be taken into consideration, including the availability of nutrients and the plant's ability to withstand stress and disease. Research conducted by Poveda *et al.* (2021) and Fuhrmann *et al.* (2022) has shown that

microorganisms found in BSFF frass contribute to plant growth promotion, as well as stress and disease control. Similarly, Choi & Neelah Hassanzadeh (2019) discovered that the presence of chitin material in BSFF not only defends plants against pathogens but also improves soil fertility and create a favorable soil environment.

4.3.2. Effects on plant height and ear height of maize

As it can be observed from Table 6, maize plants grown on the soil treated with BSFF, BS, CF and the control resulted in plant having height of 218.46, 205, 205.47 and 199.6 cm, respectively. These results revealed that maize grown on the soil treated BSFF showed significantly ($p \leq 0.05$) larger plant height (218.46 cm) compared to the other treatments. Plant heights for the maize plants grown on the soil treated with CF (205.47 cm) and BS (205 cm) were not significantly different, and it was intermediate between those of BSFF and the control. Plants grown on the soil with no fertilizer (the control) resulted in the significantly ($p \leq 0.05$) smallest plant height to compare other treatments.

In terms of ear height, BSFF treatment again resulted in the highest value of 102 cm, followed by, BS with 98.067 cm. The ear height of the maize plants grown on the soil treated with CF (83.13 cm) and the control (83.1 cm) were not significantly ($p \leq 0.05$) differed. Although variations in plant height were observed in maize due to different treatments, this could be attributed to the availability of nutrients required for plant growth and development.

Overall, it can be inferred that using BSFF as soil amendment for maize cultivation may have more effects on both plant height and ear height compared to all other treatments. In line with the current results, Beesigamukama *et al.* (2020) and Tanga *et al.* (2021) found from experiment with maize that treated with BSFF produced significantly taller maize plants than those of plants treated with mineral and an organic commercial fertilizer. The authors demonstrated that BSFF is containing higher nutrient concentrations and ability to faster release nutrients associated with BSFF capable of improving soil nutrient availability and plant growth. Other observation also reported by Wu *et al.* (2023), who found that the application of frass had a positive impact on maize height, possibly due to its role as an organic fertilizer, improving nutrient availability and soil fertility.

The increase in vegetative growth was due to supplementary application of BSFF, which in turn attributed to low nutrient status determined by analysis of soil before planting for the experimental site or control treatments (Table 3). Several studies have indicated that BSFF is a nutrient rich fertilizer containing significant amounts of nitrogen, phosphorus, and potassium, which promote overall plant growth (Chen *et al.*, 2019; Gärttling *et al.*, 2020; Watson *et al.*, 2021). Particularly nitrogen is essential for photosynthesis, cell division, protein formation, and vegetative growth. Melese Damtew (2022) report application of organic manure improves maize plant height than control treatments. The authors found that increased plant height due to the presence of high nitrogen contents, which enhances the number of nodes, internode length, and ultimately plant height.

4.3.3. Effects on tasseling and silking and maturity

According to Table 7, the mean number of days required for 50% tasseling in maize plants grown on soil treated with BSFF (58 days) was significantly shorter ($p \leq 0.05$) compared to plants grown on soil treated with CF (63 days) and the control (65 days). The mean number of days to 50% tasseling in maize plants grown on soil treated with BS (60.6 days) did not show a significant difference ($p \leq 0.05$) compared to BSFF. For 50% silking, the mean number of days taken for BSFF, BS, CF, and the control were 63.3, 65.66, 67, and 67.66 days, respectively (Table 7). These results indicated that the BSFF treatment resulted in the shortest time to reach 50% silking, followed closely by the BS treatment (Table 7). The control and CF treatments took a significantly longer time ($p \leq 0.05$) to reach 50% silking compared to BSFF and BS.

Table 7. Effect of fertilizer on days to tasseling, silking and maturity of maize

Treatmet	%50 Tsl (days)	%50 Silk (days)	75% maturity (days)
C	65±0.52 ^a	67.66±0.71 ^a	131±.052 ^a
BSFF	58±0.52 ^c	63.33±0.71 ^c	124±.052 ^c
BS	60.6±0.52 ^b	65.66±0.71 ^b	126.3±.052 ^{bc}
CF	63±0.52 ^{ab}	67±0.71 ^{ab}	128±.052 ^b

Where C: Control, BSFF: Black soldier fly frass, CF: chemical fertilizer, BS: Bioslurry, %50 Emrg: Days to 50% seedling emergence, %50 Tsl: Days to 50% tasseling, %50 Silk: Days to 50% silking.

Different letter in the column show significant differences among the means of the respective parameters ($P < 0.05$).

The current study findings suggest that using BSFF and BS as organic fertilizers may potentially accelerate the silking process compared to the CF or C. The longer days in control in line with the research work of Golla and Chalchisa, (2019) and Jassal *et al.* (2017). Who found under the control treatment, plants took more days to attain 50% tasseling and silkings, and the application of nitrogen fertilizer hastened the days to tasseling and silkings. This due to inadequate nutrient availability may have caused plant starvation, slowing growth and delaying flowering and anthesis.

As indicated in Table 4 this effect in current study may be due to the fact that BSFF and BS are organic fertilizers that provide significant amounts of nitrogen and phosphorus, stimulating plant growth at the overall level. Similarly Ashenafi *et al.* (2023) also found that fertilizer causes the crop to grow vigorously and more rapidly during the vegetative stage, which eventually causes the crop to tassel sooner rather than later. This could also be attributed to their synergistic effect on promoting vegetative growth, which resulted in preserving enough food reserves to allow buds to develop into flower buds.

The results in table 7 revealed a highly significant ($P < 0.05$) effect of fertilizers application on the days to 75% maturity of maize. The minimum days to 75% maturity (124 days) were observed under the application of BSFF, which significantly ($P \leq 0.05$) shortened the time compared to maize treated with CF. However, significantly similar with BS application. The BS treatment recorded the shortest days to 75% maturity (126.3 days), which was not significantly different from CF (128 days). The longest days to 75% maturity (131 days) were observed in the control group, which was significantly longer than all the treatment groups (Table 7). These findings are consistent with Gurm and Mintesnot (2020), who reported that the application of NPS fertilizer and compost resulted in early maturity compared to the control group. This is due to vigorous plant growth, early tasseling, and silking of the crop. In contrast, plants with lower nutrient application matured later due to insufficient nutrients.

4.4. Effects of Fertilizers on Stand Count, Total Biomass, Stalk Weight and Grain Yield

4.4.1. Stand count at harvest, total biomass yield and stalk weight

Table 8 shows maize plant stand count at harvest, total biomass and grain yield. As it can be observed from Table 8, plants grown on the soil treated with BSFF resulted in

significantly ($p \leq 0.05$) larger mean plant stand count (40 plants) at harvest compared to the control. The mean plant stand count at harvest for the plots treated with BS (38 plants) and CF (37.3 plants) were not significantly ($p \leq 0.05$) different from that of the BSFF (Table 8). The result demonstrated that all application of fertilizers was improved the maize plant stand count.

Soil treated with BSFF, CF and BS were resulted the mean total biomass 20.40, 17.6 and 17.3 t ha⁻¹, respectively while it was about 16.1 t ha⁻¹ for the control (Table 8). The mean total biomass for BSFF was the largest but it was not significantly ($p \leq 0.05$) larger than of CF and BS, and the total biomass obtained from the control soil was significantly ($p \leq 0.05$) smaller compared to that of the BSFF (Table 8). This shows that without the amendment of any fertilizer, maize growth and biomass production would be limited. The relatively larger total biomass observed in the application of BSFF suggests that using BSFF as an organic fertilizer contributes more significantly to the improvement of maize total biomass compared to other treatments. This finding is consistent with the results reported by Houben *et al.* (2020), who discovered that insect frass improved nutrient uptake and total biomass in barley production. This may due to rapid mineralization of frass throughout the maize growing season releases vital nutrients in the required quantity.

Additionally, Choi and Hassanzadeh (2019) found that insect frass fertilizer provides additional benefits to soil health, including improved drought and salt tolerance, disease suppression, and higher crop growth and total biomass yield in green bush bean plants. Kebede *et al.* (2023) report the application of sole bio-slurry as well as their combinations with chemical fertilizer increased maize biomass yield over the control. This is due to application of bioslurry provides both macro and micronutrients and increase growth and yield variables maize. Muhammad *et al.* (2016) also reported that compost application improves maize total biomass. This improvement may depend on crop growth, plant height, ear plant, and grain yield, which are influenced by the increased availability of nutrients through compost addition.

Table 8. Effect of fertilizer on yield and yield components of maize

Trt	SC (t ha ⁻¹)	TBM (t ha ⁻¹)	SW (t ha ⁻¹)	NE	EW(t ha ⁻¹)	LC(cm)	Wt.100 seeds (g plot ⁻¹)	GY t ha ⁻¹)
C	36±0.72 ^b	16.07±0.7 ^b	6.37±0.33 ^b	36±1.11 ^b	3.64±0.23 ^c	13.67±0.25 ^c	24±0.76 ^b	2.48±0.26 ^b
BSFF	40±0.72 ^a	20.40±0.7 ^a	8±0.33 ^a	42.3±1.11 ^a	5.85±0.23 ^a	18.86±0.25 ^a	28±0.76 ^a	4±0.26 ^a
BS	38±0.72 ^{ab}	17.3±0.7 ^{ab}	6.74±0.33 ^{ab}	38.67±1.1 ^{ab}	5.04±0.23 ^{ab}	16.8±0.25 ^b	25±0.76 ^{ab}	3.28±0.26 ^{ab}
CF	37.3±0.72 ^{ab}	17.62±0.7 ^{ab}	6.51±0.33 ^{ab}	37.3±1.11 ^{ab}	4.57±0.23 ^{bc}	15.46±0.25 ^b	28±0.76 ^a	2.98±0.26 ^{ab}

BSFF = Black soldier fly frass, BS= Bioslurry, CF= chemical fertilizer with, SC= Stand count, TBM=total biomass, NE= No. of ear, EW= Ear weight, LC=Length of Cob, W.100 Sd =Weight of 100 seeds, GY= Grain yield

Different letter in the column show significant differences among the means of the respective parameters (P<0.05).

In terms of stalk weight, the highest stalk weight was observed in the BSFF treatment (8 t ha⁻¹), while the lowest was observed in the control group (6.37 t ha⁻¹) (Table 8). As shown in Table 6, the mean stalk weight of maize treated with BSFF was significantly higher than that of the unfertilized plot. However, there was no significant difference between BS and CF treatments. The mean stalk weight of maize with BS (6.74 t ha⁻¹) was statistically comparable to that of CF (6.51 t ha⁻¹). The stalk weight in the BS and CF treatments was high but not significantly higher than the control. The present study demonstrated the application of different fertilizer increase stalk weight of maize over control. This result was in line with findings of Tsehay Kebede *et al.* (2023) who found application of bio-slurry increased Stover yield over the chemical fertilizer application and the control.

4.4.2. Effects on number of ears, ear weight and cob length of maize

The variation in the number of ear height and ear weight of the maize crop for the different treatments is shown in Table 8. The results in Table 8 revealed that the application of all treatments affected the number of maize ears among the different fertilizer treatments ($P \leq 0.05$). The soil treated with BSFF, BS, and CF resulted in mean ear numbers of 42.3, 38.67, and 37.3, respectively, while the control had an average of approximately 36 ears (Table 8). The mean number of ears for BSFF was significantly larger ($p \leq 0.05$) than that of the control, but it was not significantly larger ($p \leq 0.05$) than BS and CF (Table 8). The mean ear number obtained from the soil treated with BS and CF was higher, with some difference compared to the control, but not significantly different. However, the results indicate that the application of fertilizer increased the number of ears in maize.

Relatively larger ear number in the application of BSFF suggesting that using BSFF as an organic fertilizer more contributed the improvement ear number of maize compared to the other treatments. In agreement with the present result, Ali *et al.*, (2015) and Muhammad *et al.* (2016) who report that application of compost increases in number of ears number maize plants. The authors suggest that the application of compost may improve soil fertility, leading to enhanced plant growth. The vigorous plant growth, in turn, may have resulted in an increased number of ears per plant.

In terms of ear weight, the soil treated with BSFF, BS, and CF resulted in mean values of 5.85, 5.04, and 4.57 t ha⁻¹, respectively, while the control had an average of 3.64 t ha⁻¹ (Table 8). The mean ear weight for BSFF was significantly larger ($p \leq 0.05$) than that of CF

but not significantly different ($p \leq 0.05$) from BS. The ear weight obtained from the control soil was significantly smaller ($p \leq 0.05$) compared to that of BSFF and BS but not significantly different ($p \leq 0.05$) from CF (Table 8). The higher ear weight recorded in the current study due to the application of BSFF and BS is in agreement with the findings of Kandil *et al.* (2020), who reported that the application of compost increased crop productivity in terms of yield and yield components of maize, including ear weight.

The cob lengths obtained from the soil treated with BSFF, BS, and CF were 18.86, 16.8, and 14.6 cm, respectively, while the control treatment had a cob length of 13.67 cm (Table 8). The cob length of maize was significantly affected by all fertilizers ($P \leq 0.05$). The results indicate that the mean length of cobs in soil treated with BSFF was significantly larger than that of BS and CF. The mean cob length obtained from BS was higher than that of CF but not significantly different. The lowest mean cob length (13.67 cm) was recorded from the control treatment, which was significantly lower than all other treatments ($P \leq 0.05$). Based on these results, the present study found that the application of BSFF improved the cob length of maize plants. This finding is consistent with a previous study conducted by Fanuel and Gifole (2013), where they reported a higher cob length in maize plants treated with compost compared to the control. The better cob length may be attributed to increased photosynthetic activity of the plants due to an adequate supply of nitrogen, which is essential for cob growth.

4.4.3. Grain yield

Table 8 shows the maize grain yield obtained from different soil treatments. The grain yields for soil treated with BSFF, BS, and CF were 4.0, 3.28, and 2.98 t ha⁻¹, respectively while it was 2.48 t ha⁻¹ for the control (Table 8). Furthermore, the grain yield from the soil treated with BSFF (4.0 t ha⁻¹) was significantly greater ($p \leq 0.05$) than the yield from the control (2.48 t ha⁻¹). Although the grain yield from soil treated with BSFF was the highest, it was not significantly different from yields from BS and CF. Notably, the lowest grain yield of 2.48 t ha⁻¹ was found from the maize grown on the control. The results from the present study demonstrated that the application of all fertilizers increased maize grain yield compared to the control.

This may be attributed to improvement of the physicochemical properties of the soil due to the applications of the fertilizers (Table 4), particularly the decreasing in bulk density,

increasing in porosity, improvement in, SOM, SOC and TN as a result of amendments of BSFF and BS. The present result is consistent with the findings reported by Cokkızgın *et al.* (2022) where the application of organic fertilizer adequately improved the nutrient in the soil and grain yield of maize compared to the control. Moreover, previous studies demonstrated that significant increase in maize grain yield by the application of organic fertilizers depends on simultaneous improvements in yield components such as total above ground biomass, cob length and hundred seed weights as these parameters were positively correlated with the yield (Aman *et al.*, 2020; Michael *et al.*, 2020; Ashenafi *et al.*, 2023). The results in Table 8 also demonstrated the improvement of maize yield and yield components with the application of fertilizers compared to the control.

As it can be seen from Table 8, the highest grain yield (4.0 t/ha) was obtained from maize grown in plots treated with BSFF. The treatments with BSFF resulted in an increase in the maize yield by 61.29%, 34.22%, and 21.95% when compared to yields from the control, CF, and BS, respectively. This result is consistent with the findings reported by Tanga *et al.* (2021) where the application of BSFF increased maize grain yield compared to chemical fertilizer and the control. Similarly, Beesigamukama *et al.* (2020) reported that maize treated with 7.5 t ha⁻¹ of BSFF had a higher grain yield compared to equivalent rates of commercial organic fertilizer and urea. This could be due to the higher nutrient concentrations and the high release of nutrients resulting from the high mineralization rate of BSFF, thus providing nutrients in a faster, readily available form for plant uptake (Beesigamukama *et al.*, 2020; Tanga *et al.*, 2021). As it can be seen from Table 3 and Table 4, BSFF had more plant nutrients and improved soil fertility, respectively compared to other fertilizers which might have resulted in higher maize grain yield.

Generally, the average yields of maize (Melkassa-1) grown on the soil treated with the three types of fertilizers was 3.42 t ha⁻¹ while it was 3.64 for maize grown on the soil treated with BSFF and BS. The yields obtained in the present study were larger than the average yield reported by Abate *et al.* (2015) for Melkassa-1 variety which ranged from 2.5 to 3.5 ha⁻¹.

However, the yields of maize (Melkassa-1) obtained in the current study are slightly lower than the national maize yield average (4.2 t ha⁻¹) (FAO, 2021). In addition to plant nutrients in the soil, several climatic factors such as rainfall patterns, temperature extremes, drought, and heat stress during the cropping season can influence the maize yield. Prolonged

periods of drought can result in wilting, stunted growth, and reduced ear development, and finally reduced the grain yield (Koliai *et al.*, 2012; Belay, 2020). Moreover, different maize varieties have varying levels of yield potential. According to Abate *et al.* (2015), the average yields of maize varieties such as BH547 and BH661 ranged from 6.5 - 7.5 and 6.5 - 8.5 t ha⁻¹, respectively compared to 2.5 – 3.5 t ha⁻¹ for Melkassa-1 and 3.5-4.0 t ha⁻¹ for other Melkassa varieties.

The mean weight of 100 seeds for maize grains obtained from plants grown on soil treated with different treatments was presented in table 8. As it can be seen from Table 8, Soil treated with BSFF, CF and BS resulted the mean weight of 100 seeds 28, 28 and 25g, respectively while the mean of 24g for control. The highest weight of 100 seeds was observed in the BSFF and CF treatments (28g), followed by BS (25g), while the lowest weight was recorded in the control group (24g). These results indicate that the weight of 100 seeds for maize grains treated with BSFF and CF was significantly higher ($p \leq 0.05$) compared to the control, however not significantly different from plots treated with BS. The mean weight of 100 seed were recorded from control significantly small to compare BSFF and CF treatments, but not significantly small when compared with BS treatments.

The current study demonstrated that application of all fertilizer was increase weight of 100 seeds for maize grains more than control. This may due to nutrients positively influence grain development and can result in an increase in the weight of individual maize grains. This result was in line with Detebo Orebo *et al.* (2021), who found maximum weight of 100 seeds of maize with chemical fertilizer. The authors stated that due to the greater nutrient contribution fertilizer by producing healthy kernels or well filled kernels and bigger kernels. Additionally, the thousand grain weight values are primarily determined by the genetic structure of the maize variety. However, environmental conditions can also have an impact on this trait (Cokkızgın *et al.*, 2022).

4.5. Effects of Various Fertilizers on Growth Parameters and Yield of Swiss chard

4.5.1. Effect on plant vigor and uniformity

The application of different fertilizers had a significant effect on the vigorsity and uniformity of Swiss chard plants ($P \leq 0.05$) (Table 9). Table 9 indicates that Swiss chard plant vigorsity and uniformity were significantly affected ($P \leq 0.05$) by the application of BSFF compared to all treatments except CF, showing similar levels of vigor. Plants treated

with BS also exhibited higher vigor and uniformity, which were significantly different ($p \leq 0.05$) from the control.

The present study found that the application of organic or inorganic fertilizers resulted in improved vigor and uniformity in Swiss chard plants. This improvement is likely attributed to the provision of essential nutrients by the fertilizers, promoting healthier and stronger plant growth. This can be observed through the development of larger leaves, stronger stems, and an overall improved plant structure. Balanced nutrient levels also contribute to consistent growth rates and a more uniform crop stand. The current study's findings were supported by previous researches reported by Gärttling and Schulz, (2021) and Abiya *et al.* (2022) which reported that BSFF contains high organic matter, serving as a major reservoir of micronutrients. This suggests that BSFF provides a good range of essential macro, secondary, and micronutrients necessary for healthy and vigorous plant growth.

Table 9. Effects of different fertilizer on seedling vigorsity and uniformity for Swiss chard

Treatment	Vigorsity	Uniformity
C	2.16±0.11 ^c	1.6 ± 0.09 ^c
BSFF	4.66±0.11 ^a	4.7 6 ± 0.09 ^a
BS	4.1±0.11 ^b	3.26 ± 0.09 ^b
CF	4.36±0.11 ^{ab}	3.366 ± 0.09 ^b

Different letter in the column show significant differences among the means of the respective parameters ($P < 0.05$).

4.5.2. Plant height

The effects of different fertilizers on growth parameters of Swiss chard are presented in Table 10. As it can be observed from Table 10, Swiss chard plants grown on the soil treated with BSFF resulted in significantly ($p \leq 0.05$) larger mean plant height (72.85 cm) compared to the other treatments. Plants treated with CF and BS resulted in the mean plant height of 63.32 and 63.9 cm, respectively which were significantly ($p \leq 0.05$) larger than that of the control (58 cm). However, there were no significant differences in plant height with BS and CF. The results of present study was found that BSFF performed better than BS and CF regarding growth in height of Swiss chard. This may be attributed to improvement of the physicochemical properties of the soil due to the applications of the fertilizers (Table 5), particularly improvement in, SOM, SOC and TN as a result of ammendments of BSFF. The current findings is line with Abiya *et al.* (2022), who observed that the application of BSFF to Kale and Swiss chard led to taller plants

compared to chemical fertilizer and the control. Similarly Anyega *et al.* (2021) found increasing the height of tomatoes, kales, and French beans with BSFF and when combined with chemical fertilizer. This improvement can be attributed to the enhanced supply and availability of nutrients provided by the BSFF fertilizer.

Table 10. Effects of different fertilizer on growth parameters of Swiss chard

Treatment	PH (cm)	LL (cm)	LW (cm)	LN	LA (cm ²)
C	58±0.77 ^c	38.63±0.65 ^c	20.8±0.53 ^c	10.53±0.3 ^c	579.15±21.02 ^c
BSFF	72.85±0.77 ^a	50.73±0.65 ^a	32.37±0.53 ^a	17.3±0.33 ^a	1037.23±21.02 ^a
BS	63.32±0.77 ^b	41.52±0.65 ^b	24.21±0.53 ^b	12.8±0.3 ^b	692.64±21.02 ^b
CF	63.9±0.77 ^b	41.12±0.65 ^b	23.18±0.53 ^b	12.5±0.33 ^b	674.02±21.02 ^b

BSFF = Black soldier fly frass, BS= Bioslurry, CF=chemical fertilizer with, PH=Plant Height, LL= Leaf Length, LW= Leaf Width, LA= Leaf Area

Different letter in the column show significant differences among the means of the respective parameters (P<0.05).

The mean plant heights of Swiss chard for different treatments reached their maximum values on the 58th day after transplantation. Specifically, the heights were 72.85 cm, 63.9 cm, 63.32 cm, and 58 cm for the Swiss chard plants grown in soil treated with BSFF, CF, BS, and C, respectively (as shown in Table 10 and Figure 4). The growth patterns in height of the Swiss chard plants indicate that plants grown in soil treated with BSFF exhibited the largest plant height throughout the entire growing season, while the plants in the control group showed the lowest plant height over the same period (Figure 4). However, the growth in height of the plants treated with BS and CF were comparable to each other, particularly after the 44th day of transplantation during the growing period (as shown in Figure 4). The consistent benefits observed throughout the entire growing season of Swiss chard when using BSFF suggest that it can provide long term support for plant growth and development.

These results suggest that the application of fertilizers, the use of BSFF resulted in consistently higher growth rates of Swiss chard, indicating its potential as an effective fertilizer for promoting plant height growth. To meet crop needs throughout a growing season, water and soil fertility must be kept consistently adequate or high. White and Brown, (2010) the several nutrients those are required for plants and they are supplied to plants from soil and fertilizer sources. Islam *et al.* (2017) Organic fertilizers improve soil

fertility and provide nutrient necessary for the growth of crops. Table 3 and 5, also shows the nutrient content of BSFF and its effect on soil property after application of it.

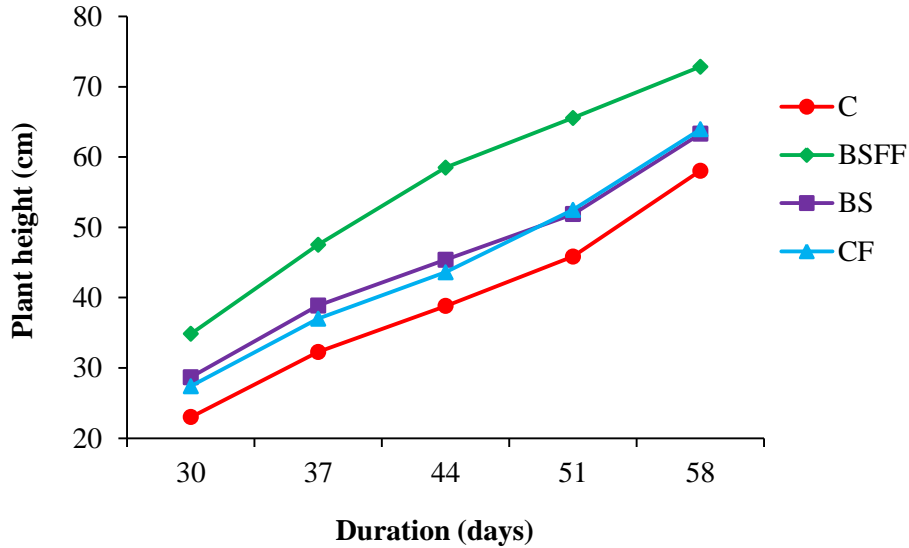


Figure 4. Pattern of growth in plant height for various treatments

4.5.3. Leaf length and leaf width

There were significant differences in the leaf length of Swiss chard grown using different fertilizer treatments ($p \leq 0.05$). The leaf length of Swiss chard plants treated with BSFF (50.73 cm) was significantly larger ($p \leq 0.05$) than that of the other treatments. The leaf lengths of Swiss chard treated with BS (41.52 cm) and CF (41.12 cm) did not significantly differ from each other, but both were significantly larger ($p \leq 0.05$) than the control (38.63 cm). Similarly, leaf width was significantly influenced by the application of different fertilizers ($p \leq 0.05$). The mean leaf length recorded for the treatments BSFF, BS, CF, and C were 32.37, 24.21, 23.18 and 20.8 cm, respectively (Table 10). The mean leaf width of Swiss chard from soil treated with BSFF was significantly ($P \leq 0.05$) wider than that of plots treated with other treatments. However the mean leaf width of Swiss chard treated with BS and CF were significantly similar with each other. The control treatment produced smaller (20.8 cm) leaf with and which significantly ($P \leq 0.05$) lower compared to those of other treatments.

The results of the current study indicate that the application of both organic and inorganic fertilizers improved the growth parameters, specifically leaf length and leaf width, of Swiss chard compared to the control treatments. According to Rather *et al.* (2018), the increase in

growth parameters can be attributed to the meristematic activity, which leads to the production of more tissues and organs. This is because nitrogen (N) plays a major role in protein and nucleic acid synthesis, as well as protoplasm formation.

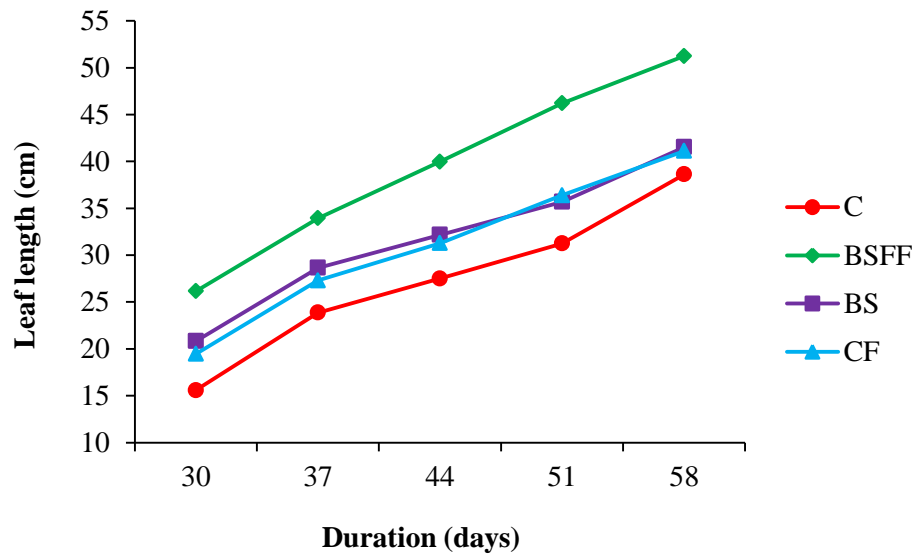


Figure 5. Pattern of growth in leaf length for various treatments

During growing period, it was observed that the LL and also LW of plant grown on the soil with BSFF were very longer and wider starting from the 30th day after transplantation up until the harvesting day (Figure 5 and 6).

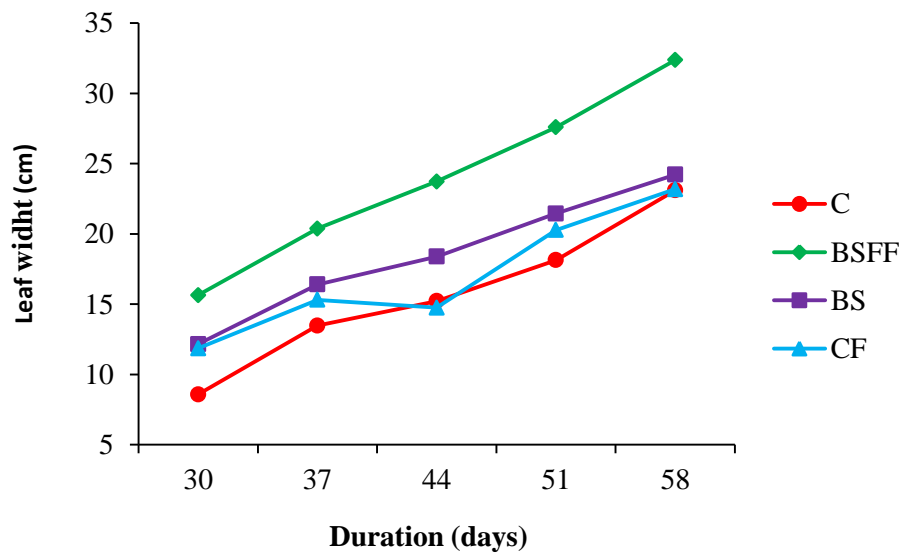


Figure 6. Pattern of growth in leaf width for various treatments

4.5.4. Leaf number

Swiss chard plant grown on the soil treated with BSFF produced significantly ($p \leq 0.05$) larger mean leaf number (17.37) per plant compared those of other treatments (Table 10). The number of leave produced by Swiss chard plans grown on soil treated with BS (12.8) and CF (12.5) were significantly larger compared to ($p \leq 0.05$) that of the control (10.53). The largest mean leaf numbers per plant (17.37) was obtained from plants grown on the soil treated with BSFF whereas the smallest mean leaf number per plant (10.53) was found from plants grown on the soil without fertilizer. Depend on this result the present study indicated that all fertilizer application was produce more number of Swiss chard to compare control treatments. Moreover, the mean leaf number of the Swiss chard plant grown on soil treated with BSFF was the largest throughout the growing period compared to that of BS, CF and the control (Figure 7).

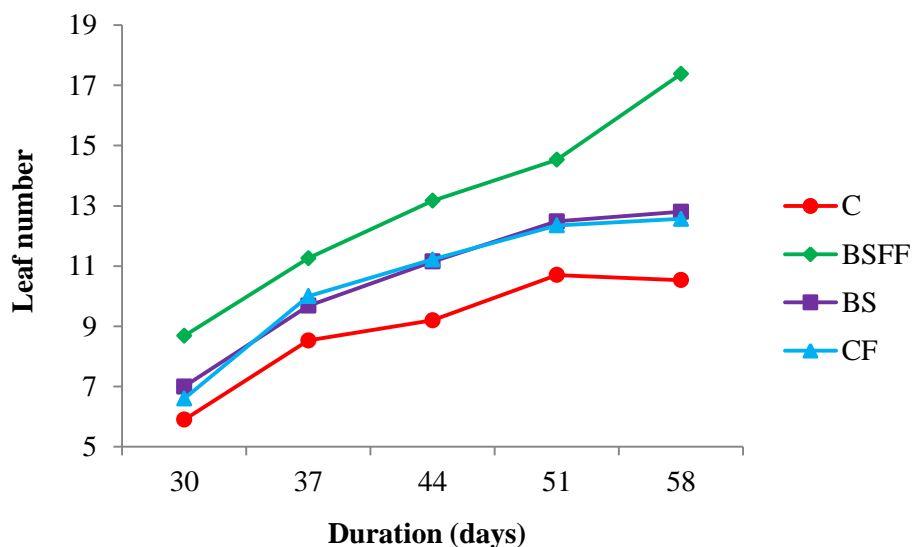


Figure 7. Pattern of growth in leaf Number for various treatments

4.5.5. Leaf area

The size of the leaf area directly affects the amount of light that can be harvested for photosynthesis, thus influencing plant growth and productivity. The application of different fertilizers in the present study significantly affected the leaf area of Swiss chard plants (≤ 0.05) (Table 10). The mean leaf area measurements obtained for Swiss chard with different treatments resulted 1037.22, 692.63 and 674.02 cm^2 for BSFF, BS and CF, respectively while 579.14 cm^2 for the control (Table 10). These values indicate that the mean leaf area of Swiss chard with BSFF was significantly higher than that of BS and CF.

The mean value of leaf area treated with BS also showed a relatively higher value but was not significantly higher than the plot treated with CF. The leaf area from the control (579.14 cm²) was significantly (≤ 0.05) lower compared to all other fertilizer treatments.

The present study found that application of BSFF as a treatment may have positively influenced the leaf area of Swiss chard, resulting in larger leaf surfaces. This may be due to BSFF enhanced nutrient availability provided by the frass could have supported increased photosynthetic activity, leading to more robust growth and development of the plants. Optimal nitrogen levels have been shown to enhance photosynthetic processes and increase leaf area production (Rafiq *et al.*, 2010). Similarly, the use of bio-slurry has been found to increase leaf area, as reported by Haile and Ayalew (2018), who observed higher leaf area in kale plants treated with bio-slurry compared to the control group. This suggests that the increased leaf size induced by bio-slurry application is an adaptive response to maximize light interception and overall plant performance. Furthermore, from the data collected at predetermined time intervals, it was found that the mean leaf area of the plants grown on the soil treated with BSFF was the largest, while that of the plants grown on the soil treated with the control was the smallest throughout the measurement period (Figure 8).

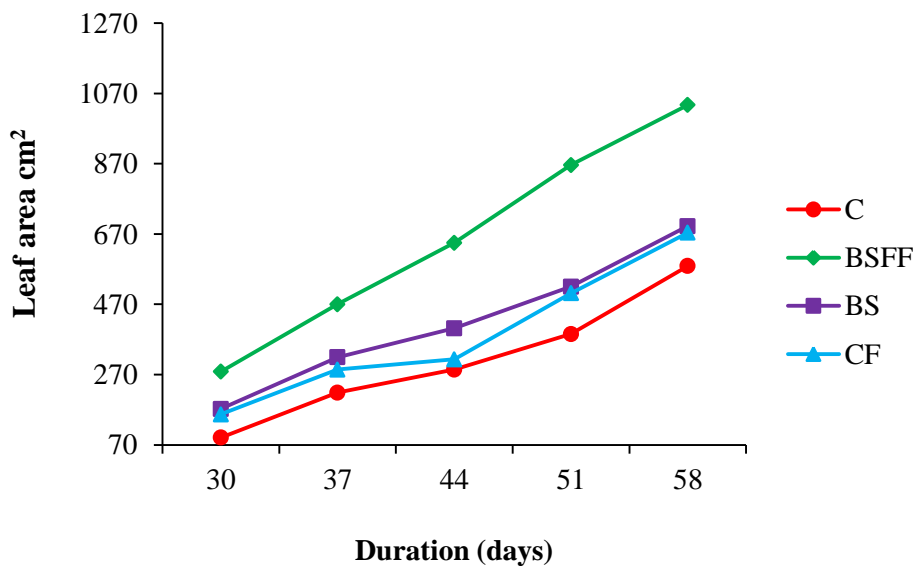


Figure 8. Pattern of growth in leaf area.

4.5.6. Effects on relative growth rate in height

The relative growth rates of Swiss chard plant under different fertilizer application are shown in figure 9. As it can be observed from Figure 9, the mean relative growth rates in

height for Swiss chard plants treated with BSFF were consistently higher compared to the other treatments throughout the four week period. It is worth noting that there was a slight decrease in growth rate observed during the fourth week compared to the third week, indicating a minimal change. Swiss chard plants treated with BS showed some variability over the four week period but then exhibited an increase in growth rates during the third and fourth weeks. The growth rates with CF indicated a higher increment in the first and fourth weeks. The BS and CF treatments also demonstrated some growth enhancement compared to the control group, although with more variability. However, the growth rates in the control group were consistently lower than those observed in the fertilizer-treated groups.

Furthermore, the relative growth rates in height of the plants of BSFF treatments were increasing throughout the measurement period. This demonstrated that the plants were growing faster in height during the measurement period. The minimal change during later week was it may be due to various factors such as reaching a growth plateau or saturation point. Overall, the decrease in relative growth rate at the end of the growth period indicates a decline in the plant's growth rate, which can have consequences for its size, biomass accumulation, reproductive output, and eventual senescence (Shajari *et al.*, 2020). This decline in RGR is simultaneous with an increase in respiration. It is attributed to the fact that the parts added to the plant are structural tissue, lacking active metabolic tissue, and therefore do not contribute to growth, causing a decrease in RGR (Zhang *et al.*, 2019; Price *et al.*, 2020).

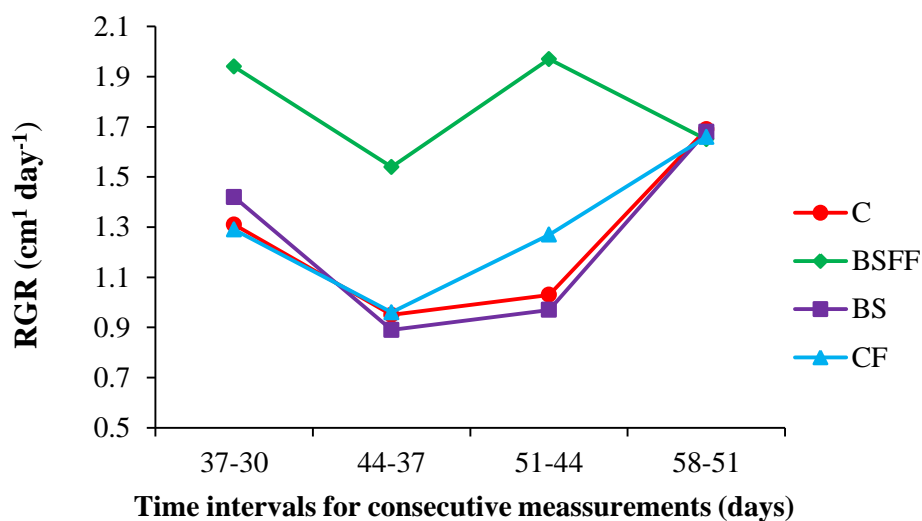


Figure 9. The relative growth rate in height of Swiss chard plants treated with different fertilizers.

4.5.7. Effects on leaf fresh weight

Figure 10 shows the mean leaf fresh weight (marketable yield) of Swiss chard with the application of different fertilizers. As it can be seen from figure 10, the mean marketable yields obtained from the plots treated with BSFF, BS, and CF were 125, 100.5 and 99.4 t ha⁻¹, respectively while it was 74.4 t ha⁻¹ for the control. The results showed that the mean marketable yield of Swiss chard was significantly ($p \leq 0.05$) affected by the application of all fertilizers. Based on these results, significantly larger significantly ($p \leq 0.05$) mean marketable yield (125 t ha⁻¹) was obtained from the soil treated with BSFF compared to the soil treated with other fertilizers and the control. Moreover, the smallest marketable yield (74.4 t ha⁻¹) was obtained from the control. The yields obtained from the plants grown on the plots treated with BS and CF did not significantly differ. In the present study, the application of different fertilizers increased the leaf fresh weight of Swiss chard by 33.6-68 % compared to the control. Moreover, the application of BSFF resulted in 25.75% and 24.37% increase in the marketable yield compared to the application of CF and BS, respectively.

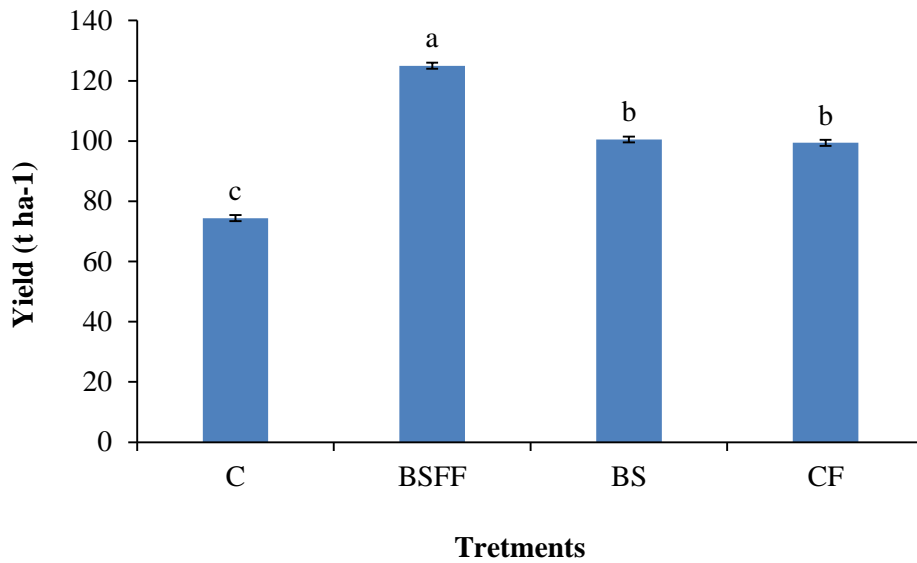


Figure 10. Effects of different treatments on the marketable yield of Swiss chard.

Bars show means \pm SE and different letters indicate significant ($p < 0.05$) differences among the mean marketable.

The results from the current study suggested that BSFF can be used as an organic fertilizer to improve the growth and leaf fresh weight (marketable yield) of Swiss chard. The result of the present study is in agreement with the findings reported by Terfa *et al.* (2021) where the application of BSFF to vegetables resulted in significantly higher yield compared to those treated with commercial inorganic fertilizers and the control. Similarly, Chirere *et al.* (2021) reported that the application of BSFF significantly ($p \leq 0.05$) increased the yield of Swiss chard compared to unfertilized control. These authors suggested that using BSFF as organic fertilizer in crop cultivation could be a way of efficiently returning plant nutrients in different organic wastes to the human food chain through the crops and vegetable we consume. Furthermore, as it is presented in Table 5, application of BSFF improved different soil physico-chemical properties after Swiss chard cultivation.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

As the soil of the experimental site was low in organic matter, soil organic carbon, total nitrogen, it required organic fertilizer amendment for sustaining crop production. The application all fertilize had improved soil soil bulk density, porosity, soil organic carbon, total nitrogen, available phosphorus and cation exchange capacity of the soil. The SOM, SOC, TN and available phosphorus were more increased in soil treated with BSFF and BS compared to the control. Furthermore, application of BSFF to the soil increased the availability of important exchangeable cations such as calcium (Ca^{2+}) and potassium (K^+). Maize and Swiss chard plants grown in soil treated with BSFF exhibited significantly improved growth performance and yields. This can be attributed to the nutrient-rich content of BSFF when used as a fertilizer, which greatly benefited soil fertility and enhanced crop production by enabling essential nutrients more readily available to plants. Generally, the from the results of the study, it can be concluded that BSFF suggested to be an effective organic fertilizer for maize and Swiss chard production and for the soil health.

5.2. Recommendation

Based on the results obtained from the present study, the following recommendations were forwarded.

As the experiment was done only for one season and at one study site, similar experiments should be carried out for several seasons and different locations to make a more conclusive recommendation.

- 1) As only one type of fertilizer rate was used for each fertilizer in the present study, conducting further research to determine different rates of black soldier fly frass, bioslurry and chemical fertilizer using different crops and soil types in Ethiopia is needed.
- 2) Mixtures of different fertilizers were not used in the current experiment although such treatments might result in better crop growth and yield. Therefore, experiments that employed the mixtures of black soldier fly frass, bioslurry and chemical fertilizer should be carried out.

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ANNEX



Annex 1. Measuring of organic fertilizer



Annex 2. Prepared plot area (left) and maize seed sowing (right)



Annex 3. Agricultural practice and pesticide



Annex 4. Picture of the experimental field during vegetative growth of maize plant



Annex 5. Seedling on seed bed (left) and transplanting (right)





Annex 6. Picture of the experimental field during vegetative growth



Annex 7: Picture during data collection of growth parameters and fresh weight yield



Annex 8: Picture during harvesting of Swiss chard