Role of Black Soldier Fly (*Hermetia illucens*) Larvae Frass Bio-fertilizer on Vegetable Growth and Sustainable Farming in Sub-Saharan Africa

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ABSTRACT

Food insecurity throughout Sub-Saharan African countries is a common problem and needs a sustainable solution to improve crop yield production, rather than agricultural area expansion. Vegetables are important in sustaining the livelihood of many small-scale and subsistence farmers throughout Sub-Saharan African and contain vitamins, minerals, and essential amino acids, none has cholesterol and most are low in fat and calories. Vegetables also high in fiber, which helps keep the digestive system healthy. Vegetable production in Sub-Saharan Africa faces numerous agronomic constraints that will have to be overcome to feed the increasing population and to fight malnutrition. Major areas on the continent consequently experience nutrient limitation as a major yield gap component, especially in densely populated areas. Now a day one possible solution may come from insect farming, a growing industry with broad potential. Black soldier fly (*Hermetia illucens*) (L) feces (frass) may have great potential as a valuable organic bio-fertilizer by positively affecting soil fertility and ultimately vegetable yields. However, the understanding of this positive effect of frass is still limited in our community and very few researchers are trying to determine the effects of this bio-fertilizer on vegetable growth and soil fertility amendment and to explore the utilization of this waste product as a novel organic bio-fertilizer. As nitrogen and phosphorus uptake observed in plots treated with black soldier fly frass fertilizer compared to plots treated with the commercial organic and mineral fertilizers could be attributed to better supply and availability of nutrients from the newly introduced frass fertilizer. Clearly black soldier fly frass fertilizer performed better than commercial and inorganic fertilizer. Therefore, further study and awareness creation should be conducted to promote the feasibility of black soldier fly frass bio-fertilizer application in vegetable production and its role in soil fertility amendment.

Keywords

bio-fertilizer, black soldier fly, food security, frass, sustainable, vegetable

1. Introduction

High levels of hunger and food insecurity dominate most regions of African, and the situation continues to worsen due to increase soil degradation [1]. Food insecurity throughout Sub-Saharan African (SSA) countries is a common and sustainable solution that is required to improve crop yields and thus the livelihoods of peoples. Improving food security in SSA requires strategies that can match the future food demands with increasing population growth while conserving soil resources [2]. Currently, one possible solution may come from insect farming, a growing industry with broad potential, which produces insect frass as a side product after the insect larvae are harvested [3]. Black soldier fly (*Hermetia illucens* L) is seen as “Haber-Bosch ammonia factory” which converts organic matters from a complex form into minerals, water, and beneficial microorganisms such as nitrogen fixer or phosphate and potash solubilizer [4]. In worldwide, insect farming industry is a growing industry and can aid the
processing of organic waste streams by converting it into high-protein larvae that can be utilized as a sustainable food source for animals and humans [5]. Insect farming also generates considerably fewer greenhouse gases, which may become increasingly relevant in the future [6]. Since it can be fed on a great variety of insect substrates, ranging from human and animal manure to green and food waste, *Hermetia illucens*, also called black soldier fly (BSF), may show great potential for insect farming industry [4, 7]. The idea of using fly larvae for the processing of organic waste was proposed almost 100 years ago. Since then, numerous laboratory studies have shown that several fly species are well suited for bio-degradation of organic waste, with the house fly (Musca domestica L.) and the black soldier fly being the most extensively studied insects for this purpose [8]. The use of black soldier fly in organic waste composting is a novel and environment friendly approach that holds enormous potential and therefore, is strongly captivating people’s attention worldwide [9].

Above all, after the larvae are harvested, considerable amounts of larvae excrements are left behind, which is generally referred to as either insect frass. Frass deposition to soil is an important pathway by which herbivorous insects impact decomposition and soil nutrient availability. Frass also contains nitrifying bacteria and nitrogen-fixing bacteria, which partake in the nitrogen cycle and assist in the plant’s uptake of nitrogen [10]. Black soldier fly frass can store carbon and nitrogen in the soil and also prevents atmospheric loss of nitrogen and groundwater in the soil [11]. 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. In frass, bacteria like bacillus and pseudomonas help fix atmospheric bacteria while other nitrifying bacteria make nitrogen within the soil accessible to plants for photosynthesis [3].

However, a little is known about how frass quality influences the ecosystem and it is often assumed that frass may find utilization as a bio-fertilizer [7, 8, 12]. There is only a limited understanding of how this bio-fertilizer might impact on plant growth and soil fertility and most importantly whether these effects will be positive. The frass quality is significantly affected by the type and nutrient composition of substrates [13, 14, 15], since many other potential insect substrates, such as green and food waste may contain considerably fewer nutrients [16], that is why conclusions about the effect of frass on plant growth may not be possible.

Although, farming of black soldier fly larvae shows broad potential throughout the world, no more detail of experiments was so far conducted in utilizing frass black soldier fly larvae as a bio-fertilizer [17]. The use of insect black soldier fly frass as organic fertilizer is a relatively a new concept. Adoption of a new concept or product as fertilizer in any farming system requires information on its performance in terms of how it influences crop growth, yield, nutrient uptake, and use efficiency in comparison to existing fertilizers [2]. Many small-scale and subsistence farmers are struggling to afford a synthetic fertilizer application, whereas green waste may be abundant and at little or no cost. Moreover, 98% of all farms worldwide are managed on small-scale, thus playing 70% of the global food supply [18].

Even though composting can transform organic wastes into bio-products which can be used as bio-fertilizers, very few researchers are trying to explore the utilization of this waste product as a novel organic bio-fertilizer and in order to determine the effects of this bio-fertilizer on vegetable growth such as onions and soil fertility [3]. Therefore, since vegetables are important in sustaining the livelihood of many small-scale and subsistence farmers throughout SSA and they are grown for home consumption in the backyard of almost every homestead across Sub-Saharan Africa. They are an important source of vitamins, minerals, and fibers etc. and an important cash crop for both smallholders, medium-scale commercial farmers. Advances in this field of research may find immediate application, thus ultimately contribute to the food security as well as waste management [19].
This study aims to review the effect of black soldier fly frass on vegetable growth and soil fertility amendment in sustainable farming.

2. Why intensification farming system is important for sustainable farming

The total human population of SSA countries is more than 1.1 billion currently [20]. A majority of SSA population lives in rural areas and agriculture is a backbone, since almost all rural households depend directly or indirectly on agriculture and give the sector’s large contribution to the overall economy [21], but the growth is precarious. In most countries, it has yet to reach the sustained 6% annual rate estimated by New Partnership for Africa’s Development (NEPAD) as necessary to meet the Millennium Development Goal of reducing/cutting poverty and the growth needs to be accelerated, secured and used more effectively to promote broadly shared development [22]. So, the important role of the agriculture sector in contributing to food security is reflected in its prioritization in the development agenda.

One of the greatest challenges of the twenty-one century is meeting an ever-increasing food demanding while reducing agriculture’s negative environmental impact [23, 24]. Society transition and industrial transformation are developing to ensure sustainable food production in the next four decades [25, 26]. Intensification of African smallholder agriculture is desirable for several reasons and the sustainable intensification concept covers the important dimensions of how such intensified agriculture could be sustained [27].

In Sub-Saharan Africa, as increasing urbanizing population growth has failed to match equivalent increments in yields of the major crops, with increased production resulting rather from agricultural area expansion [28], very often at the expense of the natural resource base, such as carbon-rich and bio-diversity forest land [29]. Major areas on the continent consequently experience nutrient limitation as a major yield gap component, especially in densely populated areas, where soil fertility regeneration through fallow periods is no longer feasible. Nutrients moved via crops to urban centers are hardly ever recycled and commonly end up in streams, lakes, or the ocean [30]. Increasing agricultural production in SSA is likely going to be the result of intensification and area expansion [31]. Intensification of agricultural production is a must in the more densely populated areas in order to feed the rapidly growing and urbanizing population. Production of vegetables and legumes helps intensify cropping systems by utilizing underexploited production niches, serving as rotation, inter, and double crops with cereals. Vegetables can be grown in small spaces such as a backyard or home gardens [32].

3. Vegetable production in Sub-Saharan Africa

Vegetables are among the most important and widely cultivated food and income-generating crops in many parts of Africa. Vegetables in Africa are either exotic or indigenous (native to a particular African country) [33, 34]. In the African context, indigenous plants are considered native to Africa, while indigenized species originated in other continents like Asia, south and Central America, but have been integrated with traditional Africa food culture and agriculture [35]. Vegetables are cultivated using seeds, rhizomes, corms, stem cutting, and bulbs depending on the types [36]. Vegetables are plants grown for their leaves, succulent stems, young shoot, fruits and a combination of these plant parts. Vegetables contain vitamins, minerals, and essential amino acids, none has cholesterol and most are low in fat and calories and also high in fiber, which help keep the digestive system healthy. They are cultivated extensively by small scale farmers and a few large-scale enterprise [21, 34]. Vegetable production in Sub-Saharan Africa faces numerous agronomic constraints that will have to be overcome to feed the increasing population and to fight malnutrition.
Technology transfer and the adoption of low-tech protected cultivation techniques affordable for smallholders are believed to be able to meet this challenge [37].

Although world vegetable production underwent a remarkable increasing from year to year, large yield gaps still exist worldwide and many countries still do not produce enough vegetables to satisfy the micro-nutrient needs of their population, especially in developing countries, particularly in SSA [38]. The main vegetables products in SSA countries were tomatoes, onion, watermelons, cabbages and other brassica and their area coverage and annual productions may be varying from year to year (see Table 1). During 2019 cropping season, 136,5684 ha, 1,072,912 ha, 209,379 ha, and 174,897 ha of land covered by tomatoes, onion, cabbage, and watermelons respectively and with the annually production of 10,567,866 tons, 8,818,040 tons, 2,768,334 tons and 2,373,908 tons, respectively (Table 1). While in Ethiopia, 42,499 ha, 39,658 ha, 6,012 ha of land was covered by cabbage, onion, and tomatoes with 435,863 tons, 317,456 tons and 34,947 tons production, respectively [39]. This indicates that as these vegetables are highly demandable throughout the SSA countries. The consumption of tomato, cabbage and onion has high income elasticity of demand [21]. Vegetable production faces several problems such as drought, floods and low soil fertility. As a result, vegetable product depends to a great extent on climatic condition leading to make seasonal variation in supply [37].

Table 1: Annual production of major vegetables in SSA Counties from 2017–2019

| Vegetable name | 2017 cropping season | 2018 cropping season | 2019 cropping season |
|---------------|-----------------------|-----------------------|-----------------------|
|               | Total area covered (ha) | Total production (ton) | Total area covered (ha) | Total production (ton) | Total area covered (ha) | Total production (ton) |
| Cabbage       | 228,706                | 2,623,275             | 250,798                | 2,666,701             | 209,379                | 2,768,334             |
| Onion         | 1,169,226              | 13,722,163            | 1,040,182              | 8,573,049             | 1,072,912              | 8,818,040             |
| Tomato        | 1,166,663              | 9,260,317             | 1,252,323              | 10,036,492            | 1,365,684              | 10,567,866            |
| Watermelon    | 105,722                | 1,186,408             | 167,519                | 2,149,485             | 174,897                | 2,373,908             |

Source: FAO Stat accessed 2021

4. The importance of insect farming industry

Sufficient food production for a growing human population has become an issue of global concern. Almost all of the world’s fertile land is currently in used and arable land areas cannot be expanded significantly. The global challenge is to secure high and quality yields and to make agricultural production environmentally compatible. Insect farming already forms a part of routine activities of many communities in SSA [40], but the industry is rapidly growing in the world and only few Sub-Saharan countries such as South Africa, Uganda, Kenya, Ghana and Tanzania especially on black soldier fly frass. They started to use black soldier fly larvae for pig and poultry feeding and black soldier fly frass as soil fertility amendment.

Insects have been huge successful in terms of both species’ richness and abundance [41]. The management of organic waste streams, such as food or green waste but also waste (feces) is considered global challenges [17]. The farming of insects may play a significant role in tackling these challenges through the utilization of organic waste streams as a substrate for insects [5]. Insect farming can be achieved without neither sophisticated technology nor high capital investments, making it not only a viable option for many subsistence farmers throughout the world but furthermore a potentially sustainable financial income source [17]. Insect rearing is expected to dramatically increase during the next few years, and this will be associated with generating high quantities of frass (insect excreta). Among the essential insect is the black soldier fly (Hermetia illucens). The insect has a 45-day life cycle that is divided into
four stages and the black soldier fly goes through full metamorphosis during its life span [42]. This includes the egg, larval, pupae and adult life cycle stages and all the stages have its own time duration (See Fig. 1). Even if no much is known about the natural predators of the black soldier fly, animals that generally, eat flies includes frogs, mammals, birds, lizards, predatory insects and arachnids. The presence of a parasitoid wasp, Dirhinus giffardii has been recorded to reduce cultured black soldier fly larval population by 72% in West Africa, where the parasitoid is endemic [43]. Therefore, the introduction of precautionary measures is highly important for the success of black soldier fly larvae production [44].

Even when insects can be fed with waste streams and are highly efficient in converting feed into biomass, insect production itself also yields stream, consisting of molting skins, that consist for a large part of chitin, as well as insect feces (frass) [45]. Although insect frass emits greenhouse gases, the rate of greenhouse gas emission per unit weight is much lower than for vertebrate manure, many insects commonly utilized in insect farming have been shown to produce no NH₃ as well as significantly less nitrate (NO₃) and CO₂ than conventional livestock farming, Therefore, insect farming is considered as a more environmentally friendly for organic fertilizer production from the perspective of greenhouse gas and NH₃ emission [46].

Figure 1: Life cycle of black soldier fly (Hermetia illucens)

Many insect species are available for utilization in insect farming; the types of species may ultimately determine the possible materials that can be used as insect substrates as well as the efficiency of biomass conversion rates from this insect substrate into feed. With the emergence of an insect industry aiming at producing novel feed ingredients
by recycling organic materials fly species, particularly the common house fly (Musca domestica) and black soldier fly have attracted attention thanks to their numerous attribute [47]. Even though black soldier fly has received relatively little attention, as opposed to other insects utilized in insect farming such as Musca domestica [8, 16, 48]. Research has not only shown that black soldier fly larvae feed on a great variety of substrate, such as food and green waste as well as human feces and manure [8], but it furthermore has the potential to process large amounts of odorless organic waste at once [49]. Black soldier fly is not considered to be a disease vector unlike M. domestica [6] and less to transmit feces-borne diseases to humans, because adult flies entirely depend on fact stored in their body and thus not seek humans for prey [50]. In natural conditions, it is well known that frass deposition to soil has a great impact on soil fertility due to its high nutrient and labile carbon (C) content [13].

5. Uses of black soldier fly frass bio-fertilizer in vegetable crop production and soil amendment

The frass, which is a byproduct from black soldier fly rearing, contains substantial amounts of nutrients [51, 52] that could be useful in crop production especially for vegetable production if converted into organic fertilizer and the black soldier fly frass accumulation has a great potential to complement or to replace commercial fertilizer [53]. Chemical characterization of frass revealed that it had a concentration of N, K, and P as high as those found in farmyard manure and, especially, poultry manure [54], which confirms its high fertilizer potential by containing both macro and micro soil nutrients (Table 2). By contrast to conventional mineral fertilizer, frass also contained small concentrations of micronutrients (i.e., Cu and Zn), which may be further beneficial for crops [44]. The frass fertilizer generated would also increase income from insect farming through the sale of organic fertilizer as a second product from black soldier fly rearing or save the farmer from incurring fertilizer purchase costs.

The frass application has positively impacted plant growth [55]. Focusing on frass quality in detail, concluded that frass nutrient levels should be high enough for a fertilizing effect, but there is still a lack of understanding of how frass practically affects soil fertility and plant growth [48]. Although, the soil pH of the frass treatment was not as low as that of the NPK treatment, the addition of frass significantly decreased soil pH, most likely due to the slightly acidic nature of frass [44] as well as to its rapid decomposition which led to the production of CO₂ and organic acids. Even though all the fertilizer treatments added the same total amounts of P and K, however available K and P concentrations were greater in the frass treatment [56], and compared to mineral fertilizer, water soluble P concentration is five times lower in the presence of frass, which prevents P from loss and sorption onto soil constituents [44]. The physiochemical properties of frass may be varied because of the different larval diet (Table 2).

| References | Organic C gkg⁻¹ | TotalN gkg⁻¹ | TotalK gkg⁻¹ | TotalP gkg⁻¹ | TotalCu mgkg⁻¹ | TotalZn mgkg⁻¹ | Total Mg gkg⁻¹ | pH | EC ds⁻¹ |
|------------|-----------------|--------------|--------------|-------------|---------------|---------------|----------------|----|--------|
| [44]       | 393             | 50           | 17           | 20          | 10            | 94.2          | 5.8            | 5.3|        |
| [2]        | 352             | 21           | 1.7          | 11.6        | 1.6           | 7.7           | 2.7            |    |        |
| [57]       | 365             | 18.23        | 18.16        | 17.65       |               | 8.26          | 3.49           |    |        |
| [53]       | 470             | 22.87        |              |             |               | 5.7           | 3.69           |    |        |

Compared with commercial fertilizers, nitrogen recovery rates and nitrogen use efficiency of plants be improved when amended with black soldier fly frass [2] and the higher P concentrations in the frass could facilitate N accumulation in plants by improving N uptake, as P plays an important role in energy transfer [58]. Applying frass also introduces organic material, not included in chemical fertilizer and if frass research continues to find that the
soil micro-biome becomes more diverse when frass is applied, its application would result in the additional benefits that soil biodiversity increases in our agricultural ecosystems [59].

The optimum application rates and comparative performance of black soldier fly frass fertilizer about existing organic fertilizers are not documented. Also, identifying the equivalence of using black soldier fly frass fertilizer with mineral fertilizer is important to achieve the same crop yield [2]. In frass, bacteria like Bacillus and Pseudomonas help fix atmospheric bacteria while other nitrifying bacteria make nitrogen within the soil accessible to plants for photosynthesis. Nitrifying bacteria exist in the soil amended soil by frass convert nitrogen in its ammoniacal form to nitrate form, which allows for more efficient root uptake by plants [60, 61]. This increases the assimilation of nitrate to plant roots and avoid soil nitrogen deficiency or impairing soil gas permeability and they tap nitrogen from the atmosphere. They convert into urea and other chemical elements which are used to fertilize agriculture (Fig. 2), which makes the soils more resilient to land degradation process. The nitrifying and nitrogen-fixing bacteria are critical to horticultural production because fixed nitrogen is a limiting nutrient in most environments [3].

Therefore, phosphorus (P) and nitrogen (N) are a key element for vegetables as it stimulates the root formation and the center of the components of nucleic acid [62], what is why almost all vegetables are demanding a large amount of P and N elements. The increased plant height, chlorophyll concentration, and nitrogen and phosphorus uptake observed in plots treated with black soldier fly frass fertilizer compared to plots treated with the commercial organic and mineral fertilizers could be attributed to better supply and availability of nutrients from the newly introduced frass fertilize and it is clear black soldier fly frass fertilizer performed better than commercial and inorganic fertilizer [2, 62].

![Figure 2: Impact of nitrifying and nitrogen fixing bacteria in frass on the nitrogen cycle](Source: [61])

Black soldier fly frass derived from brewery spent grains or processed food wastes were found more effective when used as soil bio-fertilizers with minimum application rate of 10.0 tonnes/ha or 5.0 tonnes/ha respectively [47].
Therefore, Black Soldier Fly frass compost is perfect for boasting the growth of leafy plants and vegetables, rejuvenating soil, and ensuring continual plant growth. Rearing of black soldier fly on amended waste substrates and organic fertilizer production from black soldier fly frass remains a promising technology, has a great value in Low-income countries of Sub-Saharan Africa [63].

6. Conclusion

Improving food security in SSA requires strategies that can match future food demands with increasing population growth while conserving the soil resources. Vegetables are among the most important and widely cultivated food and income-generating crops in many parts of Africa. But vegetable production in SSA faces numerous agronomic constraints that will have to be overcome to feed the increasing population and to fight malnutrition, one of the greatest challenges is a limitation of soil fertility in the country. Almost all vegetables demand a large number of macro-nutrients during their growth period from the soil. In addition to the macro soil element, the vegetable also needs micro-elements which can be affordable in frass bio-fertilizer application and which may not be gained from chemical fertilizer. The farming of insects such as black soldier fly larvae frass fertilizer may play a significant role in tackling these challenges through improving soil fertility by using bio-fertilizer. Generally, frass may serve as a valuable fertilizer and does not impair the hygienic properties of soil.

Even though frass, which is a byproduct from the black soldier fly is used as a vegetable crop production improvement and soil fertility amendment, but still no optimum application rates and comparative performance of black soldier fly frass fertilizer with existing organic fertilizers is well documented. In addition to this, there is still a lack of understanding of how frass practically affects soil fertility and plant growth and no more research was conducted on the importance of this frass fertilizer in vegetable production yet. Therefore, to eliminate these problems further study and awareness creation have to be conducted on the importance of frass bio-fertilizer.

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