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Black Soldier Fly Frass for Improved Soils, Crop Yields and Environment among Smallholders-Mixed Farming System in Kenya

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ABSTRACT

The production and yields of major crops are in decline in sub-Saharan Africa (SSA) due to deterioration in soil nutrients and increasing prices of farm inputs. Farmers have used manure and artificial fertilizers to improve the production of crops. Some of these fertilizers have caused adverse effects on our environment resulting in climate change. The use of frass, although minimally used by farmers, has proved to be effective in reducing greenhouse gas emissions, providing nutrient-rich feeds to livestock and organic fertilizers to crops. This article highlights the importance of keeping black soldiers fly and adopting frass to eradicate problems smallholder farmers face in soil, crop, and environmental management. The fly's larvae feed and break organic wastes including wastes from poultry and cattle, making them free from foul odor and emission of massive carbon dioxide and methane. The larvae can also be used as livestock feeds whereas the unused organic material becomes fertilizer rich in high levels of nitrogen, phosphorus, and potassium compared to other organic and inorganic fertilizers used in SSA. For improved production, farmers need to switch to this multipurpose insect. A simulation analysis is necessary to show the future adoption of the technology. With increased awareness and training, more than a million farmers in SSA are likely to adopt this practice in less than ten years.

Keywords: Crops, Soil nutrition, Organic waste, Carbon dioxide, Climate change, Environmental management

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1.0. INTRODUCTION

The interaction between human beings, crops, and livestock has been in existence for a longer period, as their existence is mutually related. Human beings depend entirely on livestock and plants for their nutrition (Soetan et al. 2010; Day, 2013). In case the crops and animals are produced in a proper manner, they are likely to address food insecurity and malnutrition among small-scale farmers (Sekaran et al. 2021). Food insecurity and malnutrition has been caused by poverty, infertile soils, lack of or expensive farm inputs and natural calamities like drought (Tadesse et al. 2008; Nzabuheraheza and Nyiramugwera, 2017; Fagariba et al. 2018; Umesha et al. 2018; Gautam and Kumar, 2019). These four main causes may be outweighed by the adoption of a new fertilization method.

The use of black soldier fly (BSF) frass insect fertilizers has not gained track in most developed nations due to inadequate information or lack of political will to champion the technology (Anyega et al. 2021). In Kenya, this soil amendment method has been spearheaded by ICIPE but still few farmers have adopted it (Okello, 2022). Those adopted have put more emphasis on their use as a source of proteins for livestock and less on soil fertility amendments (Shumo et al. 2019; Anyega et al. 2021; Alagappan et al, 2022; Beesigamukama et al., 2022). Due to high costs of inputs and environmental damage caused by the use of artificial fertilizers, the use of insect frass can help cushion farmers' expenses and safeguard our ecosystem (Kim et al. 2021). Fertiliser is in organic form and has the ability to transform unfertile or degraded land through fertility enrichment (Beesigamukama et al. 2021; Beesigamukama et al. 2022). This can boast the socio-economic wellbeing of small-scale farmers since they will spend less money on inputs (fertilizers and chemicals) acquisition due to organic matter improvement and nutrients being held in the soil for over a longer period of time (Terfa, 2021; Kragt et al. 2023).

In Kenya, the agriculture sector has registered poor output for more than five years, in comparison with its population, and yet it is the backbone of our nation having dominated the Kenyan economy (Maiyo, 2015; Hijbeek et al. 2021). The boost comes majorly on cash crops meant for exports like tea, fruits and coffee while cereals and vegetables for subsistence have been baited down (Mohajan, 2014). The sector directly contributes 26% of the Gross Domestic Product (GDP) and indirectly 27% of GDP through linkages to other divisions (Orindi and Ochieng, 2005; Meiguranet al. 2016). About 40 % of the entire Kenyan population are directly or indirectly employed in the sector, with about 70% of them coming from rural areas (Emongor, 2014). One of the factors that has affected agricultural food production has been associated with unfertile soils (Chikowo et al. 2014; Zingore et al. 2015; Fischer et al. 2020; Asiloglu et al. 2021). Thus, to maintain consistent yield and supply of food products to the daily increasing population, the issue of soil infertility has to be dwelt with, once and for all. Soil infertility has been attributed to changes in soil chemical, physical and biological properties. The changes in soil properties are mainly as a result of use of inorganic fertilizers, use of chemicals for weed, pest and disease control and poor agronomic practices (Page, 2020). Most small-scale farmers are fighting with soil acidity which has led to unavailability or adsorption of nutrients (Kiplagat, 2014; Abate et al. 2017; Laekemariam and Kibret, 2021). The fight can be won through zero use of inorganic fertilizers and other artificial chemicals on the farm (Zingore et al. 2015). Given that most Kenyan soils have been exploited to an extent that crops cannot do well without fertilization, it calls for other alternative measures. The use of organic materials like crop residues, plant and animal waste materials have not achieved the desired outcome since these materials have become few due to many competing uses attached to them, with preferences directed to other uses rather than soil amendments (Michael, 2021; Shaji et al. 2021).

The use of insect frass fertilizer is likely to bring many improvements to farming since the growth of the insect larvae has proved to be much cheaper and can be carried out by anyone regardless of education, income and weather conditions (Poveda, 2021; Terfa, 2021; Beesigamukama, 2022, Subramanian & Tanga, 2022). In that case, this paper review has been developed to provide a lot of insight on the effects of insect frass fertilizer on farmers and encourage their adoption across the country.

2.0 BODY

2.1.0 BSF Frass

The BSF, scientifically known as Hermetia illucens, is among the common flies in the family Stratiomyidae (Moretta et al. 2020; Gujarathi & Pejaver, 2013). The fly is spread widely across the globe with adults found in an array of locations near larval habitats (Zhang, 2020). There are over 2,700 species of soldier fly insects and mostly inhabit wetlands, decaying organic matter, damp soils, animal wastes and under tree barks (Gahukar, 2016; Shumo, 2019). The species are native to the tropical terrestrial ecoregion of Americas (Triplehorn, 2005). In the last few decades, the fly has spread throughout all the continents become predominant in northern and southern part of Africa (Poveda 2021; Subramanian & Tanga, 2022). The fly has an ability to adapt to various ecological conditions making it useful to many farmers. BSF is a beneficial and non-pest fly with the ability to rest on vegetables and flowers in bright sunlit areas (Diener et al. 2015). The adults are inactive, weak fliers and will spend more time resting especially animal production facilities (Čičková et al. 2015; Sarwar, 2020). The adult fly does not feed on wastes, since it lacks mouthparts (Rana et al. 2015; Lievens et al. 2021; Tettamanti et al. 2022). BSF does not bite and neither does it transmit diseases to human beings and animals (Rana et al. 2015). The presence of the fly keeps away pathogens causing insects like housefly (Goddard, 2003). Their larvae are scavengers and flourish on any decomposing organic material, including compost heap, manure, algae, plant refuse and mold (Forsyth & Miyata, 2011; Diener et al. 2015). This ability helps to sustainably manage waste and reduce bad smell and control diseases (Banks et al. 2014; Nguyen et al. 2015). Statistics show that the insect has the ability to reduce food waste by about 75% while converting the waste into feedstuff containing 42% proteins and 37% fats (Barragan-Fonseca et al. 2017). The fly has multiple uses that need to be exploited through rearing it. Besides livestock feeds and source of manure, the fly can be a source of food to human beings, BSF larvae can produce geese for pharmaceutical industry, production of chitin and bioremediation experiments (Gordon, 2013; Albagli et al. 2015; Oonincx et al. 2015; Wang & Shelomi, 2017; Martín et al. 2023).

2.1.1 Morphological characteristics

BSF has a wasp-like look with black and/or blue in color. The adult flight has a length of 15 to 20 mm, making it a medium-sized flight (Sheppard et al. 2002). The dominating body color is black with either blue or green metallic reflection on the thorax and some may have a reddish end of their abdomen (Terfa, 2021; Kang, 2023). They also have two translucent openings in the first (basal) abdominal segment. The fly has a wide head, whose antennae being twice the head size (Wang, 2020). The antennae is elongated, projected over the head and lacks sensory organs of touch. They have membranous wings that overlap and horizontally folded when at rest (Guerreiro et al. 2020). The fly female's abdomen is usually reddish at the top while the male is bronze. On the other hand, their upper legs are black with white-yellow forelegs- tarsi (Kang, 2023). Their larvae are similar to housefly and blowfly but can be differentiated by the presence of a thin black-gray stripe on their posterior ends (Nyakeri et al. 2017; Raksasat et al. 2021). The larvae have a dull, whitish color with a projecting head containing mouth parts used for chewing (Nyakeri et al. 2017).

2.1.2 Feeding and reproduction

The BSF goes through five main stages (Figure 1) in its entire life cycle, namely egg, larval, prepupal, pupal, and adult (da Silva & Hesselberg, 2020). Adult fly breeds either in compost, manure or outdoor toilets through laying of eggs (Raksasat et al. 2021; Terfa, 2021). Commercial special scents and traps should be put at specific areas for the fly to lay eggs (Figure 2, section b) Mating occurs in shaded areas while the male and female are in flight but not at rest where the female deposits about 500 to 900 eggs especially close to the edges of decomposing materials (Julita et al. 2020). Just after partaking oviposited, the female dies (Lievens et al. 2021). The eggs are oval, creamy in color, and about 25mm in length. The eggs color can sometimes turn dark over time (da Silva & Hesselberg, 2020). The incubation periods vary, taking a minimum of 4 to 21 days for the eggs to hatch (Nyakeri et al. 2017). The wide variation depends entirely on temperature and seasons. Larvae passed through six instars in a period not exceeding 14 days to complete its development (Hall and Gerhardt, 2002). A mature larva has a length of approximately 20 mm, whereas a newly hatched one can have a minimum length of 8mm (Diclaro & Kaufman, 2009; Oliveira et al. 2015). A larvae will immediately start feeding on organic matter upon egg hatching and its consumption rate will increase after the 3rd instar. In the 6th instar larvae undergo melanization giving the cuticle a dark coloration thus becoming pre-pupae (Li et al. 2023). At the pre-pupae stage, it stops feeding and empties its digestive tract (Wong et al. 2019; Alagappan et al. 2022b). This makes it move away from the food source to dry crevices and then turn into pupae in 7-10 days (Rodrigues et al. 2022; Jalil et al. 2023). The pupae in a period of 8 days give of not feeding gives rise to an adult (Jalil et al. 2023). The young adult fly feeds only on water as it relies mostly on the fat stored during its larvae stage (Lievens et al. 2021). The adult BSF stays remotely away from human beings and does not harm crops, spread diseases, or cause any pollution or invasion of buildings (Shumo et al. 2019; Wong et al. 2019; Anyega et al. 2021). Mature BSF are inactive thus easily controlled (Figure 2, section c).

Of all the stages, the larvae stage is the most active one (Guerreiro et al. 2020). The larvae are scavengers and consume all kinds of decomposing organic wastes like algae, manure, mold, composite heap and beehives waste products (Zhang, 2020). Their feeding habit is necessitated with large and strong chewing mouthparts that allow them to break and prey on waste (Rana et al. 2015).

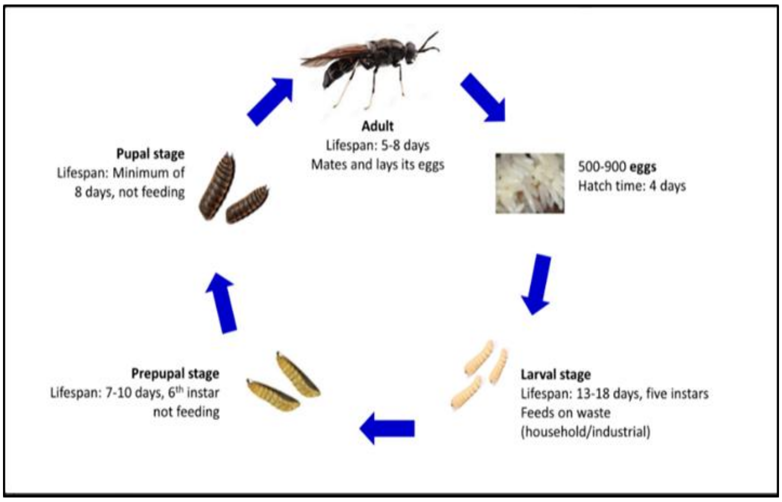

Figure 1: A diagrammatic representation of the life cycle stages of black soldier fly. Source: https://encyclopedia.pub/8454

Figure 2: Black soldier fly structures a) banana leaves used as organic waste/food, b) The laying area and traps to attract female BSF to lay eggs, c) adult black soldier fly in their nest.

2.1.2 Factors favoring growth of fly frass

The insect is known to adapt to various environmental conditions; thus, it can grow well in both optimal and adverse conditions (Chia et al. 2018). The optimal relative humidity and moisture ranged from 50 – 70% with optimal light intensity of 135–200 μmol/m^2 (Alvarez et al. 2019; Barrett et al. 2023). Lower relative humidity reduces their survival rates, whereas light intensity dictates their mating rates (Kim et al. 2021). Insects do well in a temperature of 26-27^{0}C (Chia et al. 2018). High temperature reduces the lifespan of both adult flies and the pupals (Chia et al. 2018). On the other hand, competition among larvae can affect the density and decomposition rate of the organic materials (Kragt et al. 2023). Therefore, the density needs to be controlled based on the volume of the substrate available to atcrease the survival rate of larvae and uniformity of the performance of the colony (Opare et al. 2022). The ratio of substrates to larvae in kilograms should be 1:2 for effective results (Kragt et al. 2023). The type of organic material also affects larvae growth (Kim et al. 2021; Alagappan et al. 2022). This growth rate is as high as above 80% when materials like poultry feeds, fruit, vegetable and other food waste are used (Mahmood et al. 2023). On the contrary, digested sludge may lower they fly's growth to less than 40% (Opare et al. 2022; Rodrigues et al. 2022). The high salinity of the substrate leads to decreased growth rates and larvae development (Richardson et al. 2021). The quality of the feeds greatly affects the fertility rate, survival rate, size of the adult and larvae (Mahmood et al. 2023).

2.1.4 Challenges in production of fly frass by small-scale farmers

Keeping frass fly does not require many resources but the enterprise has been encompassed with several challenges which calls for proper training and capacity building before engaging in the exercise to avoid losses and frustrations (Shumo et al. 2019; Wang & Shelomi, 2017). The insect requires a well-controlled conditions for them to grow well, find mates and produce eggs (Chia et al. 2018). Setting up such climate-controlled environment with suitable UV wavelengths may be a major set-back, especially in rural areas, especially in cold areas (Malawey et al. 2021; Sign et al. 2021). The conditions in the love cages, if not conducive, may affect the laying of eggs among the insects thus reducing the number of lavas (Zim et al. 2023). Poor conditions result in protracted incubation time and increased rate of eggs failure (Star et al. 2020). For instance, wetness in the eggs may destroy all the eggs. Thus, the correct temperature and humidity within the cages must be considered (Surendra et al. 2020; Opare et al. 2022).

BSF requires high quality and diverse organic waste feeds (Wong et al. 2019). Producing them commercially may affect the dietary measures since the farmers may lack constant supply of food waste. The safety (free from toxin) of wastes cannot be easily determined by local farmers (Surendra et al. 2020; Kim et al. 2021). Also, determining the required moisture content may be a challenge without proper training on the same (Alvarez et al. 2019). At some point, waste food might be a breeding place of ants or mites, thus affecting the growth and multiplication of the fly (da Silva & Hesselberg, 2020).

Harvesting of larvae may be a cumbersome exercise, especially when done manually (Basri et al. 2022). In most cases the larvae are mixed with frass, thus separating them can be a very rigorous exercise, especially where the mixture contains high moisture content (Beesigamukama et al. 2020). To avoid losing many frass during harvesting of larvae, it is advisable to use mechanical methods which may be costly to the farmer (Alvarez, 2012).

The larvae become livestock feeds in the long run (Kragt et al. 2023). Although the larvae are sterilized using hot water, maintaining the required temperature may be a problem, especially when larvae are added to boiled water, they may lower the temperature (Mertenat et al. 2019). This requires a suitable heating mechanism to keep the water hot even with addition of the larvae (Alagappan et al. 2022b). During drying of larvae, farmers need to adopt a method that will not diminish the nutritional value of the larvae (Nyakeri et al. 2017; Shumo et al. 2019).

2.2 Smallholders Mixed Farming System

Smallholder farmers are the majority in Kenya, accounting for up to 70% of agricultural products marketed within and outside the country (Ali-Olubandwa et al. 2010). It is only a small percentage (10 – 20%) that operate formally contributing to the value chain (Ng'endo et al. 2015). Small-scale farmers contribute about 22% of Gross Domestic Product (GDP) and over 56% of employment opportunities (Samberg et al. 2016). The declining number could be attributed to many challenges faced by small-scale farmers. Most of the smallholder farmers cultivate less than five acres of land, making them counted among the world's poor who depend on less than two dollars a day (Rao & Qaim, 2011). Most have resorted to mixed farming to intensively maximize the small area of land by producing diverse produce with the anticipation that one of the produce may fetch good yield and/or returns (Ali-Olubandwa et al. 2010). Mixed farming involves both the growth of crops and keeping of livestock (Abate et al. 2017). This practice began in United States and Japan mainly for domestic consumption and later extended to entire Asia and Africa (Keatinge et al. 2011). In Kenya, mixed farming was adopted after independence when the land was subdivided among the residents (Keatinge et al. 2011). The increase in population has contributed to further subdivision of the land impacting negatively on mixed farming. In Kenya, mixed farming is dominated, both, in rural and urban areas (Ntale & Litondo, 2013). Despite the fact that harvesting crop residues are fed directly to animals, the issue of soil fertility has been partially addressed since the manure obtained from reared animals may be applied on the farm to increase its fertility (Ali-Olubandwa et al. 2010; Abate et al. 2017).

2.2.1 Importance of mixed farming in enhancing Frass usage

Across the world and specifically in Kenya, mixed farming has been mirrored with many advantages that outweighed its disadvantages (Ntale & Litondo, 2013). In the case of crop failure or fluctuations, the farmer may depend entirely on livestock to meet their daily needs (Jaleta et al. 2013). This implies that there will be continuous availability of organic waste for the BSF to feed on (Figure 2, section a). The opposite may be true in case the livestock section becomes unprofitable. On the other hand, the farmer gets income continually throughout the season since livestock products are obtained throughout the year (Tibesigwa et al. 2017). This is opposed to crop production where income generation happens during the harvesting period of crops. This brings income stability among farmers (Tadesse et al. 2008). Unlike depending only on crops or animal production, involvement in both is likely to fetch a large income (Ali-Olubandwa et al. 2010). A reliable income obtained from the farm assists the farmer to easily obtain farm inputs, as well as acquiring the necessary materials and manpower for BSF.

The mature BSF can be used as a good source of proteins to human beings (Borgemeister, 2019). The use of crop residues as fodder for livestock may be cost-effective for farmers (Abate et al. 2017). The burden of buying feeds from external sources may be reduced and instead, the money allocated to feeds can go to other uses of the farm. Using manure that comes from the farm increases the production and speeds up the growth of crops through the replenishment of scarce nutrients (Tibesigwa et al. 2017), thus limiting the purchase of inorganic fertilizers. Polyculture provides environmental benefits and saves on space as different crops have different lifecycles, and there are less likely cases of crop failure, and suppression of diseases, pests and weeds (Mirera, 2011; Van et al. 2021).

2.2.2 Challenges in small-scale mixed farming

There is high possibility of animals interfering with crops while growing on the farm (Fanzo et al. 2016). Animals, even when restricted, can detach and feed on crops or stampede on them (Kosgei, 2013). This is likely to affect the yield of the crops grown. Given the small size of the land, the use of machines may be difficult due to the disparity of crops (Herrero et al. 2007). The machine may also affect delicate crops, as well as interfere with the well-being of animals.

In rural areas, farmers cannot transport their animals due to poor and inadequate infrastructure which includes marketing facilities, poor road network and poor communication (Abate et al. 2017). Farmers have no access to fertilizer or other farm inputs needed for the proper production of crops (Herrero et al. 2007). Their poor nature hampers their ability to employ measures for adopting and mitigating climate change. In most cases, they use poor farming methods and are always unable to fight pests and diseases that attach to their crops (Fanzo et al. 2016). Marginal provision of extension services has been witnessed where extension personnel are reluctant to offer services to small scale farmers given their large number. Post-harvest measures are challenging due to poor farm tools and equipment and lack of information (Tangka & Jabbar, 2005).

2.3 Significance of BSF Frass to soil, crops and environment

Most of the soils in SSA are known to contain less fertility due to continuous cultivation and leaching that is common in the tropical regions (Chikowo et al. 2014). The application of artificial fertilizer has never yielded a long-term solution to the problem (Jing-Yan et al. 2015; Shi et al. 2016). Most artificial fertilizers are meant for quick release and should be applied seasonally at any planting time (Pahalvi et al. 2021). Dependence on organic matter has been refuted by most farmers, as the materials have competed uses (Page et al. 2020). For instance, crop residues are fed to livestock as feeds. some residues are used as sources of energy in some places. Farmers who bury crop residues and other organic materials in the soils have complained of residues taking too long to decompose and become effective (Page et al. 2020). The longer they take to decompose, the longer the soils are deprived of nutrients. The best way to enhance soil fertility is through the use of frass fertilizers, which can be generated locally, at household level (Poveda, 2021; Terfa, 2021; Basri et al. 2022; Beesigamukama et al. 2022). Frass fertilizer carries all the components of organic fertilizer, since it is comprised of purely organic manure (Figure 2, section a). In addition, the frass fertilizer has numerous and elevated levels of both primary and secondary nutrients compared to any other organic fertilizer, thus enriching the soil (Chirere et al. 2021). These nutrients include nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. For instance, commercial frass from the Critter Depot has an N-P-K value of 5:3:2 which translates to 5% nitrogen, 3% phosphorus pentoxide, and 2% calcium (Dempster et al. 2022). The organic matter content in frass is much higher than that in compost and other types of manure (Elissen et al. 2023). Frass contains nitrogen-fixing and nitrifying bacteria that boosts plant's nitrogen uptake, reduce atmospheric nitrogen loss and contamination of ground water (Terfa, 2021). Frass simply stores nitrogen and carbon in the soil (Elissen et al. 2023). In addition, frass contain boron, iron, zinc, manganese and copper. Frass also reduces the acidity level of the soils making the soils suitable for planting of various crops and easy accessibility of nutrients by plants (Beesigamukama et al. 2021).

BSF frass fertilizer (BSFFF) is progressively gaining momentum internationally as organic fertilizer (Čičková et al. 2015; Shumo et al. 2019; Anyega et al. 2021). However, research on its performance in crop production has not been widely done on commonly grown crops in Kenya. Research shows that maize grown with BSFFF always displays the tallest stand and highest chlorophyl compared to commercial organic and inorganic fertilizers (Beesigamukama et al. 2020; 2022; Basir et al. 2022). A study by Beesigamukama et al. (2020), showed that fields that were treated with 7.5 t ha^{-1} of BSFFF had 14% higher grain yields and 23% increased nitrogen uptake than plots treated with a similar rate of commercial organic fertilizers. Also, there was a 27% and 7% increase in grain yields and increased nitrogen uptake by 76% and 29% in fields treated with 100 kg N ha^{-1} of BSFFF compared to those applied with commercial organic fertilizer and urea fertilizers, respectively.

It is estimated that more than 70% of the waste generated in Kenya is organic, made up of agricultural, yard and food waste (Shumo et al. 2019). Nairobi county is the leading county in waste generation, estimated at 2,400 tons per day (Muiruri et al. 2020). About 50% of the waste generated in Nairobi is organic in nature. Wastes in Kenya are disposed of in informal landfills and open dumpsites deprived of proper infrastructure and management (Dianati et al. 2021). In recent years, the country, especially cities, are experiencing serious challenges in collection, disposal and recycling of wastes (Njoroge et al. 2014). The challenges have brought advanced health problems and environmental degradation. Most of the wastes emit unpleasant smell, carbon dioxide & methane gas and attracts disease carrying agents (Dianati et al. 2021). Excess methane and carbon-dioxide (greenhouse gases) in the atmosphere has resulted to climate change. Climate change's effects are more averse to the farming community and the world at large. The use of frass fertilizer will eliminate the emission of greenhouse gases and bad odors as they scavenge and reduce its volume over a short time (Zhang et al. 2021; Boakye-Yiadom et al. 2022). The BSF has an ability to remove toxic substances from organic waste with a capacity to feed on 200mg of waste a day (Attiogbe et al. 2019). The fly larvae can reduce about 40% of biosolids in 20 days (Nana et al. 2018; Bohm et al. 2022). The feeding rate shows that BSF has a great potential of managing waste in SSA. As larvae converts carbon and nitrates into waste, they reduce the chances of the elements being lost to the atmosphere such as greenhouse gases (Pang et al. 2020).

3.0 CONCLUSION

The use of BSF has many benefits to our society. Besides being a source of proteins to livestock, it has been known to be the best organic fertilizer for crops and a better tool for managing our environment. With the rising effects of climate change, BSF can be used to cut down greenhouse gas emissions. It is surprising that many farmers have not adopted the practice besides being cheap and reliable. A lot of sensitizations through print and social media should be enhanced by the government to make the public aware of this BSF technology. Its adoption will help in improving soil fertility, plant yield and a clean environment. A projection analysis is needed to determine long-term utilization of frass fertilizer by farmers in Kenya.

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