

**COST EFFECTIVENESS OF RECYCLING ORGANIC WASTE USING BLACK
SOLDIER FLY AND EFFECT ON HOUSEHOLD INCOME IN KIAMBU
COUNTY, KENYA**

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the award of a Master of Science degree in Agricultural Economics of Egerton University**


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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been presented before for examination in any other university.


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DEDICATION

This thesis is dedicated to my father Joseph Mugendi Nguu, my mother Mary Kaari Nwiga, my siblings Chenshallon Mukii Mugendi, and Cyrill Mwendu Mugendi for the love and emotional support throughout this period.

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May God Bless You All

ABSTRACT

The adoption of insect-based technologies in managing organic waste is gaining traction. Information on determinants of adoption and the technologies' cost effectiveness is important for policymakers' decision-making on efficient waste management. The study determined the factors influencing the adoption of black soldier fly (BSF) in organic waste recycling, its cost effectiveness compared with conventional composting, and the effect of adopting BSF on household recycling income. Primary data was collected from a sample of 222 households, 105 using BSF and 117 using conventional composting, in Kiambu County and supplemented with secondary data from existing literature. Binary logistic regression, cost-benefit analysis, and endogenous switching regression models were used to determine the determinants of choice to adopt, cost effectiveness, and effect on recycling income, respectively. The empirical results from binary logistic regression revealed that membership in waste management groups, access to waste management extension information, and perception of diversification of recycled products significantly and positively influenced the adoption of BSF in organic waste recycling into fertilizer with odds ratios of 1.801, 3.227, and 15.299, respectively. The cost-benefit analysis indicated that households recycled 4.81 tons and 3.84 tons of organic waste per cycle using BSF and conventional composting. Recycling 1 ton of organic waste per cycle using BSF generated an annual gross margin of 55.36% and a Net Present Value (NPV) of \$2128.36 (10 years, 12% discount rate). The NPV was highly sensitive to variations in the quantity and price of fertilizer, production cycle, and labour cost. On the other hand, recycling 1 ton of organic waste per cycle using conventional composting generated an average annual gross margin of 16.63% and NPV of \$55.97 (10 years, 12% discount rate). Endogenous switching regression output indicated that the average treatment effect (ATT) of 2.224 (18.68%) indicated that the adoption of BSF positively affected household recycling income. Moreover, households not using BSF would increase their recycling income by 18.78% if they adopt BSF in recycling organic waste into fertilizer. Our findings indicate that BSF is cost-effective and has huge potential in recycling urban and peri-urban organic waste. Policy development on efficient waste management should be aimed at increasing awareness on the economic, environmental and circular economy benefits of using BSF for organic waste recycling. Moreover, households should be encouraged to adopt BSF so that they do not only benefit from recycling organic waste into fertilizer, but also benefit from diversifying their livelihood opportunities.

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LIST OF ABBREVIATIONS & ACRONYMS

ATE	Average treatment effect
ATU	Average treatment on the untreated
TDABC	Time driven activity-based costing
BCR	Benefit cost ratio
BSF	Black soldier fly
CBA	Cost benefit analysis
CIDP	County integrated development plan
CSA	Climate smart agriculture
EAC	East Africa Community
ESR	Endogenous switching regression
FF	Frass fertilizer
GHG	Greenhouse gases
GM	Gross margin
ICIPE	International Centre for Insect Physiology and Ecology
INSEFF	Insect for Food, Feed and Other Uses
LDF	Louis Dreyfus Foundation
IRR	Internal rate of return
MT	Metric tonne
MNL	Multinomial logit regression
NPV	Net present value
OLS	Ordinary least squares
PSM	Propensity score matching
ROI	Return on investment
SDG	Sustainable Development Goal

CHAPTER ONE

INTRODUCTION

1.1 Background information

One of the world's most pressing concern with far-reaching impacts on societal well-being, economies and the environment is the abundance of waste generated annually (Joly & Nikiema, 2019). The world produces over 2.1 billion metric tons of solid waste annually, with 45% being organic, mainly food waste. Only around 16% of the food waste is recycled, and more than 46% is illegally disposed of (Deus *et al.*, 2018). Food waste annually contributes to about 33 tons of greenhouse gases (GHG), such as carbon dioxide (Kumar *et al.*, 2018). Another major component of organic waste is livestock manure which releases nitrogen oxide and ammonia into the atmosphere, and nitrate leach into the surface and groundwater. Unless manure is appropriately handled and recycled, it has potential human health and environmental hazards (Wanjohi, 2018). Conventionally, organic waste is managed through composting into fertilizer. However, the composting methods are slow and, if not controlled, directly contributes to climate change through the emission of methane and carbon dioxide, and offensive smells because of hydrogen sulfide production (Ayilara *et al.*, 2020; Wanjohi, 2018). Interventions seeking to manage organic waste better have promoted the use of insects-based technologies in recycling organic waste into fertilizer.

Insects have an affinity for organic waste and utilize the waste as a food source. They bio-convert the waste into economically viable products such as protein supplement for animal feed (insect biomass), food supplement, secondary compounds (biofuel and pharmaceuticals), and the leftover is used as nutrient-rich organic fertilizer (Mannaa *et al.*, 2023). These products are profitable substitutes that can be utilized by households in livestock and crop production. (Beesigamukama *et al.*, 2022). The waste bioconversion process is a feasible solution to managing organic waste in urban and peri-urban areas regarding space, time, energy requirements, and environmentally friendly (Van Huis & Oonincx, 2017). Insects commonly reared include black soldier fly (BSF), crickets, houseflies, and codling moths. Currently, rearing of BSF is emerging as an enterprise in Kenya for recycling organic waste and a livelihood opportunity for household to diversify income streams (Beesigamukama *et al.*, 2022) The BSF larvae bio-converts a wide range of organic waste into high value bio-fertilizer with non-pathogenic footprint because the adult fly does not feed (Fowles *et al.*, 2020; Wang & Shelomi, 2017). Consequently, producers

and investors need to know the economic benefits of using BSF in recycling organic waste compared to conventional composting methods.

Conventionally used composting methods include traditional approaches for heaping the organic waste and leaving it to decompose slowly and naturally on the farm, and improved methods including bin, basket, trench, and windrow composting (Singh *et al.*, 2020). The composting process directly contributes to surface and groundwater pollution through runoff and leaching of nutrients, creating a need for treating drinking water (Ledda *et al.*, 2016). On the other hand, the concentration of undesired nutrients in rivers and lakes causes eutrophication and rapid growth of aquatic plants like water hyacinths and algae (Salvador *et al.*, 2016). Zoonotic pathogens can also be transmitted through the manure to humans causing local infections (Venglovsky *et al.*, 2009). Therefore, a need exists to manage organic waste more efficiently because of its potential hazards to human health and the environment.

The use of BSF in recycling organic waste appears promising and innovative because the insects transform the organic waste into a high nutritional composition fertilizer known as frass fertilizer (FF) (Ites *et al.*, 2019). The FF is a suitable alternative for revitalizing agricultural production. Its nutritional composition is 41.2% nitrogen (N), 32.4% phosphorous oxide (P_2O_5), and 77.1% potassium oxide (K_2O), higher than conventional compost from windrow composting (Sarpong *et al.*, 2019). Conventional compost has a nutritional composition of 2.01% N, 2.83% P_2O_5 , and 1.97% K_2O (Erdal *et al.*, 2017; Mladenov, 2018) The insects take a shorter time of about two weeks to accumulate biomass rich in protein used as protein source in feed formulation and fat used to produce biodiesel (Raksasat *et al.*, 2020) and transform about 50% of the waste into frass (Singh & Kumari, 2019). Transforming the waste using BSF emits less GHG and has a reduced effect on the surface and groundwater (Parodi *et al.*, 2020).

Despite the steady increase in literature on the use of BSF in recycling organic waste into high value products such as frass, information on the economic aspects of its production is limited (Joly & Nikiema, 2019). Existing studies include a review on the use of BSF larvae in organic waste treatment in Asian countries (Kim *et al.*, 2021), and the potential technical and economic feasibility of replacing conventional animal feeds with insect-based feeds in poultry production (Abro *et al.*, 2020). Additional studies identified the ecological and economic value of using frass fertilizer in maize production using experimental data (Beesigamukama *et al.*, 2022), the cost effectiveness of using BSF larvae as a protein source in animal feed (Sumbule *et al.*, 2021), and

the potential socioeconomic impact of using insect-based feed in poultry production (Waithaka *et al.*, 2022). All these studies reveal the potential of adopting insects as a substitute feed in animal production and fertilizer in agricultural production.

In Kenya, the organic waste menace is prominent in urban and peri-urban areas. The main challenge is inappropriate recycling infrastructure, open dumping, and illegal disposal (Kaundia & Rosenthal, 2018). Kiambu County government has launched a program to promote organic waste management (County Government of Kiambu, 2023) and currently hosts the largest number of households recycling organic waste into fertilizer. However, households using BSF are few. Adoption of BSF in recycling organic waste requires households to understand its cost effectiveness and implication on their household recycling income. Existing literature does not outline the economic aspects of recycling organic waste into fertilizer using BSF in terms of its cost effectiveness compared to the conventional composting methods particularly windrow composting. Additionally, literature does not provide information on the determinants of adopting BSF in recycling organic waste and its effect on household recycling income, which is relevant when exploring adoption and scalability of BSF for recycling organic waste into frass.

The existing literature is, therefore, inadequate for individuals, investors, and organizations involved in research or practices of organic waste management as it assumes the economic aspects involved. The economics of using BSF in recycling organic waste influence the decision to adopt BSF in organic waste management, especially in urban and peri-urban areas of Kiambu County. Against this background, this study aimed to add to the existing body of knowledge by determining the cost effectiveness of recycling organic waste into fertilizer using BSF and its effect on household recycling income in Kiambu County.

1.2 Statement of the problem

The abundance of organic waste is one of the world's most pressing concerns. In Kenya, the menace of organic waste is prominent in urban and peri-urban areas because of inappropriate collection and recycling infrastructure and open dumping. Organic waste is conventionally managed through composting into fertilizer. However, the composting methods used are slow and, if not controlled, directly contribute to GHG (methane and carbon dioxide) emissions and eutrophication and can transmit zoonotic pathogens. The rising pressure of organic waste generated by the rapidly growing population calls for efficient methods with reduced

environmental and human health footprints. Using insects like BSF is emerging as a promising and innovative technology that rapidly recycles organic waste into high-value products with minimum environmental and public health footprint. However, few households have adopted BSF technology for recycling organic waste into fertilizer. Existing literature does not reveal the determinants of adopting BSF for recycling organic waste into fertilizer, its cost effectiveness compared to conventional composting, and its effect on household recycling income. This study added to the body of knowledge by determining factors influencing the adoption of BSF for recycling organic waste into fertilizer, the cost effectiveness of recycling organic waste using BSF, and its effect on household recycling income in Kiambu County. This study provides information on the economic benefits of using BSF in recycling organic waste and thereby supporting the development and promotion of frass fertilizer production and scalability among recyclers, bio-fertilizer producers, investors, and policymakers on cost effectiveness of using BSF in recycling waste, and its impact on households' livelihoods.

1.3 Objectives

1.3.1 General objective

To contribute to improved welfare and environmental conservation through the use of a sustainable and cost-effective insect-based technology for recycling organic waste into fertilizer in Kiambu County, Kenya.

1.3.2 Specific Objectives

- i. To determine factors influencing the adoption of black soldier fly for recycling organic waste into fertilizer among households in Kiambu County
- ii. To evaluate the cost effectiveness of recycling organic waste into fertilizer using black soldier fly compared to conventional composting among households in Kiambu County
- iii. To determine the effect of recycling organic waste into fertilizer using black soldier fly on household recycling income in Kiambu County

1.4 Research questions

- i. What factors influence the choice of black soldier fly for recycling organic waste into fertilizer among households in Kiambu County?

- ii. What is the cost effectiveness of recycling organic waste into fertilizer using black soldier fly among households in Kiambu County?
- iii. What effect does recycling organic waste into fertilizer using black soldier fly have on household recycling income in Kiambu County?

1.5 Justification of the study

Recycling organic waste into fertilizer is vital for environmental conservation in urban and peri-urban areas. However, the conventional methods used to transform organic waste are slow, emit GHG, and the fertilizer has low nutritional composition. Using insects in recycling waste seems to offer an efficient and sustainable alternative. Insects such as BSF contribute to revitalizing agricultural production by transforming waste into a fertilizer that amends the soil while improving and sustaining soil fertility with a reduced environment and health footprint. It also offers households an alternative livelihood option for diversifying their income streams. Understanding factors influencing producer households' choice of BSF for recycling organic waste into fertilizer is vital in ensuring that significant factors are availed to the households and recyclers to improve their efficiency and maximize profits. Assessing the cost effectiveness of recycling organic waste using BSF provides a clear understanding of the economic aspects of using insects *visa vis* conventional methods. Determining the effect of recycling organic waste into fertilizer using BSF on household income reveals the welfare implications of adopting an insect-based technology for recycling organic waste. The study will facilitate job creation and empowerment among the youth and women as recycling organic waste into fertilizer provides entrepreneurial opportunities. This study will also inform policymakers in developing efficient organic waste management policies.

The proposed study will aid in realizing the Kiambu County Integrated Development Plan (CIDP) 2023 - 2027 on improving solid waste management and promoting a cleaner environment. The study is also consistent with the Kenyan government's plan, "The Bottom-Up Economic Transformation Agenda (BETA) 2022 - 2027," of environment and climate change, anchored on efficient solid waste management, and thus, recycling organic waste is a vital component. The study aligns with the country's realization of Vision 2030 under the waste management program, which calls for efficient solid waste management. The study will also contribute to the attainment of the East Africa Community (EAC) regional vision 2050 on green economy promotion, the

African Union Agenda 2063 of environmentally sustainable economies and communities, the Millennium development goal of environmental sustainability and sustainable development goals (SDGs 12 and 13) of ensuring sustainable consumption and production patterns, and climate action.

1.6 Scope and limitations of the study

The proposed study was conducted in the 12 sub-counties of Kiambu County. It entailed cross-sectional data collection on recycling organic waste into fertilizer among urban and peri-urban households of Kiambu County. Households using BSF to transform organic waste into fertilizer and those using conventional windrow composting method were considered as potential respondents. The study only looked into BSF farming from an organic waste recycling into fertilizer for agricultural revitalization and replenishing depleted soils perspective. A recall method for the last 12 months' production period was adopted.

The study was limited to only household recycling organic waste into fertilizer using BSF and windrow composting methods. Due to limitation in financial resources, the study only focused on financial cost-benefit analysis but did not look at the environmental/societal cost-benefit analysis of recycling organic waste into fertilizer using BSF vis a vis conventional composting. To mitigate this limitation, the study conducted a synthesis of existing literature on similar studies on the environmental and societal costs and benefits (externalities) of using BSF in recycling organic waste compared to conventional composting. Additionally, a recall method was used during the interviews because producers lack updated records, but probing was used to overcome the limitation.

1.7 Operational definition of terms

Black soldier fly - refers to an insect in the family of Stratiomyidae that is emerging as a technology for recycling organic waste into fertilizer and animal feed.

Conventional composting - refers to the common methods used in transforming organic waste into fertilizer using traditional and improved methods. This study used windrow composting (including traditional heaping) as the conventional method because the fertilizer produced can be quantified.

Cost effectiveness - refers to the analysis of the monetary value obtained from adopting BSF as a technology for recycling organic waste into fertilizer relative to the cost incurred vis a vis using conventional composting

Household – refers to one or more people who make common provision for food, regularly take their food from the same pot, pool their income to purchase food and other needs and are actively involved in decision making.

Household head - refers to the person in charge of major decision making in the household with reference to recycling organic waste.

Household recycling income - refers to gross income generated by a household from recycling organic waste into value added products such as fertilizer and insect biomass.

Insect-based technology - refers to using BSF larvae to transform organic waste into organic fertilizer.

Organic waste - refers to any type of waste materials from plants or animals that can be biodegraded into economically valuable products for agricultural or energy uses.

Recycling - refers to the process of converting organic solid waste into economic-value products such as fertilizer and protein biomass.

Production cycle - refers to the time taken to transform organic waste into fertilizer. Conventional windrow composting method take 3 - 4 months, while BSF takes 12 - 28 days.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of recycling organic waste into fertilizer

Economic development in areas with rapid population growth often results in mass production, consumption, and waste generation because individuals tend to adopt a consumeristic style of living (Ioannou *et al.*, 2022; Weng & Fujiwara, 2011). The primary goal of waste management in urban and peri-urban areas is to reduce the levels of waste generated, thereby reducing the amount of waste disposed of in landfills. Inefficient and ineffective waste management mechanisms like uncontrolled burning and open disposal in landfills adversely affect human health and the environment (Kaza, 2021). Around 50 - 70% of the garbage in open dumpsites is organic matter, while the remaining proportion is paper, glass, plastics, metal, and electronic waste (Komakech *et al.*, 2015). Recycling companies collect the inorganic proportion of the waste, and the organic waste is left to decompose in the open dumpsites (Komakech *et al.*, 2015).

The organic component consists of mainly food waste, yard waste, livestock waste and agricultural waste (Fie-Consult, 2023). Food waste comprises over 45% of the organic waste produced (Bras *et al.*, 2021). Only 10% of the waste produced is properly disposed in designated dumpsites. The illegally disposed organic waste (about 90%) results into economic losses, public health hazards, and environmental degradation (Fie-Consult, 2023). The decomposition process generates carbon dioxide and methane, which leads to the accumulation of GHG later contributing to climate change (Isibika *et al.*, 2019). Additionally, the decomposing waste form breeding grounds for flies, vermin, and rodents which are vectors for diseases like malaria and cholera (Chowdhury *et al.*, 2017). Managing organic waste is a multifaceted problem that is caused by inefficient recycling and composting technologies, inappropriate collection and disposal infrastructure, and weak enforcement of laws and regulations that pave way for illegal littering and dumping (Bundhoo, 2018).

Composting is a waste bioconversion technique that can reduce the quantity of organic waste disposed of in open dumpsites. Saprophage organisms enhance the composting process by feeding on the organic waste and transforming it into a product (fertilizer) with economic value (Diener *et al.*, 2011). However, if not controlled, composting is a slow process and contributes to climate change through the depletion of oxygen and emission of carbon dioxide, as well as offensive smells

because of the production of hydrogen sulphide (Ayilara *et al.*, 2020). Conventional practices in urban and peri-urban areas that recycle organic waste include windrow, trench, basket, and bin composting techniques. However, these conventional methods do not appear to offer efficient organic waste management (Diener *et al.*, 2011). Another composting technique is vermicomposting. Earthworms and microorganisms are introduced into the organic waste and transform the waste into a vermicompost fertilizer. The vermicompost has superior characteristics compared to the fertilizer obtained from the conventional approaches. However, the vermicomposting process takes 3-6 months and emits harmful gases like nitrous oxide and methane (Thakur *et al.*, 2021).

The use of insects such as black soldier fly (BSF) is emerging as one of the local technologies that bio-convert organic waste into larval biomass that is used as an animal feed and the residual is a nutrient rich organic fertilizer for fertilizing depleted soils. These products are substitutes to the skyrocketing prices for protein source in animal feed formulations and commercial fertilizer (Kibaara & Tanga, 2023). The use of BSF in composting allows rapid transformation of the organic waste because the larvae have a high affinity for organic waste. (De Smit *et al.*, 2018). BSF transforms a wide range of organic waste into frass, including animal manure, food waste, and agro-industrial waste (Nguyen *et al.*, 2015; Rehman *et al.*, 2017). The BSF larvae are also enriched with crude proteins, minerals, and fats and are suitable as a protein source for animal feed formulation (Liu *et al.*, 2017; Xiao *et al.*, 2018). Moreover, the waste bioconversion process is a feasible solution to managing organic waste in urban and peri-urban areas regarding space, time, energy requirements, and environmentally friendly (Van Huis & Oonincx, 2017)

The frass is compound fertilizer enriched with organic matter, micro and macronutrients, making it a suitable alternative fertilizer for agricultural production. In addition, the recycling process reduces pathogen levels in the substrate such that the frass produced is of high quality and reduces the frequency of using pesticides on the farm (Surendra *et al.*, 2016). The frass is also free from heavy metals because the BSF larvae accumulate the heavy metals during the transformation process (Biancarosa *et al.*, 2017). Frass is also endowed with beneficial microbes such as nitrogen fixing and nitrifying bacteria that enhance the uptake of nitrogen for plant growth. Chitin in the frass promotes plant growth, induces plant defense mechanism and triggers improvement in soil microbes thus contributing to improvement in soil fertility (Surendra *et al.*, 2016). Additionally, frass is rich in phosphorus which promotes accumulation of nitrogen in plants.

Frass is more stable and has higher nutritional composition compared to conventional compost (Liu *et al.*, 2019; Sarpong *et al.*, 2019). Moreover, its production reduces global warming (Mertenat *et al.*, 2019) and is efficient on space, time and energy requirement compared to conventional compost (Liu *et al.*, 2022). Frass can also be used as a soil amendment, animal feed, feedstock (biogas and vermicomposting), and growing media (Liu *et al.*, 2019). Utilizing frass as a product from recycling organic waste generates additional income compared to rearing BSF for larval biomass alone (Beesigumakama *et al.*, 2021). Unlike conventional composting techniques, BSF takes a shorter time of about two weeks to transform 50% of the waste with little pollution (Raksasat *et al.*, 2020). BSF is, therefore, a potential technology for managing organic waste, especially in urban and peri-urban areas of Kiambu County. However, despite the steady increase in research on using frass in agricultural production, data on the economic aspects of producing the frass is limited (Joly & Nikiema, 2019).

. A combination of frass and the sale of BSF larvae yields higher profits among households/individuals who recycle organic waste compared to rearing BSF for feeds alone (Beesigamukama *et al.*, 2021). Farmers take up pro-environment innovations and technologies when they are convinced that adopting them will address household food security and afford them a decent livelihood (Kotu *et al.* 2019). BSF is assumed to be a low-cost and efficient organic waste recycling technique that produces animal feed and bio-fertilizer with high nutritional value and little environmental impact. Nevertheless, its cost effectiveness compared to conventional composting is not clear from literature. Understanding the determinants of adopting BSF as a technology for recycling organic waste, its cost effectiveness, and its effect on household recycling income is vital in promoting the use of BSF.

The cost effectiveness . Moreover, determining the cost effectiveness of using BSF in recycling organic waste is desirable because it reveals the benefits of adopting BSF compared to conventionally used windrow composting method. It also ensures households select a viable option that is able to reduce the cost of managing organic waste while maximizing the output (fertilizer and animal biomass) and improving the general welfare of the recycling households (Beesigamukama *et al.*, 2022)

2.2 Empirical literature

2.2.1 Factors influencing the choice of black soldier fly for recycling organic waste into fertilizer among households.

Organic waste management techniques present a choice for which households choose a method for recycling organic waste into fertilizer. Despite mixed results, several studies have conducted empirical reviews on the influence of socioeconomic characteristics on the choice of organic waste management techniques. Alhassan *et al.* (2020) used the Multinomial Logit (MNL) model to determine the household choice of waste disposal and separation options in Ghana. The study identified that the main factors were attitude towards the methods, household size, income, age of the household head, education, gender, and dwelling facility. The findings are consistent with Banga (2013) study on household knowledge, attitudes and practices in solid waste segregation and recycling in Kampala, Uganda. It used a logistic regression and identified that gender, household income, education level, and knowledge of waste management techniques were crucial determinants in influencing household behaviour in waste management. However, the findings contradict Anbazu *et al.* (2022) study on determinants of the choice of disposal methods among residents in urban areas of Southern Ghana and Mongtoeun (2019) study on determinants of household solid waste generation and socioeconomic in the Cambodia. These studies indicated that demographic characteristics such as the age of the household head, gender, household income, and marital status were insignificant factors influencing the choice of waste management techniques. Similarly, Massoud *et al.* (2021) study on determinants of waste management practices and willingness to pay for improving waste services in low-middle income countries, stated that the gender and age of the household head do not affect the choice of waste management techniques. Therefore, it is not clear whether socioeconomic characteristics influence the choice of waste management techniques.

Nthambi *et al.* (2013) study on economic assessment of household solid waste management options in Kibera Slum, Nairobi- Kenya used multinomial regression model in assessing the factors influencing the choice of solid waste management techniques in Nairobi County. It indicated that in addition to socioeconomic factors, contractual agreements, livestock production, and urban gardening were essential determinants in the choice of waste management techniques. Moreover, transforming organic waste into fertilizer presented an alternative fertilizer for improving soil fertility and generating producers' revenues. Additionally, Molem & Enjema (2017)

study on determinants of households' choice of waste management in the Buea municipality, indicated that the composition of trash, frequency of trash disposal, and participation in urban cleaning programs greatly influenced the choice of waste management and transformation techniques.

Similarly, Kabasiita *et al.* (2021) employed the Probit regression model to explore the factors influencing household decisions to use compost from municipal waste among urban farmers in western Uganda. The study identified that level of experience, group membership, and cost of the composting techniques were key determinants and predicted future utilization of composting methods. Group membership was insignificant, contrary to Kumar *et al.* (2020) study on adoption and diffusion of improved technologies in Nepal which found out that belonging to a group positively contributed to the household decision to adopt agricultural innovations. A similar study by Wang *et al.* (2018) on household solid waste management in rural villages in developing countries used the Probit regression model to determine the determinants of households' waste management behaviour. It established that disposal regulations and collective action encouraged proper waste management behaviour. This study differs from the existing studies as it sought to establish how the mentioned factors influence the choice of BSF for recycling organic waste.

A study by (Nsimbe *et al.*, 2018) employed binary logistic regression to determine the factors associated with municipal waste composting in Central Uganda. The study found that involvement in waste segregation, ownership of a garden, and peri-urban dwelling facility were the main factors associated with the choice of composting solid waste. Inadequate technical expertise in composting techniques caused low involvement in composting. In addition, the urban dwelling facility presented a space constraint linked to limited involvement in composting. The attitude and perceptions towards composting techniques were also unsatisfactory and directly influenced the low adoption of composting methods. A similar study by Onyia *et al.* (2020) in Enugu State, Nigeria examined the determinants of using eco-friendly pig waste management techniques and used binary logistic regression. The study identified wrong attitudes, intentions, and low awareness of appropriate pig waste management abound. Other constraints included high waste management costs, lack of access to credit, inadequate technical know-how, and low-profit margins. This study adopted binary logistic regression and some factors used in existing studies to determine how they influence a household's choice of BSF as a technology for recycling organic waste.

The studies mentioned above identified socioeconomic and institutional characteristics as significant in determining the choice of organic waste management among households. However, the studies do not clearly outline factors that influence the choice of BSF households recycling organic waste. This study added to the existing body of knowledge by determining socio-demographic characteristics and institutional factors that influence the choice of BSF for recycling organic waste into fertilizer.

2.2.2 Cost effectiveness of recycling organic waste into fertilizer using BSF among households

Cost accounting is an important exercise to evaluate the cost effectiveness of using BSF in recycling organic waste into fertilizer. Assessing the cost effectiveness of using BSF compared to conventional composting methods presents crucial information for decision-making and informing policy formulation (Kuosmanen & Kortelainen, 2007). A study by Askarany & Franklin-Smith (2014) in New Zealand used Time-Driven Activity-Based Costing (TDABC) and evaluated the cost effectiveness of organic waste using two composting approaches. The findings indicated that organic fertilizer production using tunnel pile system was more cost efficient compared to vacuum aerated system. In addition, composting was an economically viable method for managing organic waste compared to landfilling. The findings are consistent with Kim et al. (2011) on evaluating food waste disposal options in Jungnang case, South Korea and Morawski (2008) on composting of municipal solid waste in United States of America who indicated that composting had economic benefits and was more efficient compared to landfilling. However, TDABC determines the benefits and costs with minimal accuracy. This study determined the economic costs and benefits incurred while recycling organic waste into fertilizer using cost benefit analysis (CBA).

De Boni *et al.* (2022) assessed community composting techniques regarding their environmental, economic, and social sustainability in Southern Italy. The study employed Life Cycle to determine the environmental efficiency and CBA to evaluate the economic and social benefits. The study identified that organic waste management through composting was best suited to managing organic waste as it ensured economic and environmental sustainability. Boldrin *et al.* (2011) indicated that composting as a method of organic waste management produced high-value fertilizer with economic benefits. The study used CBA and identified that composting was a promising method for organic waste management and saved 27% of total GHG emissions compared to open landfill dumping. The use of insects in composting organic waste assists in

shortening the composting process from 8-24 weeks to around four weeks (Beesigamukama *et al.*, 2021). This study adopted CBA to determine the cost effectiveness of using BSF by comparing the benefits and costs of producing fertilizer using BSF to conventional composting because CBA is an efficient tool for assessing cost effectiveness of adopting a technology.

A study by Beesigamukama *et al.* (2022) used gross margin analysis and assessed the ecological and economic value of rearing BSF for both larvae and frass, and growing maize using frass obtained in Nairobi Kenya. The findings indicated that farming BSF as a technology for recycling organic waste increased the farmers' income because the BSF larvae is used as a protein source in animal feed formulation, and frass is a substitute for the high-priced commercial fertilizer. A similar study by Abro *et al.* (2020) evaluated the socioeconomic benefits of recycling organic waste using BSF larvae for animal feed formulation among producers and consumers in Kenya. The study found that the insect-based technology had potential of realizing profits of at least 16 million USD from recycling 2 - 18 million tonnes of organic waste. The findings are consistent with a study by Munthali *et al.* (2023) which indicated that recycling organic waste for fish feed formulation had potential of realizing a gross profit of over \$2500 annually among the farmers. This study contributed to existing knowledge on the economic benefits of recycling organic waste by assessing the cost-effectiveness of recycling the organic waste into fertilizer.

A study by Dbida *et al.* (2021) in Kampala, Uganda (low-income regions) indicated that using BSF larvae in recycling household waste, sewage, and fecal sludge could produce 108,000 tons of frass per year. Revenue from the sale of the frass was estimated at 5.1 to 47 million U.S. dollars. Similar studies identified the potential technical and economic feasibility of rearing BSF larvae (Abro *et al.*, 2020; Chia *et al.*, 2019). A study by Beesigamukama *et al.* (2022) in Nairobi, Kenya found that producing frass fertilizer among farmers rearing BSF as a feed supplement would create additional revenue. Although recent studies have identified the nutritional composition of frass, technical efficiency, and ecological value of rearing BSF as a waste recycler, there is limited research on the economic benefits of producing frass among households. Beesigamukama *et al.* (2022) estimated the technical and economic value of producing frass for maize production. However, the study by Beesigamukama *et al.* (2022) did not consider the cost effectiveness of producing frass compared to conventional compost. This study contributed to literature by evaluating the cost effectiveness of recycling organic waste into frass fertilizer by comparing it with conventional compost. This study also discussed externalities (immaterial benefits)

associated with recycling organic waste into fertilizer among households based on existing literature.

Ng'ang'a *et al.* (2021) study on cost and benefit analysis of climate smart agriculture in Ghana indicated that the cost effectiveness of adopting technologies is assessed by computing the CBA decision indicators. The study further stated that economic CBA indicators assess the private profitability, environmental and social effects of the adopted technology, thus an ideal approach for assessing cost effectiveness. However, this study will adopt financial CBA indicators to assess the cost effectiveness of recycling organic waste into fertilizer using BSF compared to conventional composting. Additionally, the study will discuss externalities such as GHG emissions, social impact on labour, soil health and crop health using information derived from relevant literature and experiments conducted by research institutions and government agencies.

Mogaka *et al.* (2022) study on comparative profitability and relative risk of adopting climate-smart soil practices in Western Kenya and Oberndorfer *et al.* (2020) on probabilistic and deterministic approaches for risk assessment in the Eastern European Alps, stated that studies employing CBA methodology often use deterministic approaches. The shortcoming of using a deterministic approach is that it does not consider the uncertainty and variability of the resultant indicator because the value attached to the variables is calculated at the mode or mean. Failing to consider uncertainty and variability results in overlooking or underestimating the risks that a household takes when deciding on the method they will use in recycling organic waste into fertilizer. Ng'ang'a *et al.* (2021) study on cost and benefit analysis of climate smart agriculture in Ghana stated that incorporating sensitivity analysis overcomes the shortcoming as it allows for robustness in the range of values that can establish the level of risk under certain scenarios when input variables change. Sain *et al.* (2017) study on costs and benefits of climate-smart agriculture in Guatemala further indicated that another method for overcoming the deterministic approach shortcoming is using a probabilistic approach, which allocates likelihood to each range of values for the indicators allowing for robust values. However, using probabilistic values result in complex net present values that may complicate the analysis and interpretation of the results. Therefore, this study adopted a CBA methodology incorporated with sensitivity analysis.

2.2.3 Effect of recycling organic waste into fertilizer using BSF on household income

A study by Beesigamukama *et al.* (2022) determined the ecological and economic benefits of using frass fertilizer on maize productivity in Nairobi, Kenya. The study revealed that households that obtained organic waste from the farm had positive net income, while those that amended the fertilizer received higher income. However, Beesigamukama *et al.* (2022) did not establish the income earned from recycling the organic waste to produce frass fertilizer, in addition to using an econometric model to determine the effect of adopting BSF on household income.

Apart from Beesigamukama *et al.* (2022), to the best of my knowledge, the effect of adopting BSF for recycling organic waste into frass on household recycling income is unknown. The empirical review was therefore, on the effect of adopting agricultural technologies on household income. Wordofa *et al.* (2021) determined the impact of adopting improved agricultural technologies on household income using the propensity score matching (PSM) estimation model in eastern Ethiopia. The study revealed that households that adopted the improved technologies obtained higher farm income than those that did not. The farm income estimation was robust, as confirmed by the convergence of the matched algorithms and quality analysis results. A related study by Munongo & Shallone (2013) on the role of agricultural technologies in improving rural household welfare in Masvingo, Zimbabwe, revealed that household that adopted agricultural technology increased their consumption expenditure and farm income, and as a result, general household welfare improved. Yang *et al.* (2021) on whether the influence of cooperatives participation on technology adoption improves farmers' welfare in China, further stated that the effect on farm income was more significant among low-income households than their high-income counterparts. However, using PSM does not account for unobservable variables like the household head's innate perceptions, attitudes, motivations, entrepreneurial skills, and network ties that influence the outcome. Moreover, factors influencing a household's choice of a technology could also affect household income, causing endogeneity issues that the PSM model does not control.

An ordinary least square (OLS) regression model is also used to model the effect of adopting technology on household income (Getacher *et al.*, 2013). Mango *et al.* (2018) used multiple OLS regression to determine the impact of adopting irrigation farming on household income in Chinyanja Triangle, Southern Africa. The findings indicated that technology adoption was significant and explained the variation in the farm income earned. The findings were consistent with Jemutai *et al.* (2021) on assessing the influence of adoption and use of Modern

honey in Baringo, Kenya, who using OLS, found that adopting honey harvesting technologies had positive impact on household income. However, OLS regression is limited as it does not control for endogeneity problem. Additionally, the choice of adopting BSF could have self-selection bias which the OLS model does not control.

The Endogenous Switching Regression (ESR) model overcomes the endogeneity problem and the self-selection bias arising from unobservable and observable variables (Heckman, 1979; Ma & Abdulai, 2016; Tesfaye *et al.*, 2016). Mujeyi *et al.*, (2021) used endogenous switching regression to determine the impact of adopting climate-smart agriculture on household welfare in Zimbabwe. The results indicated that adopting CSA innovations positively and significantly impacted farmers' welfare. The education level of the household head, asset ownership, livestock units, and family labour size greatly influenced household income. The average treatment effect (ATE) from the ESR shows that non-adopters of the CSA innovations would increase income if they had adopted the CSA technologies. The findings were consistent with Ogada *et al.* (2020) study on climate-smart agriculture, household income and asset accumulation among smallholder farmers in the Nyando basin, Kenya and Wekesa *et al.* (2018) study on effect of climate-smart agricultural practices on household food security in smallholder production systems in Kenya, which indicated that the adoption of CSA technologies positively impacted household welfare. This study determined how adopting BSF technology in recycling organic waste into fertilizer affects household recycling income. It adopted the ESR model because it controls for selection bias in choosing an organic waste recycling approach. It also controls for the endogeneity between household income and the choice of a recycling approach.

A related study by (Wu, 2022) on adopting agricultural technology on farm income in China used endogenous switching regression. Farmer characteristics and resource endowment influenced the adoption of the technology. The farm families that adopted the new technology positively and significantly affected their farm income. Twumasi *et al.* (2021) used ESR to establish the impact of cooperative membership on household income in Ghana. The study identified that education level, off-farm work, peer influence, and access to financing influenced the fish farmers' choice to join a cooperative. The study further indicated that household head participation in off-farm activities negatively influenced farm income. The findings were consistent with Ma & Abdulai (2016) study on whether cooperative membership improve household welfare in Ghana and Siaw *et al.* (2020) study on the impact of internet use on income

in rural Ghana, who stated that off-farm activities reduced attention and time needed to increase farm production, and thus farm income was affected. In this study, some of the explanatory variables used by Twumasi *et al.* (2021) and Wu (2022) to determine the effect of recycling organic waste into fertilizer using BSF on household recycling income are adopted.

2.3 Theoretical framework

The study adopted the theory of cost-benefit analysis and utility maximization theory. The cost benefit analysis theory ensures that productive resources are allocated efficiently and determines the welfare outcomes attributed to private and public investment decisions (European Commission, 2014). On the other hand, utility maximization theory ensures individuals select investment options based on the utility they derive from them. This study sought to model the recycling of organic waste investment using BSF based on its economic benefits and costs, factors influencing adoption, and impact on household income.

2.3.1 Theory of cost-benefit analysis (CBA)

CBA theory is primarily concerned with efficient allocation of resources. It directly follows the body of resource allocation theory and economic theory. The theory also rests on modern welfare economics which aggregates the utilities/wellbeing of individuals as a measure of societal wellbeing. The main goal of CBA theory is allocative efficiency which requires that a preferred investment option achieves greater benefits than costs, given there are no constraints. The theory expresses the value of change in utility based on the economic options households consider for adoption in monetary terms, that is the monetary significance of adopting an investment option. The significance attached involves an explicit decision on whether the monetary benefits are worth incurring the cost of investing in a given technology. An investment option/technology is considered viable and suitable for adoption if benefits exceed costs.

The principle of Pareto efficiency stems at the heart of welfare economics. An allocation of resources is Pareto efficient when there is no other way to allocate resources to someone without making another party worse off. Thus, the CBA theory ensures that economic surplus from adopting a technology permits gainers to compensate losers. (Boardman, 2015). Moreover, Kaldor-Hicks (K-H) principle which is an improvement of Pareto efficiency, states that a technology should be adopted and regarded as improving welfare if the gainers either satisfy the

Pareto criterion or they could compensate those who have not adopted the technology as well off as they would have been without the technology. This criterion enables an analyst to gauge a technology based on whether economic welfare was increased, decreased or left unchanged after adopting the technology. CBA theory offers a decision rule where adopting a technology leads to greatest Pareto improvement if the benefits exceed costs.

In this study, a household recycling organic waste into fertilizer either adopt BSF technology or use conventional windrow composting method. The attractiveness of adopting BSF technology depends on individual, household and institutional characteristics. Economic indicators such as net present value (NPV), internal rate of return (IRR), benefit-cost ratio (BCR), and return on investment (ROI) offer a decision framework against which households can assess the economic viability of adopting BSF technology. The theory assumes that a household would adopt an economically efficient technology option where economic and financial benefits exceeds costs, and affects household income positively. (Turečková & Nevima, 2020). The implication is that the adopters are better off with the gains from adopting an economically efficient approach even after compensating the losers. Therefore, adopting a cost-efficient method for recycling organic waste into fertilizer leads to Pareto improvement.

The CBA tool was, therefore, best suited to determine the cost effectiveness of adopting BSF for recycling organic waste into fertilizer *visa vis* conventional windrow composting. Additionally, a more comprehensive analysis incorporating the sensitivity analysis assessed the relative risk that a household considers in choosing BSF over conventional composting.

2.3.2 Utility maximization theory

Utility maximization theory focuses on how individuals make choices and decisions. It provides a framework for understanding how individuals evaluate and select among various options based on their judgments and preferences of value and satisfaction. This theory is grounded in the individual's preference-indifference relationship for a defined set X of bundles x , y , and z interpreted as decision-making options. This study considers a household H_I that wishes to maximize utility, subject to certain constraints in recycling organic waste. This household will adopt a new recycling technology (such as BSF) when the utility derived from adopting the technology exceeds the utility of using the current technology (conventional composting). The utility derived from the use of BSF is postulated to be a function of a vector of observed sociodemographic, institutional, and farm-level characteristics (X_i) and a random disturbance term

having a mean of zero, arising from unobserved variation in preference for BSF over conventional, composting, and errors in optimization.

If a household adopts BSF is denoted by $U_{bsf}(X)$, and preference for continued use of conventional composting as $U_{bau}(X)$, then the decision to adopt a recycling technology is expressed as:

$$U_{bsf}(X) = X \beta_{bsf} + e_{bsf} \quad (1)$$

Where β_{bsf} is response coefficients, e_{bsf} is random disturbances associated with adopting BSF. The probability of a household adopting BSF could be denoted by a dichotomous variable Y , which assumes a value of 1 if a household adopts BSF and zero if otherwise. Upon adoption of BSF in recycling organic waste for recycling organic waste into fertilizer, disaggregation of impacts on recycling income among adopters and non-adopters can be established.

2.4 Conceptual framework

The use of insect-based technologies such as BSF in managing organic waste is emerging in urban and peri-urban areas of Kenya because the insects transform the organic waste rapidly into a high nutritional composition fertilizer with reduced environmental and public health footprint. However, determinants of adopting BSF in recycling organic waste, the cost effectiveness of using the BSF compared to the conventional windrow composting and the effect of using BSF on household recycling income is unknown. This study added to body of knowledge by determining the factors influencing the adoption of BSF, the cost effectiveness of adopting BSF in recycling organic waste into fertilizer, and its effect on household recycling income in Kiambu County, Kenya.

Sociodemographic, institutional, and farm level/production characteristics influenced the adoption of BSF as a technology for recycling organic waste into fertilizer. Sociodemographic characteristics included age, years of schooling, experience in recycling organic waste, perception on recycling organic waste into fertilizer, income earned from agri-related activities, livestock ownership, and household size. Institutional characteristics included access to recycling information, belonging to recycling groups, access to financial support for recycling, and distance to source of waste. Farm-level characteristics include size of recycling land (Figure 2.1). These characteristics influence household choice of BSF for recycling organic waste into fertilizer. The cost effectiveness of BSF compared to conventional windrow composting is in turn influenced by production requirements such as initial investment, operating costs and revenue. The cost

effectiveness of the BSF technology influences the gross income that households earn and directly impacts household welfare indexed using recycling income. Therefore, there was a need to establish the cost effectiveness of using BSF in recycling organic waste compared to conventional windrow composting so as to contribute to improved livelihood and environmental conservation through the use of a sustainable and cost-effective technology.

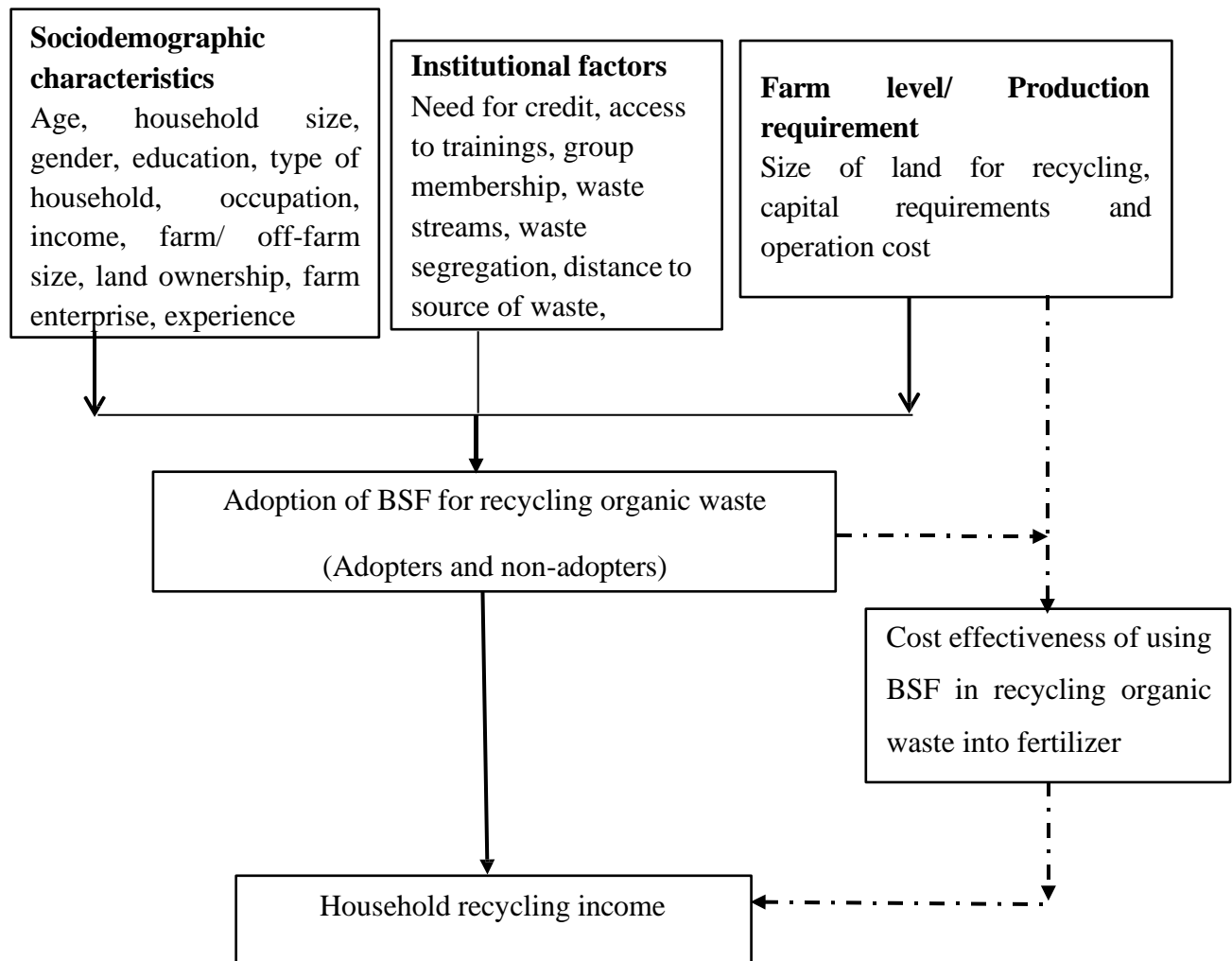


Figure 2.1: Conceptual framework

Source: Own conceptualization

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study was conducted in Kiambu County, Kenya (Figure 3.1). The County was purposively selected because recycling of organic waste had been promoted by *icip*e and the County government. Moreover, it hosts the biggest number of organic waste recyclers into fertilizer using both BSF and conventional windrow composting methods. The County borders Nyandarua County to the North West, Murang'a to the North and North East, Kajiado and Nairobi to the South, Machakos to the East, and Nakuru to the West. It is located between latitudes $00^{\circ} 25'$ and $10^{\circ} 20'$ South of the Equator and longitude $36^{\circ} 31'$ and $37^{\circ} 15'$ East. The county occupies an area of approximately $2,543.5 \text{ km}^2$ (County Government of Kiambu, 2018)

Kiambu County has 12 sub-counties: Thika Town, Kikuyu, Lari, Ruiru, Gatundu South, Kabete, Gatundu North, Kiambu, Githunguri, Kiambaa, Juja, and Limuru. Major urban centres include Githunguri, Kiambu, Ruiru, Thika Town, Kiambaa, and Juja. The county has four topographical zones; Lower Midland, Upper Midland, Upper Highland, and Lower Highland. The primary economic activity in the County is agriculture production, mainly livestock (pigs, poultry, and dairy), food crops (beans, Irish potatoes, bananas, pineapples, beans, vegetables, and maize), and industrial crops (tea and coffee). The agricultural sector supports the livelihood of the residents and employs around 304,449 directly and indirectly (County Government of Kiambu, 2018). The number of households in Kiambu County is 796,147 (KNBS & ICF, 2023). The county produces over 600 metric tonnes (MT) of waste daily. The waste comprises mainly agricultural, market, domestic, industrial, and hospital waste.

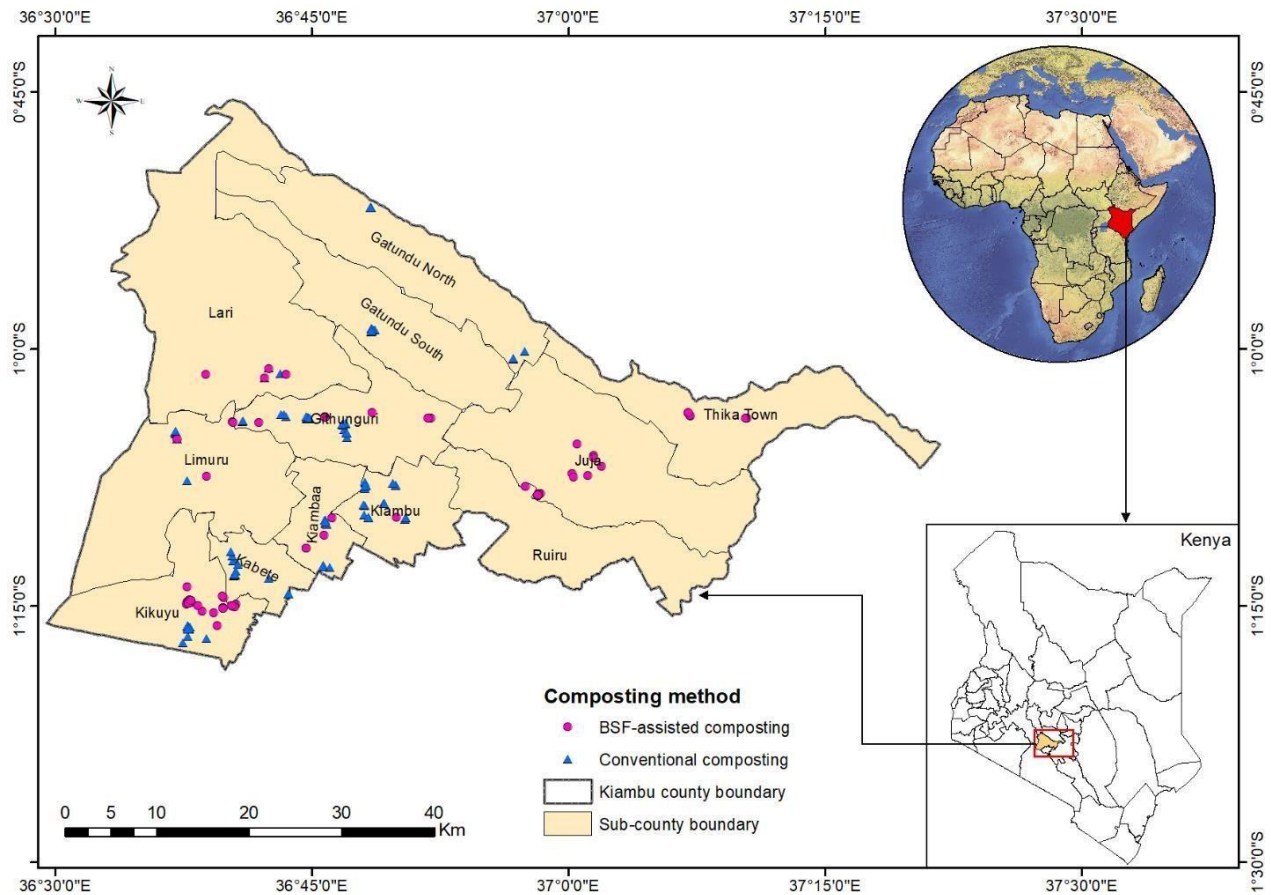


Figure 3.1: Map of the study area

Source: Geographic Information System (GIS) based on sampled households

3.2 Research design

The study adopted a survey research design. The design was suitable because data was collected from a representative sample over a relatively short time, and much information was collected during the exercise.

3.3 Target population

The study targeted households' recycling organic waste into fertilizer using BSF technology or conventional windrow composting. There were 105 households recycling organic waste using BSF and 395 households recycling organic waste using conventional windrow composting, totaling to 500 households. Female and male respondents actively involved in the recycling process and decision-making were interviewed.

3.4 Sample size determination and sampling procedure

The study employed a multistage sampling technique in selecting households using BSF and conventional composting households. In the first stage, Kiambu County was purposively selected because it hosts the highest number of households recycling organic waste into fertilizer. In the second stage, all the 12 sub-counties in Kiambu County were selected to cover a wide geographical area and incorporate diverse socioeconomic, institutional, and production requirement characteristics. Two wards were purposively selected in the third stage because the producers are not evenly distributed within the sub-counties. The final sampling unit (respondent) was chosen randomly from a list provided by the County Department of Agriculture, Livestock, and Fisheries for households using conventional composting. Each producer/household was given a unique identifier and respondent chosen randomly from each ward based on the sample size illustrated in table 3.1. On the other hand, census was conducted for all households recycling organic waste into fertilizer using BSF based on a list provided by *icip*e and lead farmers.

Yamane (1967) suggested that when the population is known, the sample size is calculated at a confidence level of 95% and 0.05 precision.

$$n = \frac{N}{1+N(e^2)}$$
$$n = \frac{500}{1+500(0.05^2)} = 222 \quad (1)$$

where n is the sample size, N is the target population, and e is the acceptable margin of error. The sample size comprised of 117 households using conventional windrow composting sampled proportionately per sub county (Table 3.1) and 105 households using BSF in recycling organic waste into fertilizer. The BSF-assisted composting producers were selected using a census, while the conventional windrow composting producers were selected proportionately.

Table 3.1: Sample distribution across the study area

	Location	Sample size
BSF	Kiambu County	105
Conventional composting	Kiambu sub-county	$\frac{75}{500} = 0.15 * 100 = 15$
Conventional composting	Kiambaa sub-county	$\frac{61}{500} = 0.12 * 100 = 12$
Conventional composting	Juja sub-county	$\frac{39}{500} = 0.08 * 100 = 8$
Conventional composting	Ruiru sub-county	$\frac{20}{500} = 0.04 * 100 = 4$
Conventional composting	Thika Town	$\frac{35}{500} = 0.07 * 100 = 7$
Conventional composting	Lari	$\frac{45}{500} = 0.09 * 100 = 9$
Conventional composting	Gatundu North	$\frac{36}{500} = 0.07 * 100 = 7$
Conventional composting	Gatundu South	$\frac{39}{500} = 0.08 * 100 = 7$
Conventional composting	Kabete	$\frac{44}{500} = 0.09 * 100 = 9$
Conventional composting	Githunguri	$\frac{56}{500} = 0.11 * 100 = 11$
Conventional composting	Kikuyu	$\frac{54}{500} = 0.11 * 100 = 11$
Conventional composting	Limuru	$\frac{86}{500} = 0.17 * 100 = 17$
Total		222

3.6 Data collection and analysis

Data was collected from primary and secondary sources. The primary data was collected using a semi-structured questionnaire (Appendix D). The questionnaire comprised of closed and open-ended questions based on the specific objectives and research questions. The data entailed sociodemographic, institutional, and production characteristics. Census and Survey Processing System (CSPRO) data collection tool was used to administer face-to-face interviews by trained enumerators. A pretest was conducted in Matungulu Sub County, Machakos County to test the validity of the questionnaire and econometric models. The secondary data was collected from in-depth literature review of relevant databases and published literature of research institutions and government agencies. Search engines such as Google scholar, Web of Science and Scopus were

used to access the published literature. The search items were BSF farming, bioconversion of organic waste using BSF, environmental implications of BSF farming, social impacts of farming BSF, and crop and soil health from using BSF frass and compost. Households recycling organic waste were the unit of analysis. EXCEL tool and STATA software were used in cleaning and running descriptive analysis and econometric models.

3.7 Model specification and analysis

3.7.1 : To determine the factors influencing the adoption of Black soldier fly for recycling organic waste into fertilizer among households in Kiambu County

Empirical evidence derived from previous agricultural technologies adoption studies informed the selection of variables used in the model. Factors that influence choice of method for recycling include household characteristics (age, gender, education, family labour, experience), asset ownership and institutional factors (farm size, size of farm for recycling, access to extension, group membership), perceived benefits (diversification, nutritional composition, profitability) and market factors (distance to source of waste, value addition, segregation) (Alhassan *et al.*, 2020; Kabasiita *et al.*, 2021). In order to make contribution to household improvements in terms of welfare through increasing households' willingness to adopt recycling technologies, it is imperative to identify factors that influence the household's choice of approach for recycling and welfare variables (household income). Farming households are considered heterogenous agents and their choices regarding adoption of new recycling technologies are influenced by access to information, resources and the technology itself (Mujeyi *et al.*, 2019).

Households are likely to invest in new technologies if the perceived benefits exceed the costs. Consequently, the decision to adopt recycling technologies can be seen via the cost benefit analysis and modern welfare lens, where the household chooses to adopt a recycling technology if it is projected to be beneficial, accessible and affordable. A combination of observable and non-observable factors determine the expected benefits. Farm households are rational; thus, they adopt organic waste recycling technologies that produces fertilizer that suit their farm fertilization requirements.

To determine the factors influencing the choice of an approach for recycling organic waste into fertilizer, the study adopted a logistic regression model. The logistic model was preferred to linear models like the Linear Probability model and Ordinary Least Square because it fits best

when the dependent variable is dichotomous. The dichotomous nature of the dependent variable violates the assumption of linearity in ordinary regression. The logistic model corrects the problem by transforming the dependent variable into logs, allowing for modeling nonlinear dependence linearity. The logistic model was preferred to the Probit model since it relies on log odds, which are transformed into odds ratio, making interpretation easier (Greene, 2012). Additionally, the use of Multinomial regression in this analysis would be misleading because it assumes that the dependent variable has more than two outcomes.

Greene (2012) stated that the functional form of a binary logistic regression model is specified as illustrated in equation (2);

$$P = (Y = 1) = \frac{e^{\beta X_i}}{1 + e^{\beta X_i}} \quad (2)$$

with a cumulative distribution function as illustrated in equation (3);

$$F(\beta x) = \frac{1}{1 + e^{\beta X_i}} \quad (3)$$

where Y = choice of an approach for recycling organic waste (specified as 1 if a household adopts BSF and 0 if the household uses conventional composting, X_i are the explanatory variables, and β s are the estimated parameters. Equation (2) can also be written as illustrated in equation (4);

$$P_i = \frac{1}{1 + e^{-Z_i}} \quad (4)$$

The probability that a producer household chooses to adopt BSF for recycling organic waste is illustrated in equation (4) and can be illustrated as is the odds ratio illustrated in equation (5);

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{1 + e^{-Z_i}} \quad (5)$$

where $\frac{P_i}{1 - P_i}$ is the odds ratio (choice of BSF over conventional composting) in favour of a household choice of adopting BSF. Therefore, taking the natural logarithms of equation (5) will be expressed as illustrated in equation (6);

$$L_i = \ln \left[\frac{P_i}{1 - P_i} \right] = Z_i = \beta_0 + \beta_1 X_1 + \dots + \beta_n X_n + \varepsilon \quad (6)$$

where P_i is the probability that a household adopts BSF as an organic waste recycling approach, which ranges between 1 and 0, Z_i is a function of n explanatory variables, and X_i is a vector of the explanatory variables. The probability that a household adopts BSF in recycling organic waste is denoted by 1 and 0 if a household adopts windrow composting. β_0 is the intercept,

$\beta_1 \dots \beta_n$ are coefficients of the model, and ε is the error term. The probability that a producer household adopts BSF in recycling organic waste was modelled as follows;

$$Z_i_{BSF} = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Education} + \beta_3 \text{Familylabor} + \beta_4 \text{Frmsize} + \beta_5 \text{Frmfertilizer} + \beta_6 \text{Segregation} + \beta_7 \text{Distancewaste} + \beta_8 \text{Experience} + \beta_9 \text{Accessinfo} + \beta_{10} \text{Groupmem} + \beta_{11} \text{Product} + \beta_{12} \text{Profitability} + \beta_{13} \text{Nutritionalcomp} + \beta_{14} \text{Valueaddition} + \varepsilon \quad (8)$$

The explanatory variables (Table 3.2) that were used to determine the choice of BSF for recycling organic waste were adapted from previous studies on the adoption of environmental and agricultural technologies (Alhassan *et al.*, 2020; Kabasiita *et al.*, 2021; Nsimbe *et al.*, 2018; Onyia *et al.*, 2020; Wang *et al.*, 2018). The study hypothesizes that age is a proxy for expertise, with older household heads expected to be more aware of environmental and agricultural innovations (Alhassan *et al.*, 2020; Asante *et al.*, 2024). However, older household heads are often characterized by risk aversion, which results in a reduced propensity to engage in activities that could increase their adoption of agricultural and environmental innovations (Foster & Rosenzweig, 2019). This risk aversion reduces their willingness to learn about and adopt new technologies. Fisher *et al.* (2018) observed a negative correlation between the age of household heads and their familiarity with advanced conservation agriculture practices, such as crop rotation and the use of organic manure. As a result, the effect of age on the adoption of agricultural and environmental innovations remains ambiguous. The study also hypothesizes that experience is linked to training and knowledge regarding agricultural and environmental technologies, which in turn influences their adoption. However, Asante *et al.* (2024) stated that experienced farmers tend to be more conservative in adopting modern technologies.

The study hypothesizes that educated household heads are more knowledgeable about agricultural/environmental technologies than those with lower education levels. Materu *et al.* (2016) stated that educated households were more innovative and receptive to adopting new technologies. Alatinga and Williams (2019) reinforced these findings by indicating that individuals with higher levels of education quickly process information on new technologies and are more likely to adopt technologies compared to those with lower levels of education (Liu *et al.*, 2024; Nsimbe *et al.*, 2018).

Several studies have found a positive relationship between farm size, livestock ownership, farm income, and adoption of technologies (Allahyari *et al.*, 2017; Fisher *et al.*, 2018). Ownership of assets such as land, livestock, and farm income can be used as collateral to access financial

services, thus driving adoptability (Fisher *et al.*, 2018). This study hypothesizes that an increase in farm size, livestock ownership (a proxy for ownership of productive assets), and off-farm income are positively related to households' adoption of BSF in recycling organic waste. Household size is a proxy for resource endowment in terms of labour, contributing to the adoption of agricultural/environmental technologies, which are somewhat labour-intensive (Kabasiita *et al.*, 2021). This study hypothesizes that an increase in household size is related to the adoption of BSF.

Efficient dissemination of information is vital in adopting agricultural/environmental technologies. Asante *et al.* (2024) found that access to extension information is a key driver in facilitating the adoption of agricultural technologies. Moreover, belonging to social associations increases the desire among households to adopt agricultural technologies (Onyia *et al.*, 2020; Yu *et al.*, 2021; Zhang *et al.*, 2020). This study hypothesizes that access to information on efficient waste management and belonging to social associations (agricultural/environmental groups) is related to the adoption of BSF. Moreover, household adoption of technologies is influenced by their perception of the technology (Hassan *et al.*, 2020). The study hypothesizes that positive perception is related to the adoption of BSF for recycling organic waste.

To test the robustness of the study findings, this study conducted diagnostic tests for heteroscedasticity using white test and multicollinearity using Variance inflation factor. The White test offers an advantage over the Breusch-Pagan test as it is capable of identifying both linear and non-linear forms of heteroskedasticity by considering the magnitude and direction of the changes (Uyanto, 2022).

Table 3.2: Descriptions of variables used in the binary logistic model

Variable	Definition	Expected sign
Dependent		
Method	Method of recycling organic waste (1 = BSF, 0 = Conventional composting)	
Independent		
Age	Age of the household head in years	+
Education	Number of years of schooling	+
Familylabor	Number of household members engaged in recycling organic waste	+/-
Frmsize	Size of land used for agricultural production in acres	+/-
Frmfertilizer	Size of land used in recycling organic waste in square paces	+
Ofrmincome	Income earned by the household from off farm activities (USD)	+/-
Livestockown	Type of livestock owned by household (1 = dairy, 0 = small ruminants and non - ruminants)	+/-
Segregation	Segregation or access to segregated waste (1 = yes, 0 = No)	+/-
Distancewaste	Distance to source of waste in walking minutes	+
Experience	Number of years the household has been recycling organic waste into fertilizer	+
Accessinfo	Access to environmental/agricultural information on recycling organic waste (1 = Yes, 0 = No)	+/-
Valueadition	Value addition/amendment/processing of the organic fertilizer (1 = Yes, 0 = No)	+/-
Groupmem	Number of groups/social associations a household belongs	+
Product	Perception on diversification of products recycled from organic waste (1 = Yes, 0 = No)	+/-
Profitability	Perception on profitability of recycling organic waste into fertilizer (1 = Yes, 0 = No)	+/-
Nutrionalcomp	<u>Perception that nutritional composition influenced by method of recycling organic waste (1 = Yes, 0 = No)</u>	+/-

3.7.2 : To evaluate the cost effectiveness of recycling organic waste into fertilizer using BSF among households in Kiambu County

In determining the economic benefits of using BSF in recycling organic waste into fertilizer, this study adopted an allocative efficiency perspective that determines the cost effectiveness of using BSF compared to conventional windrow composting. CBA methodology

allows computations for estimating the cost effectiveness of using BSF in recycling organic waste into fertilizer compared to conventional composting. The study considers not only the net present value (NPV) and internal rate of return (IRR) but also the return on investment (ROI), benefit-cost ratio, and sensitivity analysis, which allows for risk assessment. Based on the empirical literature, the study will adopt a CBA methodology that adopts a deterministic approach incorporated with sensitivity and scenario analysis to determine the cost effectiveness of approaches for recycling organic waste into fertilizer among producer households. The CBA tool has four decision indicators: NPV, BCR, IRR, and ROI (Ng'ang'a *et al.*, 2021). The study adopted the approach used by Mogaka *et al.* (2022) and Akinyi *et al.* (2021) to determine the cost effectiveness of using BSF in recycling organic waste into fertilizer compared to conventional composting.

The NPV is the present value of discounted future net benefits. A project is deemed viable when $NPV > 0$ and rejected if otherwise.

$$NPV(B, C) = \sum_{t=0}^T \frac{Bt}{(1+r)^t} - \sum_{t=0}^T \frac{Ct}{(1+r)^t} \quad (9)$$

where t is the lifecycle of transforming the organic waste into fertilizer, B is the benefits, C is the costs, and r is the discount rate (12%, which is the opportunity cost of capital (Central Bank of Kenya lending rate)). This study compared the benefits and costs of adopting BSF for recycling organic waste into fertilizer to conventional windrow composting.

The IRR calculates the discount rate at which the NPV has a zero-value equation. (10) and compares it with the predetermined discount rate (r). An investment is profitable if the IRR exceeds the discount rate.

$$\left(B_0 + \frac{Bt}{(1+i)^t} \right) - \left(C_0 + \frac{Ct}{(1+i)^t} \right) = 0 \quad (10)$$

where i is the discount rate

The benefit-cost ratio is illustrated in equation (11)

$$\frac{B}{C} = \frac{\sum_{t=0}^T \frac{Bt}{(1+r)^t}}{\sum_{t=0}^T \frac{Ct}{(1+r)^t}} \quad (11)$$

where B represents the benefits, C represents the costs, r represents the discount rate, and t represents the time in years. The recycling approach is profitable if the ratio is greater than one and positive, which implies that the approach has residue benefits after offsetting all costs incurred.

The Return on Investment measures the gains/loss accrued from an investment relative to the money invested. An investment is profitable when the ROI is higher.

$$\text{Return on investment (\%)} = \frac{\text{net income}}{\text{total variable costs}} \times 100 \quad (12)$$

When computing the decision indicators (Table 3), the following assumptions were used.

- i. Costs and revenues were expressed in US dollar, and all prices were estimated based on the previous production cycle.
- ii. The prices of the fertilizer and dried larvae were inclusive of taxes
- iii. The discount rate (12%) controlled for the inflation rate (CBK, 2023)
- iv. The lifecycle for recycling organic waste among households was arbitrarily selected to be 10 years
- v. The computation of the costs did not account for depreciation, interest on capital, sunk cost, and land value.

The variables in Table 3.3 were used in the analysis, where the different cost and revenue components were used to estimate the net benefits (Akinyi *et al.*, 2021; Mogaka *et al.*, 2022). The variables used were classified as random and non-random. Random variables take any values within possible values and are evaluated on a continuous scale. These variables are influenced by household characteristics, attributes of recycling methods, and biophysical factors, and they include installation costs such as greenhouse, recycling equipment prices, inputs, maintenance costs, and the time in years when the facility is operational. The non-random variables are beyond the control of the household and are determined by market forces of demand and supply and monetary policies. They included output prices, discount rate, and life cycles and were evaluated at the mean (Mogaka *et al.*, 2022).

Table 3.3: Description of variables in the CBA methodology

Variable	Description and Measurement	Nature
Initial investment capital (C_j)	Initial capital requirement for establishing an organic waste recycling unit. They include production unit, weighing machine, waste holding containers, BSF eggs/larvae (USD)	Random
Variable cost (C_j)	Costs incurred during organic waste recycling into fertilizer. They include labour, electricity, water, permit (USD)	Random

Output (Q)	Quantity of frass, compost, and dried larvae produced (Kgs)	Random
Output prices (P _j)	Current market prices for output (KES)	Non-random
Discount rate (r)	Average discounting rate for Central Bank of Kenya (12 %)	Non-random
Lifecycle (t)	The expected lifecycle in years by the producers.	Non-random

Note: KES = Kenyan Shillings, Kgs - Kilograms

3.7.3 Sensitivity analysis

A sensitivity analysis illustrates the effect of uncertainty/variations in a variable on the NPV. Sensitivity analysis identifies critical variables whose positive or negative variations significantly impact the project's economic and financial performance. In this study, the optimistic-pessimistic scenario was applied. It involved assigning optimistic (most favourable) and pessimistic (least favourable) values and computing the effect on NPV, *ceteris paribus*. Variables considered in this analysis included production cycle, annual labour cost, lifecycle, price per kg of frass fertilizer, price per kg of dried larvae, frass output per 1 M.T. of organic waste, 1 M.T. of organic waste, initial investment and cost of buying waste. Based on the assumptions of a perfect market, an arbitrary 10% change in the variables was chosen. The critical variables should be independent and not correlated to avoid double counting and distorted results.

The optimistic scenario included an increase of 10% in price per kg of frass fertilizer, price per kg of dried larvae, quantity of frass and dried larvae produced per 1 M.T. of organic waste, production cycle, and a decrease of 10% in the initial investment capital, cost of buying waste, annual labour cost. The contrary variation was used in the pessimistic scenario. Critical variables were variables in which a variation of +/- 10% of the value in the base case had a more than 10% variation on NPV (European Commission, 2014). The project is less risky if NPV is positive in both optimistic and pessimistic scenarios.

3.7.4 Externalities

Cost effectiveness of recycling organic waste into fertilizer using BSF larvae, also involves determination of immaterial benefits (externalities) such as effect on soil health, crop yield, GHG emissions, and social impact from adoption of BSF compared to conventional composting. The

Systematic Literature Review methodology was applied in determining the externalities. In the first step, web of science and google scholar search engines were used to identify literature related to organic waste management using composting/ BSF-assisted composting methods, economic aspects of composting, technologies used in composting, environmental effects of composting using BSF, social impact of farming BSF and crop yield and soil health using BSF frass/ compost. Duplicate fields were then dropped in the second step followed by screening to filter the irrelevant records based on research title. Full articles were then assessed for eligibility and those not mentioning the externalities excluded.

3.7.5: To determine the effect of recycling organic waste into fertilizer using BSF on household recycling income

To determine the effect of recycling organic waste into fertilizer using BSF on household welfare, the gross recycling income was used as the index. Welfare is defined as the overall utility obtained from all goods and services consumed by a household. Indicators used by researchers to measure welfare include income, consumption, food security, expenditure, poverty and asset-based wealth indices (Afolami *et al.*, 2015; Khonje *et al.*, 2015). This study used recycling income as the indicator because the main focus was on household livelihood related with recycling of organic waste and was computed as the total revenue generated from recycling of organic waste into fertilizer. Adopting BSF for recycling organic waste and producing organic fertilizer generates direct income through the sale of fertilizer and passive income through forgoing the cost of purchasing fertilizer and cost of disposing of the organic waste.

The study used endogenous switching regression (ESR) to determine the relationship between the exogenous variables and outcome variable (household recycling income). The simplest method to determine the effect of recycling organic waste into fertilizer using BSF on household recycling income was to use ordinary least squares (OLS) regression (Mango *et al.*, 2018; Getacher *et al.*, 2013). Using the OLS, a dummy variable equal to one is included in the household income equation if the household adopts BSF for producing fertilizer and equals zero if using a conventional method. However, the OLS method assumes that adopting BSF as a recycling technology is exogenously determined, yet it is probably determined endogenously. Additionally, the choice of a recycling method is voluntary and may have individual self-selection bias.

Propensity Score Matching (PSM) was also a potential model that allows for comparison between the average outcomes of the fertilizer producers by assigning a conditional propensity score value. The model allocates a conditional probability to a selected treatment and controls for the selection bias problem. However, the PSM model assumes that observable factors influence selection. The model, therefore, does not account for the unobservable characteristics of the treated and control units directly (Olwande *et al.*, 2015). Therefore, ESR is the most suitable model for determining the effect of recycling organic waste using BSF on household recycling income using the Full Information Maximum Likelihood estimation technique. The ESR model partitions the producers based on their selected method for producing organic fertilizer into treatment as a BSF approach and control as a conventional approach to account for the differential responses between the two categories (Coulibaly *et al.*, 2017). The ESR has two stages estimated simultaneously in STATA.

The first stage of the switching regression is a selection equation where households are faced with two options, to adopt BSF as an approach or not. The selection equation determines the relationship between selecting BSF and the possible factors influencing it. The equation was specified as follows:

$$Ai^* = \alpha Zi + \mu_i \quad (13)$$

$$Ai = 1 \text{ if } Ai^* > 0, Ai = 0 \text{ if otherwise'}$$

where; Ai^* = latent (binary) dependent variable for selection of BSF

α = vector of parameters estimated

Zi = vector of observable variables influencing the choice of BSF for recycling organic waste into fertilizer

μ_i = error term with mean zero and constant variance (captures unobservable factors).

The second stage of the ESR is an outcome equation, where the outcomes of the two regimes encountered by recycling household are estimated.

$$\text{Regime 1 (BSF adopters): } y_{1i} = \beta_1 X_{1i} + \varepsilon_{1i} \text{ if } Ai = 1 \quad (14)$$

$$\text{Regime 2 (BSF non-adopters): } y_{0i} = \beta_0 X_{0i} + \varepsilon_{0i} \text{ if } Ai = 0 \quad (15)$$

where; y_{1i} and y_{0i} represent outcome levels (household recycling income) for using BSF (adopters) and conventional composting (non-adopters), respectively.

β_1 and β_0 are parameters that were estimated.

X_{1i} and X_{0i} represents vector of estimated observable explanatory variables affecting the household recycling income

ε_{1i} and ε_{0i} are the error terms for using BSF and conventional methods

The ESR model compares the expected outcome (recycling income) among the households that adopted the technology (BSF) with respect to households that did not adopt it (conventional composting), and the expected recycling income counterfactuals that the BSF adopters had not adopted and the BSF non-adopters had adopted as illustrated in equation 16, 17, 18, 19 respectively. There is a possibility that some unobserved factors that influence adoption of BSF also influence household recycling income (outcome variable); that is, the error term of the selection and outcome equation may be correlated. In order to solve the correlation problem, the equations were estimated simultaneously.

An exclusion restriction was included to correctly identify the ESR model. Therefore, the model is identified more specifically by including instrumental variables that correlate with the choice of BSF for recycling but not with the household recycling income, the outcome variable (Olwande *et al.*, 2015). In this study, the variable used as selection instruments in the household income function were access to agricultural/environmental extension information and number of years they have been recycling organic waste. The variables were a valid instrument if they influence the adoption decision but not the net recycling income per metric ton of organic waste recycled. The study conducted a falsification test to ensure the validity of the instrumental variable (Di Falco *et al.*, 2011).

The expected net benefits will be presented in four scenarios as follows

$$E(y_{1i} | A_i = 1) = \beta_1 X_{1i} + \sigma_1 \mu \lambda_{1i} \text{ actual} \quad (16)$$

$$E(y_{0i} | A_i = 0) = \beta_0 X_{0i} + \sigma_0 \mu \lambda_{0i} \text{ actual} \quad (17)$$

$$E(y_{0i} | A_i = 1) = \beta_0 X_{1i} + \sigma_0 \mu \lambda_{1i} \text{ counterfactual} \quad (18)$$

$$E(y_{1i} | A_i = 0) = \beta_1 X_{0i} + \sigma_1 \mu \lambda_{0i} \text{ counterfactual} \quad (19)$$

where $\sigma\mu$ represents the covariance between the regime equation and error of selection, λ_i represents the inverse mill ratio computed from the probabilities estimated in the regime equations ($\sigma_1\mu = cov(\mu_i, \varepsilon_{1i})$; $\sigma_0\mu = cov(\mu_i, \varepsilon_{0i})$). The standard errors in the regime equations account for heteroscedasticity arising from the generated regressor (λ_i). The conditional and unconditional expected net farm income among the organic fertilizer producers using the two approaches were calculated based on the β_1 and β_0 .

Adopting the formulae of Kabunga *et al.* (2012) and Kassie *et al.* (2015), the average treatment effect (ATT) estimates the change in household recycling income among the adopters (those using BSF) and was estimated as (Table 3.4)

$$ATT = E (y_{1i} | A_i = 1) - E (y_{0i} | A_i = 1) \quad (20)$$

Similarly, the average treatment effect on household recycling income of using conventional methods in recycling organic waste was estimated as follows

$$ATU = E (y_{0i} | A_i = 0) - E (y_{1i} | A_i = 0) \quad (21)$$

Table 3.4: Average treatment effects on household recycling income

Transition heterogeneity	Decision stage		Treatment effects
Producers use	BSF approach	Conventional approach	
BSF composting	(a) $E(y_{1i} A_i = 1)$	(c) $E(y_{0i} A_i = 1)$	<i>ATT</i>
Conventional composting	(d) $E(y_{1i} A_i = 0)$	(b) $E(y_{0i} A_i = 0)$	<i>ATU</i>

where a and b are the actual expected net benefits, while c and d are counterfactual net benefits, $A_i = 1$ is the producer households using BSF composting, and $A_i = 0$ is the producer households using conventional composting. y_{1i} is the outcome indicator when producer households adopt BSF, whereas y_{0i} = otherwise. *ATT* is the average effect of the treatment on the treated (BSF approach), while *ATU* is the average effect of the treatment on the untreated (conventional approach). $i = 1$ for households using BSF composting, whereas $i = 0$ if otherwise.

The variables indicated in table 3.5 are variables of interest chosen based on related empirical literature and include family labour, distance to source of waste, perceptions on recycling organic waste, size of land used in recycling, value addition of the recycled products, waste segregation, group membership and household education level (Mango *et al.*, 2018; Mujeyi *et al.*, 2021; Twumasi *et al.*, 2021; Wordofa *et al.*, 2021; Wu, 2022).

Table 3.5: Description of variables used in the Endogenous switching regression model

Variable	Definition	Expected sign
Dependent		
Gross income	Gross income from recycling organic waste into fertilizer (USD)	
Independent		
Education	Number of years of schooling	+
Familylabor	Number of household members engaged in recycling organic waste	+/-
Frmsize	Size of land used for agricultural production in acres	+/-
Frmfertilizer	Size of land used in recycling organic waste in square paces	+
Segregation	Segregation or access to segregated waste (1 = yes, 0 = No)	+/-
Distancewaste	Distance to source of waste in walking minutes	+
Experience	Number of years the household has been recycling organic waste into fertilizer	+
Accessinfo	Access to environmental/agricultural information on recycling organic waste (1 = Yes, 0 = No)	+/-
Valueaddition	Value addition/amendment/processing of the organic fertilizer (1 = Yes, 0 = No)	+/-
Groupmem	Number of groups a household belongs	+
Perception	Perception on recycling organic waste into fertilizer (1 = positive, 0 = Negative)	+/-

Note: USD= United States Dollar

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter provides a comprehensive presentation of the findings and discussion derived from the analysis of the collected data. The results are organized into distinct sections aligned with the specific objectives of the study, ensuring a clear structure for the discussion of the research outcomes. The sections are three, namely: 4.1 Determining factors influencing adoption of black soldier fly for recycling organic waste into fertilizer, 4.2 Evaluating the cost effectiveness of recycling organic waste into fertilizer using black soldier fly, and 4.3 Determining the effect of recycling organic waste into fertilizer using black soldier fly on household recycling income in Kiambu County, Kenya.

4.1 Determinants of choice of adopting black soldier fly for recycling organic waste into fertilizer

Households recycle organic waste into fertilizer using BSF and conventional windrow composting. The chi-square was used to show the difference between the households using BSF and households using conventional composting with respect to the type of waste recycled. There was a statistically significant difference at 1% significance level between the type of waste recycled using the two methods (Table 4.1). The results revealed that majority of the households recycled livestock waste with 86.92% among those using BSF and 96.52% among those using conventional composting. The most probable reason for this observation is because agricultural production especially livestock is a major economic activity in Kiambu County, and thus, the need to recycle the high volumes of livestock waste generated (County Government of Kiambu, 2018). Moreover, the organic fertilizer produced is an essential soil amendment needed for optimal agricultural production among the farmers.

Households that recycle crop and agricultural waste were mainly those using conventional composting, with 99.13%, while those using BSF were 36.45%. On the other hand, food/ kitchen and market waste were mainly recycled by households using BSF (61.68% and 88.79%). This observation indicated that different types of waste were recycled using different methods. Food waste and market waste, which comprises the largest percentage of organic waste problem, was mainly recycled using BSF, revealing the potential of BSF in managing organic waste menace, especially in urban and peri-urban areas. Moreover, household rearing mainly small livestock

(pigs, poultry, rabbits), were observed to recycle waste using BSF (72.63%). This is because the waste was less fibrous and thus more palatable to the insects with little or no processing.

Table 4.1: Descriptive statistics on the type of waste recycled using BSF and conventional composting

Variable	Category of households using the waste	BSF-assisted composting (N = 105)		Conventional composting (N = 117)		Statistical difference (χ^2)
		No. of households	%	No. of households	%	
Livestock waste	Yes	93	86.92	111	96.52	$\chi^2 = 6.86^{***}$
Market waste	Yes	95	88.79	2	1.74	$\chi^2 = 170.71^{***}$
Food/kitchen waste	Yes	66	61.68	50	43.48	$\chi^2 = 7.36^{***}$
Crop/yard waste	Yes	39	36.45	114	99.13	$\chi^2 = 101.67^{***}$
Livestock type	Non-ruminant	69	72.63	39	36.79	$\chi^2 = 25.884^{***}$
	Ruminant	26	27.37	67	63.21	

Note: Significance level *** $p < 0.01$, Yes = households use the specific type of waste, No = households do not use the specific type of waste

The individual, household, and farm-level characteristics influencing the adoption of BSF in recycling organic waste are illustrated in Table 4.2. The t-test and chi-square were used to illustrate the difference between households using BSF and conventional composting with respect to continuous and categorical variables, respectively. The results revealed that there are significant systemic differences between farmers recycling organic waste using BSF and conventional composting in terms of individual and household characteristics, institutional factors, and production requirements.

For example, at individual levels, on average, households' heads using BSF were significantly younger (12 years), spent 5 years more in schooling than their counterparts using conventional composting. This is probably because younger farmers with higher levels of education are more likely to adopt new innovations and technologies in agriculture (Mwangi and

Kariuki, 2015). At household levels, households using BSF had slightly more family labour (2 members) than those using conventional composting. The most probable reason for this observation is because composting waste is compounded over time before the actual recycling is done and thus requires less labour during the composting process. Much labour is required when aggregating the materials for composting and was mainly hired. On the other hand, using BSF is a continuous process that takes less time but is labour intensive and has potential for creating employment for semi-skilled and unskilled individuals (Joly & Nikiema, 2019). At farm levels, households using BSF required 56% less land compared to their counterparts using conventional composting. Waste segregation was a significant practice with households using BSF segregating 36% more compared to those using conventional composting. The most plausible reason for this observation is that segregation enables specific waste combinations for recycling which is targeted for quality frass and larvae biomass.

Table 4.2: Descriptive summary statistics for variables used in logistic regression

Variable	Variable description	Mean		Statistical difference
		BSF-assisted composting (N = 105)	Conventional composting (N = 117)	
Age	Age of household head in years	43.94	56.19	t = 8.16***
Hhsize	Size of household members	4.92	4.21	t = -3.33***
Education	Number of years spent by household head in schooling	16.30	11.25	t = -11.05***
Farmfert	Size of land used for fertilizer/BSF production in square paces	27.05	42.37	t = 8.84***
Groupmem	Number of groups a household head belongs to that promote recycling of organic waste	2.35	1.43	t = -8.12***
Accessinfo	Household access to environmental/agricultural information	2.54	0.94	t = -9.46***
Experience	Number of years the household has been efficiently recycling organic waste	2.10	5.07	t = 11.38 ***
Farminc	Income earned by the household from agri-related activities (USD)	12.34	11.28	t = -0.96**
Segregation	Household access to or practice of segregating waste at source	0.55	0.19	$\chi^2=31.01$ ***
Product	Household perception of recycling waste into diverse products	0.92	0.56	$\chi^2 = 36.29$ ***
Profitability	Household perception of profitability of recycling waste	0.91	0.53	$\chi^2 = 38.21$ ***
Livestockown	Type of livestock owned by household	0.73	0.37	$\chi^2 = 26.17$ ***
Nutritional-comp	Household perception of high nutritional comp organic fertilizer	0.77	0.52	$\chi^2=14.39$ ***
Value-add	Value addition/ amendment to the recycled organic fertilizer	0.30	0.11	$\chi^2=12.84$
Capital_req	Initial capital requirement for recycling	\$232.4	\$7.6	
Wagerate	Average market value for labour (USD)	\$2.77	\$2.36	

Significance level: *** $p < 0.01$, USD = United States Dollar, 1 USD = KES 135.8174 (CBK, April 2023)

A logistic regression model was used to determine the factors influencing the adoption of BSF for recycling organic waste into fertilizer among households in Kiambu County. The dependent variable (adoption of BSF for recycling organic waste into fertilizer) was captured as 1

(adoption of BSF) and 0 (not using BSF; using conventional composting). Preliminary diagnostics for statistical problems of multicollinearity, heteroskedasticity, and goodness of fit were conducted for variables to be used in the logistic regression model. Multicollinearity was tested using the Variance Inflation Factor (VIF). The results are presented in appendix Ca. The mean VIF was 1.38, which is below the standard threshold of 4, indicating that there was no significant multicollinearity among the variables used in the model. Therefore, there was no need to adjust the structure of the model to account for multicollinearity.

In order to detect heteroskedasticity in the hypothesized explanatory variables, the White test was used. The results of the white test are summarized in Table Appendix Cb. The test for heteroscedasticity yielded a chi-square value of 118.36 with 85 degrees of freedom. The corresponding p-value was found to be 0.01, indicating that there was no significant evidence of heteroscedasticity in the dataset at the 5% significance level (reject the null hypothesis H_0 : homoskedasticity)

The results of the logistics regressions are summarized in Table 4.3 below. The model's results demonstrated a good fit to the data as the predictors included in the model adequately explained the adoption of BSF in recycling organic waste (pseudo-R² value of 0.796). The likelihood ratio chi-square test yielded a significant Wald chi-square value of 56.15 with 14 degrees of freedom, indicating that the model adequately explained the relationship between the predictors and the choice of BSF for recycling organic waste into fertilizer.

Household characteristics, institutional factors, market factors, and perceived benefits significantly influence household choices in adopting BSF technology for recycling organic waste. Variables that significantly influenced the choice included the age of the household head, number of years spent in schooling, size of land explicitly used for fertilizer production, type of livestock owned, income earned from agri-related activities, number of social associations/ groups a household head belongs, access to agricultural/environmental extension information, household perception of recycling organic waste into diverse products and experience in recycling organic waste.

Age of the household head had negative and significant influence on the adoption of BSF at 5% significance level. This implies that households reduce their likelihood of adopting technologies as the head ages. The odds ratio (Table 4.3) indicate that as the age of the household head increases by one year, the odds favouring the adoption of BSF for recycling organic waste

into fertilizer decreases by 0.92 times. The plausible reason for this outcome is the high labour requirement for sourcing and pre-treating the waste before recycling using BSF larvae. Since older farmers have less energy than younger ones, they would likely adopt a recycling approach that does not require much effort and time. Our findings are consistent with previous studies by Mwangi & Kariuki (2015) and Zondo (2020), highlighting that old farmers are risk-averse compared to their younger counterparts. Hence, young farmers are more likely to choose and adopt new agricultural and environmentally friendly technologies such as BSF and make long-term investments in them.

Table 4.3: Logistic Regression Model results for factors influencing the choice of BSF for recycling organic waste into fertilizer among households.

Adoption of BSF	Coef.	S.E	Wald	Sig.	Odds ratio
Age	- 0.084 **	0.035	-2.42	0.016	0.920
Education	0.396 ***	0.137	2.89	0.004	1.486
Household size	0.437 *	0.257	1.70	0.089	1.548
Farm fertilizer	-0.074 **	0.034	-2.19	0.028	0.929
Experience	-.898 **	0.351	-2.55	0.011	0.407
Access information	1.171 ***	0.355	3.30	0.001	3.227
Farm income	0.722 ***	0.136	2.58	0.01	0.486
Livestock ownership	1.864 ***	0.598	3.12	0.002	6.449
Segregation	-0.313	0.804	-0.39	0.697	0.731
Group membership	2.127 **	1.026	2.07	0.038	1.801
Products	2.728 **	1.078	2.53	0.011	15.299
Profitability	1.692	1.761	0.96	0.337	5.430
Nutritional composition	0.108	0.697	0.15	0.877	1.114
Value-addition	0.588	0.363	1.62	.105	8.392
Constant	-6.707	3.189	-2.10	.035	0.001
Number of observations = 222					
Wald chi square (14) = 56.15					
P value = < 0.01					
Pseudo R2 = 0.80					

Significance level: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$, S.E = robust standard error

As expected, household size was a significant positive predictor at 10% significance level. The odds ratio indicates that an increase in household size by one member increases the odds favouring household's adoption of BSF by 1.548 times. This implies that farmers with larger families are more likely to adopt BSF. Labour is an important input in recycling organic waste. Larger families translate to more labour available for transforming waste into fertilizer (Zondo,

2020). The findings were consistent with previous studies by Zegeye (2021) and Zegeye *et al.* (2022), which stated that larger family-sized households were likely to adopt agricultural technologies because the technologies require more labour force.

The number of years spent in schooling demonstrated a statistically significant positive association. The associated odds ratio (Table 4.3) suggests that an additional year of schooling increases the odds for selecting BSF by 1.486 times. Farmers with higher levels of formal education are more cognizant of new technologies within relatively short durations (Bulinda *et al.*, 2023). The findings were consistent with a study by Sennuga *et al.* (2020) that indicated that there is an essential link between education levels and making informed choices. This is because education empowers the farmers to interpret, perceive, and respond to new technologies and practices and justifies their efficient production performance. Mwangi & Kariuki (2015) also found that higher education-level farmers embraced innovations and technologies.

The size of land explicitly used for recycling organic waste into fertilizer (production unit) demonstrated a statistically significant negative association. The odds ratio indicates that an increase in the size of land required for recycling organic waste by a square pace ($\frac{1}{43560}$ acre) reduces the odds for adopting BSF by 0.928 times. This implies that the less land requirement for recycling increases the likelihood of using new technologies like BSF. This is because land is a scarce resource, especially in urban and peri-urban areas among the urban poor and those working in informal sectors. These results are consistent with a study by Hanboonsong *et al.* (2013) and Kibaara *et al.* (2022), which reported that using insect-based technologies in recycling organic waste required minimal land and therefore offered suitable economic opportunities for the urban poor, youth, and women.

The number of social associations/groups a household head belonged to was a significant positive predictor. The associated odds ratio (Table 4.3) suggests that, an increase in the number of social associations/ groups the household head belonged to, favours adoption of BSF by 1.801 times. This reveals that belonging to a social group fosters social networking and knowledge exchange about the advantages of new technologies (Abdulai & Huffman, 2014). The findings were consistent with a study by Sseguya *et al.* (2021), which stated that belonging to a group fosters farmer peer learning and consolidation of inputs through community banking models, thus encouraging the adoption of technologies.

Another critical factor positively and significantly influencing adoption of BSF is household farm income. An increase in income generated from farming and agricultural-related activities increases the log odds of adopting BSF by 0.486 times. This implies that households with higher of farm income are likely to adopt agricultural/environmental technologies as the income generated from these activities can supplement the financial needs of adopting the technology (Massresha *et al.*, 2021). These findings are consistent with a study by Njeru and Mbugua (2016), which found that household farm income was a positive and significant determinant in household decision to adopt conservation agriculture.

Ownership of productive assets such as livestock positively and significantly influenced adoption of BSF. Household ownership of large ruminants such as dairy cattle increases the odds of adopting BSF by 6.449 times compared to households owning small ruminants/non-ruminants such as shoats and poultry. This implies that households owning dairy cattle are more likely to adopt technologies because livestock is a proxy for measuring household wealth or asset possession (Massresha *et al.*, 2021). These findings were aligned with a study by Abay *et al.* (2016) and Feyisa (2020), which found that households with larger livestock units have improved financial capacity to acquire and adopt technologies.

Access to agricultural/environmental extension information on recycling organic waste was a significant positive predictor. The corresponding odds ratio indicates that households that accessed extension information had an increased odds for adopting BSF by 3.227 times. These results reveal that access to extension information increases awareness and the probability of adopting BSF technology for organic waste management. Our findings were similar to a study by Zondo (2020), which reported that extension agents are essential service providers who empower farmers with relevant agricultural and environmental technologies that will enhance their productivity and profit margins. This emphasizes the importance of extension information in disseminating and promoting agricultural technologies and innovations.

Respondents' perception of recycling organic waste into diverse products was a significant positive predictor. The odds ratio indicates that respondents who perceived recycling of organic waste as a potential diversification process for soil amendment, animal protein source, and bio-energy increased their odds for adopting BSF by 15.299 times than those who did not perceive recycling to have potential for diversification. The results indicate that perception is a vital factor affecting adoption of insect-based technologies. These findings were consistent with a study by

Liu *et al.* (2022), which stated that household perception of using BSF technology to convert organic waste into diverse, economically viable products increased adoption levels. Moreover, a study by Salam *et al.* (2023) found that perception of BSF as an economically valuable and cleanest method for managing organic waste improved adoptability.

Finally, the number of years the household has been recycling organic waste using recommended recycling practices was a significant negative predictor. The odds ratio indicates that, an increase in experience with recycling organic waste by one year reduces the odds favouring adoption of BSF by 0.407. This implies that as household heads gain more experience with recycling, they become less likely to adopt new technologies. The plausible reason for this observation is the risk-averse nature of households. Adopting new technologies requires new capital investment, which may be unattractive to households that are already using an existing technology.

4.2 Cost effectiveness of using BSF in recycling organic waste into fertilizer

The initial capital investment for BSF is, on average, \$232.4 compared to conventional composting at \$7.6 (Table 4.2), spread evenly across a period of 10 years. The contribution of the various cost components to initial capital requirements (fixed costs) are illustrated in (Figure 4.1 (A & B)). There is a variation in the cost components between the two methods, which is driven by the variation in the production process. Labour costs constitute the largest proportion of the variable cost in both methods, with 53.28% for BSF and 54.14% for conventional composting (Figure 4.1 (C & D)). Recycling organic waste is labour intensive and involves transporting the waste, pre-processing, loading and unloading to/from the containers, and post-processing in BSF farming and transporting the waste, pre-processing, turning, and post-processing in conventional composting. The most probable reason for the high initial investment cost for BSF is the required specialized infrastructure for rearing BSF and waste/substrate processing. Other variable costs included water, fuel, NEMA permit, search cost, electricity, buying waste, and transportation.

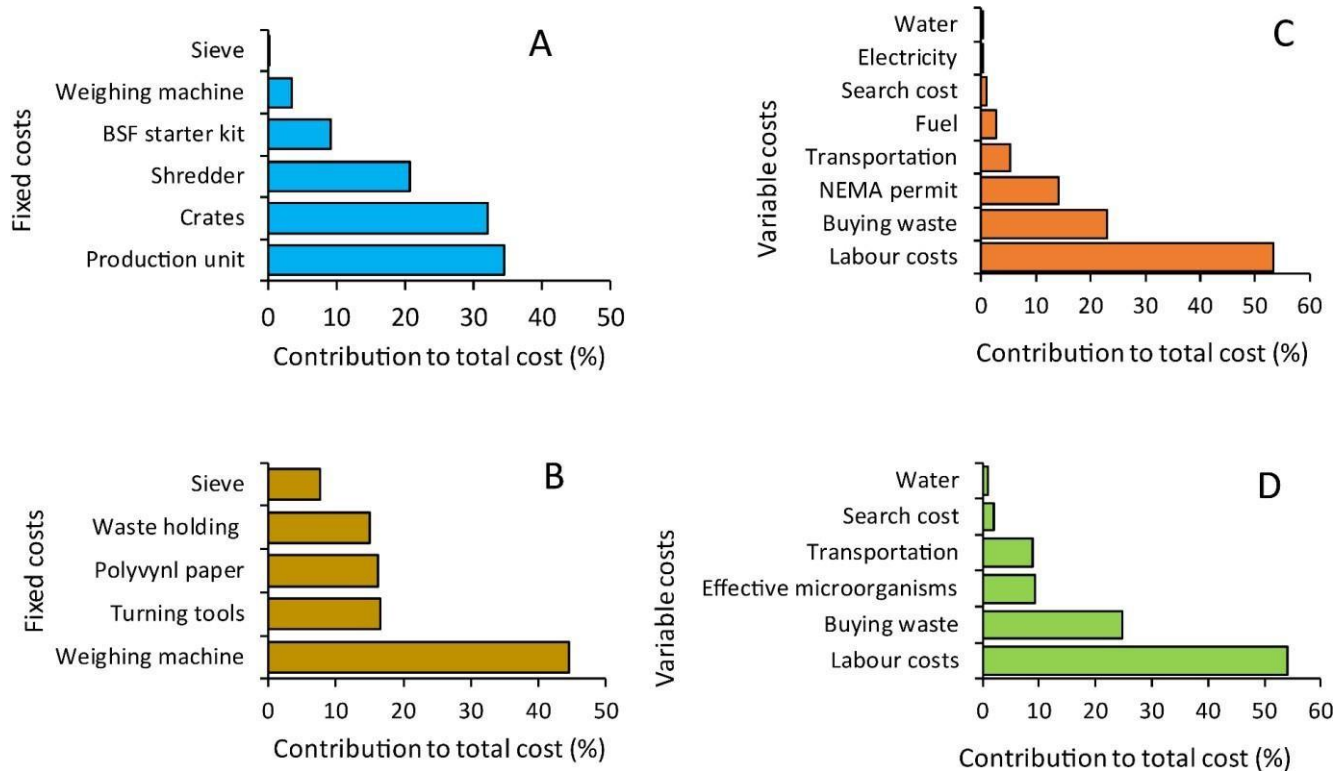


Figure 4.1: Estimated contribution of various cost components to initial capital investment (fixed costs) and variable costs for recycling organic waste into fertilizer using BSF (A & C) and conventional composting (B & D).

Note: The computation of the costs did not account for depreciation, interest on capital, sunk cost, and land value.

Recycling 1 MT of organic waste with BSF yielded substantially 36 folds higher average profit (\$417.82) and 3 folds higher gross margin (55.4%) than using conventional composting which yielded average profit of \$11.25 and gross margin of 16.6% (Table 4.4) without accounting for the market value of family labour. In a scenario where we account for family labour as an opportunity cost of time, recycling 1 MT of organic waste using BSF generated, on average, an annual profit of \$345.89. In contrast, using conventional composting generated, on average, a loss of \$9.00. However, conventional composting farmers benefited from utilizing the compost on their farms, reducing fertilization and crop production costs.

The main benefit of adopting BSF technology for organic waste management is its rapid conversion rate, typically within 2-5 weeks, which translates to high profit margins. Value addition of the produced organic fertilizer (drying/sorting/grading/packaging) and amending the waste

during processing yielded higher profits than without value addition and waste amendment. Households using BSF generated \$606.76 from value addition while those using conventional composting generated \$110.21. If compost was retailed at the same market price as frass, revenue generated would be \$364.86, which is still lower than income generated from BSF larvae composting.

Generally, frass market prices compared to compost was 225% higher than compost before value addition, and upon value addition, frass market price was 93% higher compared to compost. The market price of frass increased by 11% on average upon value addition (from \$0.26 per kg to \$0.29 per kg), contrasted with compost, whose average market price increased by 87.5% upon value addition (from \$0.08 per kg to \$0.15 per kg). Farmers recycling organic waste using BSF larvae produced, on average, 7-8 cycles, while those using conventional composting produced 2-3 cycles annually. Additionally, BSF farmers recycled, on average, 3-fold higher volume of organic waste (38.48 MT) than their counterparts conventional composting farmers, who recycled 11.52 MT of organic waste annually; the difference was statistically significant ($t = 5.20$ ***).

Table 4.4: Estimated annual profit for recycling organic waste into fertilizer

	Quantity	Sale price (\$)	Annual revenue (\$)	Annual cost (\$)	Annual profit (\$)	Gross margin
BSF frass	2930.67	0.26	771.97			
BSF dried larvae	390.5	1.03	402.52	756.67	417.81	55.36%
Compost	1385	0.08	113.42	102.16	11.25	16.63%
If family labour was valued at labour market price				Frass	345.89	
				Compost	-9.01	
Value addition (packaging, treatment, amendment)				Frass	606.76	
				Compost	110.21	
If compost was sold at the same market price as frass					364.86	

Note: \$1 = KES 135.8174 (CBK, April 2023)

Using BSF larvae in recycling organic waste into fertilizer realized on average, 38.02-fold higher net present value (\$2128.36) than conventional composting (\$55.97) (Table 4.5). Recycling organic waste using BSF and conventional composting had an internal rate of return greater than the discount rate, indicating that both practices are profitable. Using BSF larvae to recycle waste had a higher IRR of 150% than conventional composting, with an IRR of 121%. The benefit cost ratio for BSF was 1.47 and 1.10 for conventional composting. The return on investment for BSF was 4.93 folds higher than that of conventional composting (Table 4.5).

The cost benefit analysis results reveal that using BSF to recycle organic waste into fertilizer is more cost-effective than conventional composting. The high NPV is attributed to the reduced time required to recycle organic waste using BSF and the high selling price per kg of frass. The low market price for compost accounts for the low NPV. This observation implies that compost's market price is not competitive compared with unrecycled manure. A study by Beesigamukama *et al.* (2022) on the economic value of frass found that investing in frass fertilizer production among farmers rearing insects increased their income significantly. Moreover, value addition increases frass marketability and value, resulting in higher profit margins.

The multiple recycling cycles (7-8 times annually) and higher volumes of organic waste recycled (38.84 MT annually) reveal that households recycling organic waste using BSF recycled more waste compared to those using conventional composting. To a large extent, these findings unveil the potential and efficiency of BSF technology in managing organic waste. Moreover, food and market waste, which constitutes a large proportion of organic waste illegally disposed of (Brás *et al.*, 2021), was the primary type of waste recycled using BSF. Additionally, BSF labour cost per man-day was higher compared to conventional composting, implying that BSF offers job opportunities for unskilled and semi-skilled labour. On the other hand, labour accounts for a large proportion of operating costs (Joly & Nikiema, 2019), and this calls for investing in local solutions that reduce labour requirements, such as waste segregation at source, to increase the gross margins accrued from recycling waste.

The difference in IRR between the two recycling methods is attributed to the variations in cash flow and initial capital requirement. BCR attempts to summarize the overall monetary value of an investment. The higher BCR for using BSF implies that the overall monetary benefits of recycling organic waste into frass are higher compared to conventional composting. The ROI indicates that 'BSF's profitability was 4.93-fold higher than that of conventional composting. This

work provides the first discussion on the cost effectiveness of recycling organic waste using BSF larvae compared to conventional composting.

The CBA indicators reveal that recycling organic waste into fertilizer is cost-effective. In addition, it can provide a secondary source of income for farmers and cushion them against high fertilizer prices while promoting regenerative agriculture. Of the four decision indicators discussed in this study, NPV is the most useful and clear indicator when comparing investment options to establish cost effectiveness (Akinyi *et al.*, 2022) because it reveals the allocative efficiency of the methods (Branca, 2018).

Table 4.5: Cost benefit analysis indicators for recycling organic waste into fertilizer using BSF-assisted and conventional composting

Decision indicators	BSF-assisted composting	Conventional composting
Net present value (10 years)	\$2128.36	\$55.97
Internal rate of return	150%	121%
Benefit cost ratio	1.47	1.10
Return on investment	47.22%	9.57%

4.2.1 Sensitivity analysis

The sensitivity analysis determines the extent to which the viability of an investment is influenced by variations in the variables, *ceteris paribus* (i.e., given all other variables do not change). In BSF larvae-based organic waste recycling, varying factors such as production cycle, frass quantity, sale price, labour cost, and investment cost by +/- 10% impacted the NPV by more than 10% (Figure 4.2). Varying production cycle by +/- 10% was the most influential, with a 38.54% variation on the NPV. Frass quantity and sale price followed closely with 25.33% variation on the NPV. Moderate sensitivity was observed for dried larvae quantity, dried larvae sale price, labour cost, and investment cost. NPV showed the least sensitivity to lifecycle, discount rate, and waste acquisition cost. Assessing the variable impact aids in identifying critical factors for NPV robustness. Critical variables in this study were production cycle, frass quantity, sale price and labour cost.

The scenarios help us determine the probability of earning more or less profit in incidences of occurrence. For example, in the case of using BSF in recycling organic waste, the variables used positively and significantly influenced the NPV. Among the variables selected, NPV was most

sensitive to the production cycle, followed by the sale price and quantity of frass, relatively sensitive to the quantity and sale price of dried larvae, labour cost, and investment cost. The NPV was least sensitive to lifecycle, discount rate, and cost of buying waste. Varying the variables to establish the effect they have on the NPV helps in determining the critical variables that are crucial in determining the robustness of the NPV. Therefore, there is a need to formulate policies that ensure stability in market prices for frass and recycling labour so that farmers can fully benefit from the cost effectiveness of using BSF in recycling organic waste and the revenue generated.

The findings in this study are consistent with a study by Munthali *et al.* (2023), which found that the price and yield of BSF larvae and frass and production costs were the main variables that influenced the profitability of farming BSF. A related study by Akinyi *et al.* (2022) found that the yield per hectare of sweet potato was the most sensitive variable to profitability of adopting drought tolerant sweet potato varieties. A study by Ng’ang’a *et al.* (2021) also found that NPV was most sensitive to yield and discount rate. On the contrary, Akinyi *et al.* (2022) found that NPV was least sensitive to labour cost. This observation could be because of the difference in nature of the technology adopted. BSF technology adoption is labour intensive that could be the most probable reason for its effect on robustness of the NPV in this study.

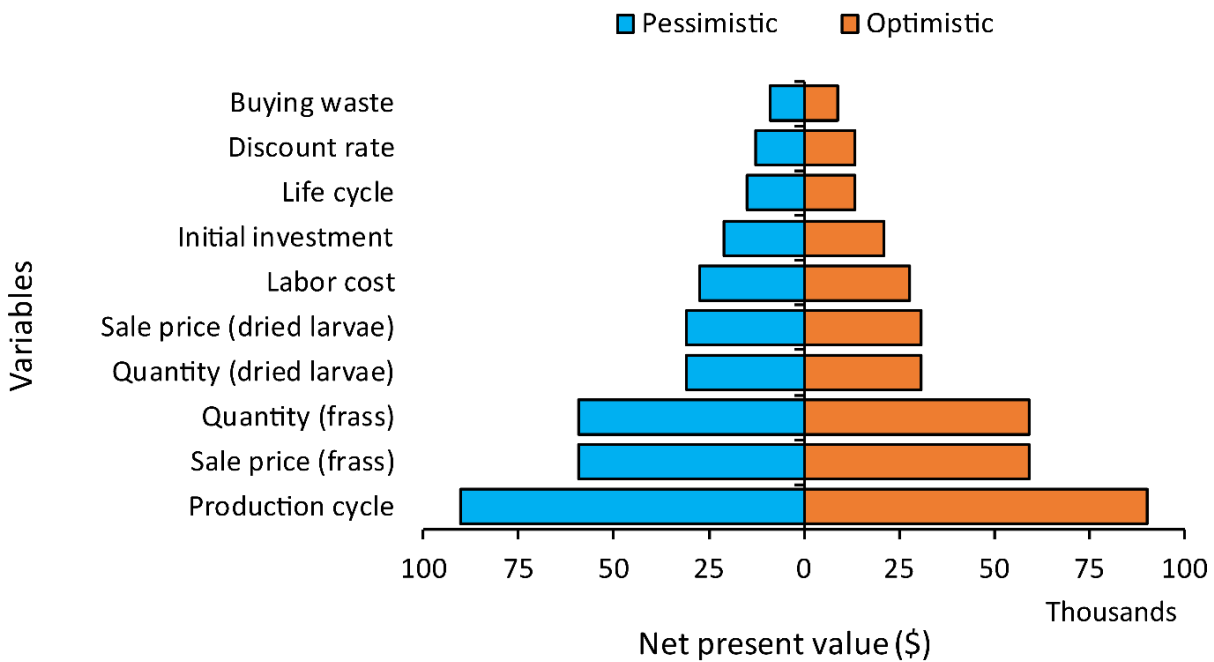


Figure 4.2: Sensitivity analysis on variations of variables on net present value

4.2.2. Externalities associated with recycling organic waste into fertilizer

Recycling organic waste generates positive or negative externalities. This study operationalizes externalities as environmental and social benefits and costs associated with recycling organic waste into fertilizer. The search in Scopus, Web of Science, and Google Scholar yielded 112, 35, and 16 documents, respectively. A total of 35 documents (20 review papers and 15 experimental journal articles) were incorporated into the final synthesis (Figure 4.3). This study operationalizes externalities as environmental and social benefits and costs associated with recycling organic waste into fertilizer. The externalities in this review include the effect on soil health, crop yield, GHG emissions, waste reduction, and social impact (evaluated as labour requirement and job creation).

Frass influences bacterial growth and soil enzymes resulting in significant impact in soil health and fertility (Elissen *et al.*, 2023). BSF-composted fertilizer could be categorized as an NPK compound fertilizer with an average composition of 3.4% N, 2.9% P₂O₅, and 3.5% K₂O, and a C/N ratio of 13-16 (Basri *et al.*, 2022; Beesigamukama *et al.*, 2021; Gärttling & Schulz, 2022). Organic fertilizer C/N ratio that is below 20 is the most beneficial to plants as the Nitrogen is readily available for absorption. Basri *et al.* (2022) found that frass had a C/N ratio of 13-16, thus an ideal organic fertilizer. Beesigamakama *et al.* (2021) concluded that more nitrogen and phosphorus were retained in the treated frass when the C/N ratio was 15. Therefore, recycling organic waste using insects produces frass, which is an amendment that promotes soil health (Nurfikari, 2022). Additionally, frass influences soil fungal/bacterial composition and rapidly releases nitrogen needed for plant absorption (Nurfikari, 2022). These findings imply that frass is a potential efficient substitute for promoting soil health.

The effect of frass on plant growth and health varies depending on the crop varieties and frass type (Gärttling *et al.*, 2020). This is because the nutritional composition of frass is greatly determined by the feed substrate (organic waste) used, especially phosphorous, potassium, and micronutrient composition (Palma *et al.*, 2020). Additionally, applying untreated frass in high concentrations caused toxicity, hence the need for post-processing (Elissen *et al.*, 2023). Germination indexes improved when frass fertilizer was used compared to conventional compost because frass is a more stable organic fertilizer (Beesigamukama *et al.*, 2020; Liu *et al.*, 2019). Plant tissues readily absorb nutrients in frass, increase abiotic tolerance and resistance to diseases/pathogens, and add microorganisms/ biomolecules promoting plant growth (Poveda,

2021). However, combining frass and commercial fertilizer produced the best crop yields and disease/pathogen resistance.

The rich nutrients and organic matter in frass fertilizer reduce the need to use chemicals for plant disease protection (Torgerson *et al.*, 2021), and crops produce higher yields compared to compost from conventional composting (Anyega *et al.*, 2021; Beesigamukama *et al.*, 2022). Additionally, the use of frass reduced the fertilization cost because frass obtained a lower optimum Nitrogen requirement of 79kg N/ha compared to conventional compost, whose Nitrogen requirement is 120kg N/ha (Beesigamukama *et al.*, 2022). Furthermore, the high mineralization of frass could contribute to better synchrony of the supply of nutrients and high yields (Beesigamukama *et al.*, 2020). These findings imply that frass could, therefore, be a partial or complete substitute to the highly-priced fertilizer while promoting efficient organic waste management (Ndambi *et al.*, 2019). The provision of fiscal incentives by the government and authorities could reduce labour costs and subsequent production costs of recycling organic waste (Matheson, 2019).

Recycling organic waste using BSF larvae reduces global warming potential by 50% compared to open windrow composting; thus, BSF technology is environmentally friendly and conserves environmental resources (Mertenat *et al.*, 2019). Additionally, recycling organic waste using BSF larvae reduces odour and GHGs (methane, ammonia, and nitrous oxide) associated with the bio-conversion of organic waste (Beskin *et al.*, 2018; Chen *et al.*, 2019). Moreover, the short waste recycling duration associated with BSF larvae reduces the emissions of nitrous oxide compared to conventional composting, whose recycling takes longer (Feng *et al.*, 2020). The total ammonia emitted from BSF composting was 0.12 to 10% that of conventional composting, implying that less overall nitrogen is lost during BSF composting (Lindberg *et al.*, 2022). Additionally, the short recycling duration for BSF reduces the buildup of nitrous oxide compared to conventional composting, whose recycling takes longer (Feng *et al.*, 2020). These results reveal that recycling organic waste using BSF has a lower environmental footprint compared to conventional composting and, therefore more environmentally efficient.

Using BSF in recycling organic waste promotes social interaction through learning from one another and may create employment through the demand for extra labour. Social interaction attracts the technical know-how required for adopting and implementing new technologies. Adopting these technologies creates job opportunities, culminating in social impact. Using BSF in

recycling organic waste requires additional labour, which could translate to employment creation among the youth and women (Khatri-Chhetri *et al.*, 2017; Ng'ang'a *et al.*, 2021). Although the additional labour cost signifies a welfare loss to the farmer, the employment created for the society signifies a welfare/economic gain to the society. Findings from this study indicated that, on average, BSF labour costs \$2.77 per man-day, while conventional composting labour costs \$2.36 per man-day (Table 4.2). A study by Joly and Nikiema (2019) stated that labour accounted for 65% of the production cycle when BSF was used to recycle organic waste.

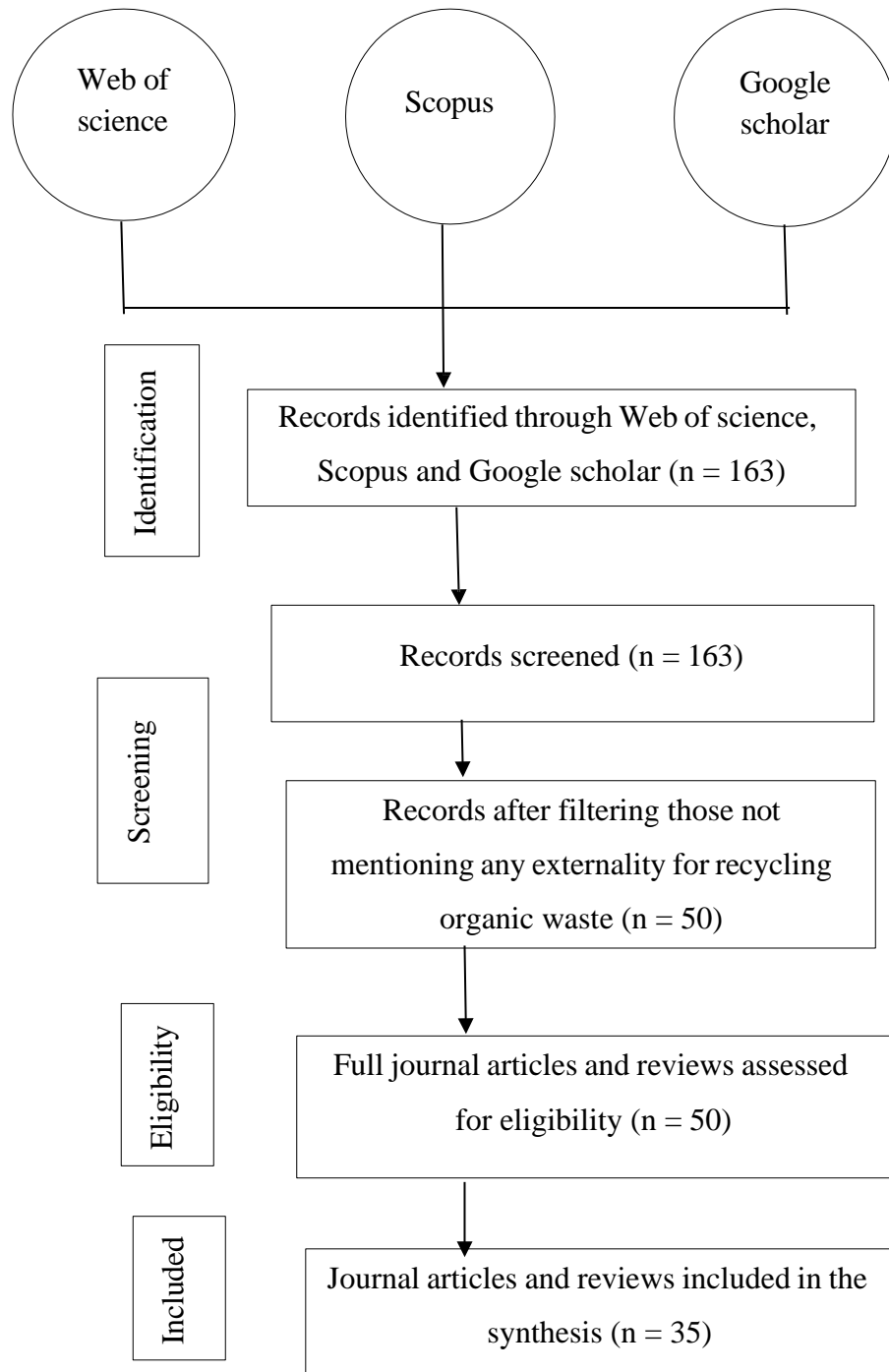


Figure 4.2: Schematic flow of methodology for literature review of externalities for recycling organic waste into fertilizer using BSF

4.3 Effect of using BSF in recycling organic waste into fertilizer on household income

The results from the estimation of the ESR model on the effect of recycling organic waste using BSF on household income is illustrated in table 4.8. The lower half of the table shows that the estimated correlation coefficient ρ_0/ρ_1 values are significantly different from zero, suggesting that there is sample selection bias that unobservable factors could cause. For example, the negative correlation coefficients among the conventional composting households indicate a negative selection deviation. The likelihood ratio (LR) test was significant and thus rejects the null hypothesis that the selection and output equations are independent at a 5% significance level. The model's goodness of fit is statistically significant at 5%, implying that the ESR model was appropriate.

The results of the ESR model first stage estimation show the factors that influence the selection of BSF for recycling organic waste. The coefficients illustrated in the selection column (Table 4.2) are obtained from the logit model, demonstrating the likelihood of households using BSF to recycle organic waste. Significant selection factors were years of schooling by the household head, size of land used for recycling, segregation/ access to segregated waste, distance to source of waste, practice of value addition, access to extension information, and experience in recycling organic waste.

The results from the ESR model second stage estimation shows the factors influencing household recycling gross income. The results are illustrated in the third and fourth columns (Table 4.6). The results reveal that there are significant differences in the estimated coefficients between households using BSF and those using conventional composting among the selected variables. For example, the coefficient of size of land used for recycling organic waste was negative at a significance level of 1% for both adopters (using BSF) and non-adopters (using conventional composting). The coefficient for distance to the source of organic waste was negative at a 1% significance level among the adopters, while the coefficient for household perceptions on the benefits of recycling organic waste was positive and significant at 5% among the non-adopters. On the contrary, the estimated results revealed that regardless of the recycling method that a household adopts, the coefficient for value addition of the organic fertilizer was positive and significant at 10%.

This study provides the first discussion on the effect of using BSF technology in recycling organic waste on household recycling income. The results from the selection equation indicate that

the size of land for recycling is a negative significant predictor for households using conventional composting and BSF. Reduction in the size of land for recycling implies that recycling of organic waste is efficient in terms of space requirement, and minimal space is required for establishing a profitable organic waste recycling unit. Moreover, the inverse relationship implies that increasing the size of land for recycling organic waste is not necessarily proportional to an increment in recycling income. This observation suggests that households have the potential to maximize organic waste recycling alongside conducting agricultural production, which would enable them to realize higher household income.

Distance to the source of waste is also a vital determinant of recycling income. Organic waste is bulky, and thus, its transportation contributes significantly to production costs. A reduction in distance to the source of waste reduces transportation cost; thus, the gross income from recycling organic waste increases. This implies that households recycling organic waste generated within their homesteads or source their waste from nearby households, markets, and eateries were likely to have increased recycling income. Another significant determinant of recycling income is the value addition of the fertilizer during pre-treatment and post-treatment. Value addition is more likely to drive households to earn higher economic returns because adding value to the organic fertilizer attracts a higher market price, which translates to higher income. Amending the substrate increases water and nutrient retention as well as the porosity of the organic matter, which increases the efficiency of the organic waste bioconversion and market value of the frass produced (Sanchez-Monedero *et al.*, 2018). Moreover, value addition through pre-treating the substrate with sawdust, gypsum, and biochar and post-treating the fertilizer through drying, packaging/branding, and supplementing with micro/macro nutrients resulted in increased net income compared to the unamended substrate and wet frass (Beesigamukama *et al.*, 2022).

Households that perceived recycling organic waste into fertilizer to have associated benefits were likely to earn higher income. The most probable reason for this finding is that perceptions influence the effort a household will put towards recycling organic waste, influencing the income generated. A positive perception towards the economic potential of recycling organic waste into fertilizer, especially using BSF, is likely to influence enthusiasm and hard work that would contribute to the realization of increased income. Hence, the results from the ESR model provide insights into the effects of various factors on recycling income among households that use BSF and conventional composting in recycling organic waste into fertilizer.

Table 4.6: Effect of using BSF on the gross recycling income using ESR model (selection equation and outcome)

Variables	Selection (coefficients)	Logarithm of gross income (Coefficients)	
		BSF	Conventional
Education	0.270 (0.082) ***	-0.007 (0.010)	-0.006 (0.008)
Size of land used for recycling	-0.044 (0.018) **	-0.009 (0.003) ***	-0.005 (0.002) ***
Segregation	0.923 (0.518) *	0.022 (0.067)	-0.047 (0.069)
Perceptions	-0.132 (0.376)	0.003 (0.046)	0.098 (0.049) **
Distance to waste	0.054 (0.013) ***	-0.001 (0.000) ***	0.001 (0.002)
Family labor	-0.188 (0.395)	0.029 (0.044)	0.077 (0.050)
Value addition	1.328 (0.639) **	0.130 (0.076) *	0.153 (0.087) *
Farm size	-0.025 (0.158)	0.004 (0.018)	0.011(0.018)
Access to information	1.058 (0.300) ***		
Experience	-0.527 (0.166) ***		
_constant	-4.822 (1.532) ***	12.108 (0.233) ***	9.374 (0.192) ***
rho0	-0.261 (0.228)		
rho1	0.714 (0.246) *		
Wald $\chi^2 = 21.48$ ***		Prob > $\chi^2 = 0.006$	
LR test $\chi^2 = 8.26$ **		Prob > $\chi^2 = 0.016$	

Note: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. The standard errors are illustrated in the parentheses

4.3.1 Estimating treatment effects

The estimated treatment effects on the expected recycling income among households using BSF and conventional composting under actual scenarios and their counterfactuals are illustrated in Table 4.9. The treatment effects compared the expected income with the adoption of the technology (a) and without the adoption of the technology (b) among the household recycling organic waste. Moreover, the treatment effects compared the households using the BSF technology should they fail to adopt (c) and households without using the BSF technology should they adopt it (d).

The expected annual recycling income from recycling a ton of organic waste per cycle among households that had adopted BSF was 11.907. On the other hand, the expected annual recycling income from recycling a ton of organic waste per cycle among households without the BSF technology, that is, those using conventional composting, was 9.683 under the counterfactual scenario. The ATT was 2.224, which is equivalent to 18.68% $((9.683 - 11.907)/11.907) * 100\%$ and was significant at a 1% significance level. Similarly, if households that did not adopt BSF adopted, the ATU was 2.232, which is equivalent to 18.78% $((11.887-9.644)/11.887) * 100\%$ and was significant at a 1% significance level (Table 4.7).

The average treatment effect on the treated indicates the income-increasing effect that is brought about by adopting BSF in recycling organic waste into fertilizer. The ATT results imply that households adopting the BSF technology would reduce their expected recycling income by 18.68% if they had not adopted it. Similarly, the average treatment on the untreated (ATU) results imply that expected income among households using conventional composting would increase by 18.78% if they adopted BSF. These results indicate that households that do not actually use BSF in recycling organic waste will experience a greater increase in their recycling income if they adopt BSF technology (ATU > ATT). Consequently, a fundamental policy implication is that households that do not currently use BSF technology to recycle organic waste should be encouraged to adopt it.

The findings of this study are consistent with previous research on the effect of adopting new technologies on household income. A study by Wu (2022) concluded that adopting new technologies improved farming families' economic benefits. Moreover, the study stated that farming families need to get the support necessary to adopt new technologies in their farms to increase production and income. A related study by (Belay *et al.*, 2023) found that adopting climate smart technologies and practices had substantial implications on household farm income and that adopting the technologies/practices mitigated the negative effects of climate change and improved agricultural production. The treatment effect revealed that households that adopted the improved technologies obtained higher farm income than those that did not, and as a result, general household welfare improved (Wordofa *et al.*, 2021). The effect on farm income was more significant among low-income households than their high-income counterparts (Yang *et al.*, 2020).

Table 4.7: Average treatment effect of the effect of using BSF in recycling organic waste into fertilizer

Outcome	Mean outcome		ATT	ATU
Annual recycling income	Adopters	Non-adopters		
	(a) 11.907 (0.209)	(c) 9.683 (0.144)	2.224 (0.174) ***	
	(d) 11.887 (0.171)	(b) 9.644 (0.127)		2.232 (0.107) ***

Note: *** $p < 0.01$; Standard errors in parenthesis; ATT refers to average treatment effects among households using the BSF technology; ATU refers to the average treatment effect among households without the BSF technology. The results of the mean outcomes and predicted ATU of both groups are in log forms, just as the ESR estimated outcome income for annual recycling revenue.

CHAPTER FIVE

CONCLUSION AND POLICY RECOMMENDATIONS

5.1 Conclusions

The following are the conclusions of the study based on the specific objectives.

- i. In determining factors influencing the adoption of BSF in recycling organic waste into fertilizer in Kiambu County, the results reveal that the decision to adopt is influenced by individual, household, farm-level, and institutional characteristics. Younger households, with more years of schooling, and larger households, are more likely to adopt BSF. Moreover, households using smaller land for recycling, belonging to many social associations/groups, accessing information on recycling often, owning dairy cattle, and earning higher farm incomes are likely to adopt BSF. These findings imply that policy guidelines targeting increasing adoption levels of agricultural and environmental technologies should consider sociodemographic and institutional factors influencing households' decision to adopt the technologies.
- ii. In evaluating the cost effectiveness of using BSF in recycling organic waste into fertilizer, the cost benefit analysis indicators such as NPV, BCR, ROI, and IRR reveal the huge potential for BSF in recycling organic waste as not only a technology that promotes livelihood diversification in urban and peri-urban areas but is also a circular approach for producing a competitive organic fertilizer while managing the organic waste menace. Using BSF has reduced environmental and health footprint. It also contributes to regenerating soil fertility, plant health, and yield and creates job opportunities in the unskilled and semi-skilled labour market compared to conventional composting.
- iii. Socio-demographic, institutional, and productive factors significantly influence the effect of adopting BSF for recycling organic waste on household income. The effect among adopters and non-adopters is influenced by the land size used for recycling, distance to waste stream, perceived benefits from recycling organic waste, and value addition of recycled products. This implies that adopting BSF could promote social equity and lessen disparities caused by perceptions and practices of recycling organic waste. Moreover, the average treatment effect results reveal that households that have not adopted BSF would experience a significant increase in their recycling income if they adopt BSF. In addition, households that have adopted BSF would experience a reduction in their recycling income

had they not adopted BSF. These findings imply that BSF is an efficient technology that has a positive increasing effect on household recycling income.

5.2 Recommendations

- i. Enhancing adoption of BSF for recycling organic waste into fertilizers, efforts should be geared towards sensitization campaigns aimed at increasing awareness, especially among households, civil societies, private agencies, and government officials involved in organic waste management, on the socio-economic, environmental and circular economy benefits of using BSF for organic waste recycling. Moreover, there is need for availing timely extension services to households recycling organic waste to overcome the impediments associated especially with adopting BSF so that they are able to cut on cost of production, maximize on revenue generation and reduce dis-adoption.
- ii. Understanding the economic benefits of recycling organic waste using BSF provides stakeholders, such as civil societies, research organizations, private sector and humanitarian agencies, and policymakers the opportunity to ensure households are aware of the financial benefits of adopting BSF so as to make informed decisions when considering recycling waste as a livelihood diversification opportunity for contributing to environmental conservation. Policymakers need to create an enabling environment that facilitates establishing and operating profitable BSF production. Moreover, there is a need for sensitization on the economic value of using frass fertilizer in agricultural production, which could significantly increase farmer's agricultural income as well as increase the market base for households recycling organic waste into fertilizer.
- iii. Understanding the effect of adopting BSF on household recycling income provides an opportunity for livelihood diversification, especially among households in urban and peri-urban areas with abundant organic waste generation and limited land resources. There is a need for waste management programs developed by national and county governments to develop policies that integrate BSF farming as one of the commercial alternatives for recycling organic waste into the broader waste management strategies. Moreover, there is a need for sensitization and capacity building among households on efficient waste management to increase the adoption of BSF and realize the income-increasing effect of its adoption.

5.2.1 Policy recommendations

To enhance the adoption and cost-effectiveness of adopting BSF for recycling organic waste into fertilizer, the government should implement a multifaceted policy approach through:

- i. Increase household awareness: Empower households, civil societies, government officials and private sector agencies, especially through digital extension systems, to ensure wide coverage.
- ii. Facilitate a favourable recycling environment: Provide financial incentives, subsidies or tax breaks for households that invest in BSF for organic waste recycling technologies, making it more cost effective.
- iii. Establish monitoring and evaluation frameworks: Develop systems to track the economic impacts of organic waste recycling on household income, allowing for data-driven adjustments to policies.

5.3 Suggestions for further research

- i. Further research on the effect of adopting BSF on farm performance and comprehensive household welfare, when panel data is available, would be a promising area in the future.
- ii. Conducting an economic CBA that monetarizes environmental and social benefits and costs associated with recycling organic waste into fertilizer could give more insights into the cost effectiveness of using BSF from a societal perspective.
- iii. Researching how to improve the nutritional composition of compost, reduce the recycling period, and price stabilization of compost, which could improve the value of compost and increase its profitability

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APPENDICES

Appendix A: Cost components of recycling 1 metric tonne per cycle of organic waste using BSF

	Cost	Maintenance	Amt	Cycles	Annual cost	Percent
Capital requirements		3%				
Production unit	1402.47	42.07408634	1444.543631	7.514018692	10854.32785	34.39%
BSF starter kit	374.192	11.22574627	385.4172886	7.514018692	2896.03271	9.18%
Sieve	6.95398	0.208619403	7.162599502	7.514018692	53.81990654	0.17%
Weighing machine	143.396	4.301865672	147.6973881	7.514018692	1109.800935	3.52%
Shredder	845.087	25.35261194	870.4396766	7.514018692	6540.5	20.72%
Crates	1306.27	39.18824627	1345.463122	7.514018692	10109.83505	32.03%
Sub-total					31564.31644	100.00%
Variable costs						
Electricity	39.4776			7.514018692	296.6354475	0.43%
Fuel	250.364			7.514018692	1881.242004	2.74%
Water	28.4813			7.514018692	214.0092169	0.31%
NEMA permit	1297.57			7.514018692	9750	14.20%
Buying waste	2088.24			7.514018692	15691.03903	22.86%
Seach cost	93.0978			7.514018692	699.5389287	1.02%
Transportation	471.11			7.514018692	3539.925915	5.16%
Labour costs	4867.24			7.514018692	36572.54747	53.28%
Sub total					68644.93802	100.00%
Total cost					<u>100209.2545</u>	

Appendix B: Cost components of recycling 1 MT of organic waste using conventional composting

	Unitcost	Maintenance	Amt	Cycles	Annual cost	Percent
Capital requirements		3%				
Turning tools	65.2947	1.958840683	67.25353011	2.55172414	171.61246	16.61%
Sieve	30.2083	0.90625	31.11458333	2.55172414	79.395833	7.69%
Polyvynl paper	63.7198	1.911595209	65.6314355	2.55172414	167.47332	16.21%
Weighing machine	175.045	5.251351351	180.2963964	2.55172414	460.06667	44.53%
Waste holding	58.7838	1.763513514	60.5472973	2.55172414	154.5	14.96%
Sub total					1033.0483	100%
Variable costs						
EM	463.267			2.55172414	1182.1304	9.20%
Water	49.9109			2.55172414	127.35889	0.99%
Buying waste	1250			2.55172414	3189.6552	24.84%
Search cost	95.8867			2.55172414	244.67643	1.91%
Transportation	449.091			2.55172414	1145.9561	8.92%
Labour costs	2724.72			2.55172414	6952.7231	54.14%
Sub total					12842.5	100.00%
Total cost					<u>13875.548</u>	

Appendix Ca: Variance Inflation Factor (VIF) test results for study variables used in logistic regression

Variable	VIF	1/VIF
Age of household head in years	1.52	0.66
Size of the household	1.11	0.90
Number of years spent in schooling	1.44	0.69
Size of land used for fertilizer/BSF production in acres	1.83	0.55
Type of livestock reared	1.21	0.83

Income earned from ag-related sources	1.77	0.57
Number of social associations a household head belongs to	1.28	0.78
Household access to or practice of segregating waste at source	1.19	0.84
Household access to environmental/agricultural information	1.53	0.65
Household perception of recycling waste into diverse products	1.18	0.85
Household perception of profitability of recycling waste	1.39	0.72
Household perception of high nutritional comp organic fertilizer	1.25	0.80
Experience in recycling organic waste	1.56	0.64
Value addition/ amendment to organic fertilizer	1.13	0.89
Mean VIF	1.38	

Appendix Cb: Test for heteroskedasticity

Source	Chi ²	df	<i>p</i> -value
Heteroskedasticity	118.36	85	0.0098
Skewness	21.88	12	0.0389
Kurtosis	1.96	1	0.1618
Total	142.20	98	0.0024

Note: df = degrees of freedom

Appendix Cd: Sensitivity analysis on net present value of recycling organic waste into fertilizer using BSF

	Base	Pessimistic	Optmistic	NPV			
		(-10%)	-10%	Pess	Pess (%)	Opt	Opt (%)
Initial Investment	31564.32	28407.88	34720.75	212868.95	8.98%	254850.90	8.98%
Labor cost	36572.55	32915.29	40229.80	206228.29	11.82%	261491.57	11.82%
Quantity (frass)	390.03	351.02	429.03	174619.09	25.33%	293100.77	25.33%
Quantity (dried larvae)	51.97	46.77	57.17	202970.55	13.21%	264749.31	13.21%
Sale price (frass)	35.78	32.20	39.35	174619.09	25.33%	293100.77	25.33%
Sale price(dried larvae)	140.00	126.00	154.00	202970.55	13.21%	264749.31	13.21%
Lifecycle	10	9	11	218734.95	6.47%	247364.37	5.77%
Production cycle	7.5140	6.7626	8.2654	143729.71	38.54%	323990.15	38.54%
Discount rate	12%	11%	13%	221313.72	5.36%	247423.10	5.80%
Buying waste	15691.04	14121.94	17260.14	224994.14	3.79%	242725.72	3.79%

Appendix D: Questionnaire

Introductory and consent statement: Dear sir/madam,

My name is _____ We are working with **Egerton University** and **ICIPE** on a study about the cost effectiveness of approaches for recycling organic waste into fertilizer and the implication on household welfare among producer households in Kiambu County. Participation is voluntary, and your primary investment is the time and sharing of your experience and knowledge. Your response and that of other organic fertilizer producers will contribute to reviewing cost effectiveness in organic fertilizer production among policymakers and investors. All information you provide will be treated with the utmost confidentiality and used for research purposes alone. You have the right not to participate; there will be no consequences if you decide not to. (*Enumerator note*: Conversion rate \$1 = KSH. 135.8174).

Module 0: Consent

Do you accept to participate in the interview?..... Code 1=Yes; 0=No. If yes, continue with the interview. Otherwise, end the interview.

Sub-county _____

Ward _____

Module 1: Household identification

HA01: Name of respondent _____

HA02: Gender of respondent

male	1
female	2
prefer not to say	3

HA03: Type of household

male headed	1
female headed	2

HA04: Position of the respondent in the household

household head (HH)	1
spouse of household head	2
father/mother of household head	3
child of household head	4
brother/sister of HH head	5
other relative (specify)	99

HA05: Age of respondent (years) _____

HA06: What is the size of your household? (People whom you live together and share meals with in the last 6 months _____

Module 2: Socio-economic characteristics

HB01 Number of years spent in school _____

HB02 Main occupation of household head

Organic fertilizer/BSF production	1
salaried worker	2

wage worker	3
self-employed	4
Unemployed	5
Retired	6
other (specify)	99

HB03 Type of agricultural enterprises owned by your household

1=crops (namely/ how many seasons per annum)
2=livestock (namely)

HB05 Type of non-agricultural enterprises owned by your household

None	0
small business	1
salaried labour	2
casual labour	3
land rent	4
other specify	99

HB6 Total size of land used for agricultural purposes in acres _____

HB07 How is the land owned?

owned with title	1
rented in	2
rented out	3
borrowed in	4

HB08 Size of land used for organic fertilizer/BSF production _____

HB09 No of years they have been producing organic fertilizer/BSF _____

HB10 How many years do you intend to continue producing organic fertilizer/BSF _____

HB11 On average how much income did you earn from agricultural activities besides fertilizer/BSF production in the last 12 months (KSH & USD) _____

HB12 On average how much income did you earn from non-agricultural activities besides fertilizer in the last 12 months (KSH & USD) _____

Module 3: Institutional factors

Group membership

HC01: Do you belong to a group?

Yes	1
No	0

HC02: If yes, which type of group?

microfinance/ SACCOs/ merry go round	1
mutual help group	2
agricultural groups	3
Organic fertilizer/BSF production associations/groups	4
others (specify)	99

HC03: To what extent does the group influence your organic fertilizer/ BSF production?

not at all	1
small extent	2
medium extent	3
high extent	4
very high extent	5

3.2 Need for credit

HD01: Did you need credit for producing organic fertilizer/BSF in the last 12 months?

Yes	1
No	0

HD02: Did you get the credit?

Yes	1
No	0

HD03: What was the source of the credit?

microfinance	1
banks	2
friends/relatives	3
mobile lenders	4
others (specify)	99

3.3 Trainings and sourcing organic waste

HE01: Have you received training on recycling organic waste to economically viable products?

Yes	1
-----	---

No	0
----	---

HE02: If yes how many times in the past 12 months? _____

HE03: What is the distance in kms to the nearest extension/ training facility? _____

HE04: Where do you source organic waste used during organic fertilizer/BSF production?

Farms	1
Markets	2
Eateries	3
Industries	4
Others specify	99

HE05: What is the distance in km to the source of organic waste? _____

HE06: To what extent is the waste you source segregated?

not at all	1
small extent	2
medium extent	3
high extent	4
very high extent	5

Module 4: Production requirements

4.1 Input acquisition

HG01: Type of waste used during organic fertilizer/BSF production.

kitchen waste (list the examples)	1
crop waste (list the examples)	2
livestock waste (list the examples)	3
food waste (list the examples)	4
market waste (list the examples)	5
other (specify)	99

HG02: Volume of waste used per production period in kgs _____

HG03: Number of production cycles in one year _____

HG05: What is the extent of availability of the waste

not at all	1
small extent	2

medium extent	3
high extent	4
very high extent	5

HG06: What is the extent of affordability of the waste

not at all	1
small extent	2
medium extent	3
high extent	4
very high extent	5

HG07: What is the extent of accessibility of the waste

not at all	1
small extent	2
medium extent	3
high extent	4
very high extent	5

4.2 Capital requirement (conventional)

What are the resources and cost required to start off a production process?

Resources	Units required	Estimated cost per unit	Total cost
turning tools			
weighing machine			
waste holding containers			
sieve			
polyvinyl paper			
others specify			

4.2a Capital requirements (BSF)

What are the resources and cost required to start off a production process?

Resources	Units required	Estimated cost per unit	Total cost
Greenhouse and adult cage			

weighing machine			
waste holding containers			
sieve			
others specify			

4.3 Operating and maintenance cost (conventional)

What are the resources and costs required to conduct a complete production cycle?

Resources	Units required	Cost per unit of resource required	Total cost per production cycle
Effective Microorganisms (EM)			
Water			
annual NEMA permit			
transport (including fuel, driver)			
buying waste			
own waste			
packaging bags			
transaction cost (search cost)			
storage cost			
other costs (specify)			

4.3 a Operating and maintenance cost (BSF)

What are the resources and costs required to conduct a complete production cycle?

Resources	Units required	Cost per unit of resource required	Total cost per production cycle
Electricity/firewood/charcoal			
Water			
annual NEMA permit			
transport (including fuel, driver)			
buying waste			
own waste			
packaging bags			
transaction cost (search cost)			

storage cost			
other costs (specify)			

4.4 labour costs

HK01: How many employees does your production facility have?

Permanent	
Temporary	
Family labour	

HK02: How many days per production cycle do the temporary employee and family labour work?

Temporary employee	
Family labour	

HK03 What is the average pay for the employees?

Permanent employee (pay per month)	
Temporary employee (pay per day)	

4.5 Revenue Stream

HM01 Number of 50kg bags of organic/frass fertilizer produced per production cycle _____

HM02 What is the market price for 50kg bag of organic/frass fertilizer? _____

HM04 How do you utilize the organic/frass fertilizer produced?

Own farm utilization (100%)	1
Own farm utilization and selling	2
Selling (100%)	3

HM05: If selling where do you sell?

local farmers	1
agro vets	2
large scale farmers	3
farmer groups	4
other specify	5

HM05: Distance to the market in kms _____

4.6 Fertilizer treatment

HQ01: Do you treat or amend your frass fertilizer before using in the farm or selling?

Yes	1
-----	---

No	0
----	---

HQ02: What materials do you use to treat or amend the frass fertilizer? _____

4.7 Associated benefits of producing BSF

HR01 Other benefits associated with frass fertilizer per production cycle in kgs

Associated product	Volume in kgs/ltr	Market price (ksh)	Market price (USD)
Live larvae			
Dried larvae			
Eggs			
Biodiesel			






4.8 Perceptions and attitude about organic waste recycling

Practice	Perception/attitude (Likert scale 1-5)
Recycling organic waste is expensive	
Recycling organic waste is labour intensive	
Recycling organic is time consuming	
Organic fertilizer produced has high nutritional composition	
Recycling organic waste is a profitable venture	
Organic waste can be recycled into several economically viable products	

4.9 What motivated you to start recycling organic waste _____

Thank you for your time and cooperation

Appendix E: Research Permit from NACOSTI

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