Novel Soil Booster: Insect-composted organic fertilizer for increased crop yield, nutritional quality, and profitability

Introduction

High levels of hunger and food insecurity dominate most regions of sub-Saharan Africa (SSA), and the situation continues to worsen due to increasing soil degradation. Most soils in SSA are deficient in nutrients required for optimal crop growth yet, farming systems in countries of SSA rely mostly on inherent soil fertility with very little (≤ 10 kg ha^{-1} $year^{-1}$) or no inputs of mineral fertilizers due to the high-cost implications and limited access. Organic fertilizers that are locally produced and economical would be the immediate alternative to mineral fertilizers, but their use is limited by poor quality, long production time and scarcity of organic matter on the farm.

Use of insects such black soldier fly (BSF) (*Hermertia illucens* L.) to efficiently recycle organic wastes into high-quality organic fertilizer for soil health management and crop production has been widely demonstrated globally (Figure 1). Through collaborative research, the International Centre of Insect Physiology and Ecology (*icipe*), has demonstrated that BSF larvae take only 5 weeks to produce mature organic fertilizer, compared 12 – 24 weeks for conventional composting.

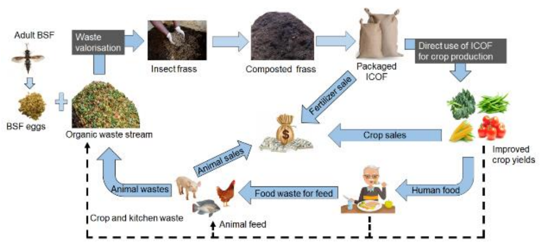

Figure 1: Schematic representation of black soldier fly (BSF) as a recycler of organic wastes into organic fertilizer for crop production

We have found that the BSF composting produces organic fertilizer that is superior in nutrients than commercial organic fertilizers (Table 1), thus high potential to benefit many farmers within a short time.

Table 1: Nutrient concentrations of ICOF, commercial organic fertilizers (Evergrow and SAFI) and locally made compost

Nutrient	BSF-composted organic fertilizer	Commercial organic fertilizers		Conventional compost
		Evergrow	SAFI organic	
Nitrogen (%)	3.6	1.0	3.0	2.5
Phosphorus (%)	1.2	0.4	1.2	0.4
Potassium (%)	0.3	0.5	1.4	0.2
Calcium (%)	1.0	1.3	0.3	0.3
Magnesium (%)	0.10	0.2	0.4	0.2
Iron (ppm)	310	0.1	-	185
Copper (ppm)	25.0	100	-	15.0
Manganese (ppm)	109	200	-	262
Zinc (ppm)	182	850	-	167

Our agronomic studies have shown that insect composted organic fertilizer (ICOF) can increase the yields of key food security crops, especially maize, tomatoes, kales, and French beans (Table 2, Figure 2 and 3) compared to existing commercial fertilizers through improved soil fertility (Figure 5). We found that maize and vegetable crops grown using ICOF were more nutritious than those grown in soil amended using commercial fertilizers (Figure 4).

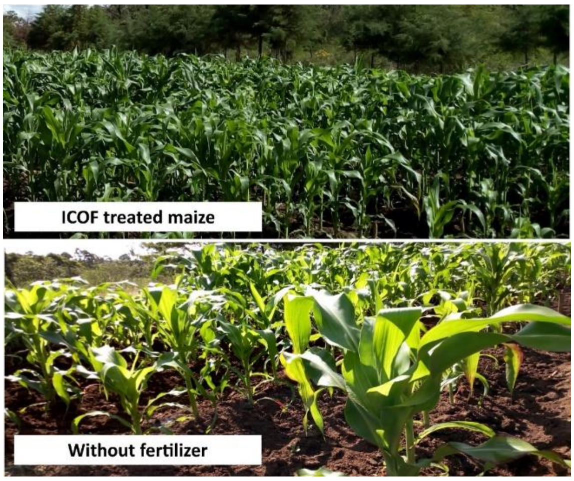

Figure 2: Maize grown using insect-composted organic fertilizer (ICOF).

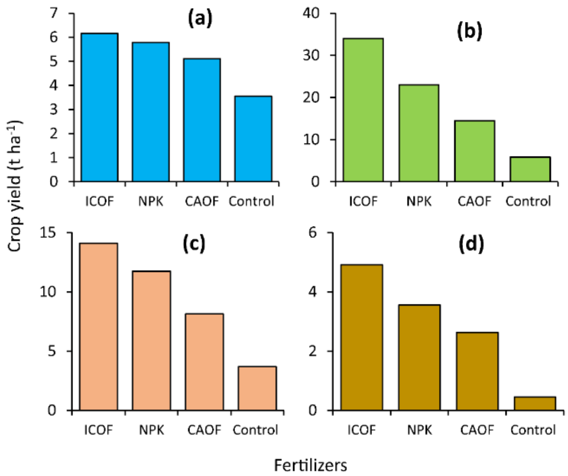

Figure 3: Yield benefits of insect composted organic fertilizers (ICOF) on maize (a), tomatoes (b), kales (c) and French bean crops (d). CAOF = commercially available organic fertilizer, NPK = synthetic fertilizer.

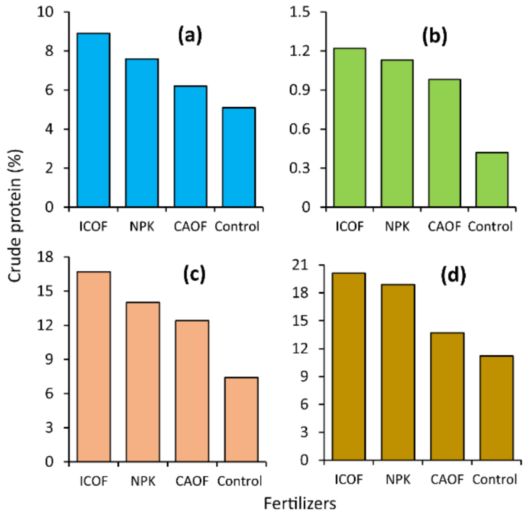

Figure 4: Nutritional benefits of insect composted organic fertilizer (ICOF) on maize (a), tomatoes (b), kales (c) and French beans (d). NPK = synthetic fertilizer, CAOF = commercially available organic fertilizer.

Table 2: Impact of insect frass on soil health and crop productivity

Parameter	Benefits of ICOF over organic fertilizers and NPK fertilizers
Crop yield	• 27% increase in maize grain yield. • 135% increase in tomato yield. • 27% increase in kale yield. • 50% increase in French bean yield.
Nutritional quality	• 65% increase tomato crude protein. • 78% increase in kale crude protein. • 82% increase in French bean crude protein. • 31% increase in maize crude protein. • 29% increase in maize crude fibre. • 30% increase maize crude ash content. • Increased ash contents of tomatoes, kales, and French beans.
Fertilizer use efficiency	• 76% increase in maize nitrogen uptake. • Higher phosphorus and potassium uptake in maize. • 59% increase in nitrogen uptake in kales. • 75% increase in nitrogen uptake in tomatoes and French beans. • 166% higher maize agronomic nitrogen use efficiency. • 106% higher tomato agronomic nitrogen use efficiency. • 89% higher kale agronomic nitrogen use efficiency.
Soil fertility	• 58% increase in nitrogen release. • 200% increase in phosphorus release. • 268% increase in magnesium release. • Higher mineral nitrogen content in topsoil. • Reduced soil nitrogen immobilization. • Increased nitrogen mineralization and nitrification. • Increased beneficial bacteria and fungi. • Reduced soil acidity. • Increased soil moisture storage.
Profitability	• 173% increase in net income from maize production. • 232% higher net income from direct use of ICOF.

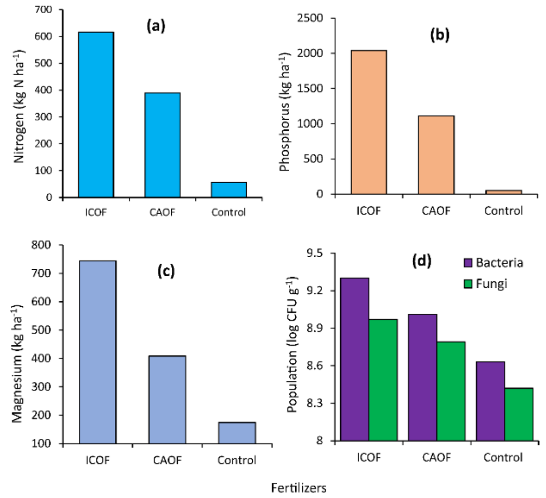

Figure 5: Soil health benefits of insect composted organic fertilizer (ICOF). CAOF = commercially available organic fertilizer.

Economic studies have established that using ICOF for maize production yielded 44% higher net income compared to commercial organic fertiliser (Table 2, Figure 6). Furthermore, we found that the direct use of ICOF for crop production would yield higher profits than synthetic fertilizer and generate 232% higher net income than purchasing similar ICOF. Thus, adoption of ICOF would save the farmer from incurring high fertilizer purchase costs while improving planetary health by minimising the deleterious effects of synthetic fertilizers.

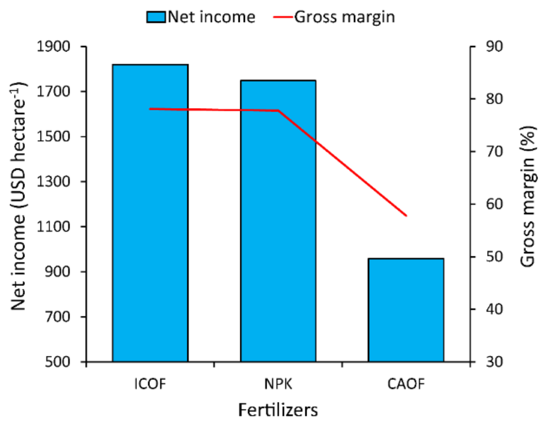

Figure 6: Economic benefits of insect-composted organic fertilizer (ICOF) on maize production. NPK= synthetic fertilizer, CAOF = commercially available organic fertilizer.

We found that the generating ICOF as an additional value-added product would increase farmer's net income by 5 – 15 folds compared to insect farming alone. The production of one megagram (Mg) of dried insect larvae would generate up to 34 Mg of ICOF worth USD 10,200. Furthermore, we established that adoption of this technology would save the environment by recycling up to 18 million tonnes of waste into ICOF worth 85 million USD/year (Table 4), create 252,000 jobs per year and lift 3.2 million people out of poverty. Therefore, use of ICOF would increase agriculture productivity, household income and improve livelihoods through the concept of circular economy.

Table 4: Organic fertilizers and environmental benefits of insect farming

	Adoption rate (%)		
Benefits	5	15	50
N production (tonnes)	8385	25,154	83,845
P production (tonnes)	3330	9991	33,303
K production (tonnes)	2272	6817	22,724
Total N-P-K(tonnes)	13,987	41,962	139,873
N-P-K values (Millions of USD)	9	26	85
Total biowaste recycled (tonnes)	1,828,406	5,485,217	18,284,056

Enhancing the contribution of ICOF to boosting crop productivity

Insect composted organic fertilizer is a relatively new fertilizer product developed and tested through collaborative research projects. Exploring the full potential of this technology for improved crop productivity requires more evidence-based research and enabling policy interventions to regulate production and marketing, and support scaling and adoption.

a) Establish standards for production, quality control and marketing of ICOF

Different insects and organic wastes produce organic fertilizers with different physical-chemical properties and varying degrees of compost maturity and stability. However, to date, there are no established standards for assessing the quality of frass fertilizers produced by insects reared on various organic wastes. Consequently, frass fertilizer quality is assessed using standards established for conventionally composted organic fertilizers[9–11], yet entomocomposting is different from conventional composting. Therefore, future research should establish the standards for assessing the quality of ICOF to ensure quality control, approval by standard regulatory bodies and integration of ICOF into existing fertilizer markets. This could be achieved through development of policy and legal framework by major stakeholders, especially researchers/research institutions, agro-input dealers, standard regulatory bodies, and governments at national and international levels. Specifically, the following should be established.

i. Standard operating procedures (SOPS) for sampling, laboratory, greenhouse and field safety, quality, and safety testing of ICOF should be developed.
ii. Develop guidelines for registering imported/locally manufactured ICOF, risk assessment, distribution and monitoring of ICOF products.

b) Diversify ICOF products to suit current production requirements

The full potential of ICOF will only be realised if other value-added products especially those targeted at extending application in the control of soil borne pests and diseases and crop protection, are introduced. The exuviae contained in insect frass (a combination uneaten substrate, feaces, and exuviae) is rich in chitin that has pesticidal properties and could be used in the control of soilborne pests and diseases. Therefore, future research should explore the pesticidal properties of chitin fortified-ICOF in the control major crop pests such as parasitic nematodes, bacterial and fungal diseases. The introduction of new value-added ICOF products into the market would significantly increase suitability of ICOF to current production practices and reduce the use of synthetic nematicides and fungicides that are expensive, dangerous to human health and cause soil and water pollution. In addition to the solid ICOF which is currently available, liquid ICOF should be produced to cater for crops with short growth cycles, especially vegetables.

c) Generate evidence-based research to support scaling up and adoption

Field experiments and farmer-managed trials should be carried out to generate accurate information for scaling up and adoption of ICOF. The impacts of ICOF on perennial crops' productivity should be adequately investigated to generate the information necessary for integrating frass fertilizer into perennial cropping systems. The mid-long-term impacts of ICOF on soil fertility, especially physical soil fertility which has not received any research attention.

d) Capacity building

There is need to develop materials for training farmers and agro-input dealers on ICOF technologies and knowledge transfer. Public awareness should be created to raise the profile of ICOF for crop production among farmers and agro-input dealers through field demonstrations, mass media and policy briefs. Policymakers should be engaged to ease business start-up policy and regulatory hurdles and sensitize the communities about ICOF using various dissemination platforms. There is need to train the personnel involved in the production, marketing, and quality control of ICOF by attaching them to experienced ICOF experts/researchers and producers.

Conclusion

Existing research has demonstrated the positive impacts of ICOF on soil health and crop productivity to conventional fertilizers. In the long term, it is anticipated that sustainable utilization of insect frass fertilizer will significantly reduce reliance on synthetic pesticides and expensive mineral fertilizers, whose sole application also has an overwhelming deleterious effect on soil and environmental health. However, exploring the full potential of ICOF more research to: (1) establish quality standards to regulate the production and marketing of ICOF; (2) develop more ICOF products that are suitable to current production requirements; (3) capacity building of stakeholders involved in ICOF production, marketing, and quality control; and (4) public-private partnerships to develop policy and legal framework for integrating ICOF into existing fertilizer markets and farming practices.