Review Article

Utilizing Insect Frass (faecal matter): A Sustainable Approach to Organic Fertilization in Agriculture

Abstract

Insect frass, commonly known as insect fecal matter, is emerging as a sustainable solution for organic fertilization in agriculture. This paper explores the potential benefits and applications of utilizing insect frass as an organic fertilizer, highlighting its role in promoting sustainable agricultural practices. Through a comprehensive review of literature, this study examines the nutrient composition of insect frass and its impact on soil fertility and plant growth. Furthermore, the paper discusses the ecological advantages of incorporating insect frass into agricultural systems, including its ability to reduce reliance on chemical fertilizers and minimize environmental pollution. Additionally, the study delves into various methods of utilizing insect frass in different agricultural settings, ranging from soil incorporation to foliar applications. Moreover, the paper addresses the economic feasibility of insect frass as a viable alternative to conventional fertilizers, considering factors such as production costs and market demand. By synthesizing existing research and providing insights into practical applications, this paper underscores the potential of insect frass as a sustainable approach to organic fertilization in agriculture. Ultimately, this study aims to promote further exploration and adoption of insect frass as a valuable resource for enhancing soil health, increasing crop yields, and fostering ecological sustainability in agricultural practices. As agricultural sustainability becomes increasingly imperative, innovative solutions are sought to reduce reliance on synthetic fertilizers and mitigate environmental impacts. In this pursuit, the utilization of insect frass as an organic fertilizer presents a promising avenue for sustainable agriculture. With the rapid expansion of the human population, the mass breeding of insects for feed and food has emerged as a highly efficient means of protein production. A notable byproduct of this process is insect feces, or frass, which exhibits remarkable nutrient content and abundance, surpassing animal biomass production by up to 40 times. Harnessing insect frass as an organic fertilizer offers numerous advantages, including enhanced soil fertility, improved crop yield, and reduced dependency on agrochemicals.

Keywords: *Insect frass, Fertilizer, Sustainable agriculture, Nitrogen, Plant growth*

1. Introduction

The global population has experienced rapid growth, soaring from 1.6 billion in 1900 to 7.9 billion in 2021. Projections suggest that by 2050, the world's population will reach 9.7 billion, intensifying the demand for essential resources such as water, food, and energy [1]. Meeting this escalating demand entails a projected 70% increase in food production by 2050 and a fourfold or threefold increase by 2100, all while mitigating the environmental repercussions of agricultural activities [2]. This trajectory underscores the reliance on synthetic fertilizers and the cultivation of high-yield cultivars to boost productivity and meet growing food needs. However, conventional agricultural practices face mounting scrutiny due to the adverse effects of deep plowing, pesticide use, and synthetic fertilizers on environmental health [3]. Agriculture's footprint extends beyond local ecosystems, contributing to deforestation, habitat loss, biodiversity decline, resource depletion, and pollution of air, soil, and water bodies. Moreover, agricultural activities account for nearly a quarter of human-generated greenhouse gas emissions and consume a substantial portion of the world's freshwater resources. The pervasive use of synthetic fertilizers and pesticides poses significant health risks, further underscoring the imperative for sustainable agricultural practices [4]. To mitigate environmental degradation and enhance agricultural sustainability, agronomists are exploring alternative approaches that prioritize soil health, biodiversity conservation, and carbon sequestration [5]. Organic and regenerative agriculture systems offer promising pathways, emphasizing practices such as organic soil amendments and reduced chemical inputs. Organic fertilizers emerge as a sustainable alternative, aligning with the principles of economically viable and environmentally friendly agriculture. Nonetheless, the quest for novel organic nutrient sources to bolster sustainable agricultural practices remains paramount. The burgeoning insect production industry presents a novel avenue for organic waste recycling, with insect feces, or "frass," emerging as a valuable by-product [6]. Embracing a circular economy necessitates leveraging frass as a resource, given its abundance relative to insect-derived products [7]. In sum, advancing sustainable agriculture demands innovative solutions and holistic approaches to address the complex interplay between food production, environmental conservation, and human well-being.

Insect frass, also known as "frass," represents a valuable byproduct of insect rearing practices, often colloquially referred to as "insect poop." Particularly in industrial insect farming, the production of insect frass is a specialized process aimed at harnessing its benefits as a natural fertilizer [8]. Abundant in nutrients and conducive to plant growth, frass offers an organic alternative to traditional agrochemicals and synthetic fertilizers, supporting soil fertility and augmenting crop yields. Employing frass in organic farming methods has demonstrated efficacy in fortifying plants and enriching soil health, ultimately improving crop quality.The composition of insect frass typically comprises a blend of exoskeletons, residual feed, dead eggs, and insect waste, all integral components of the insect rearing process. Notably, frass derived from larvae of black soldier flies (BSF) contains chitin and beneficial microorganisms, making it a potent bio-fungicide [9]. After proper processing, insect frass transforms into valuable compost teeming with nutrients. Microbial decomposers inherent in frass facilitate the absorption of micronutrients and foster robust plant growth. Insects ingest organic matter, which their digestive systems break down, absorbing essential nutrients and minerals while excreting waste as frass. The exact composition of frass varies depending on the insect species and diet. Insect frass can be sourced from natural habitats or insect farms and finds diverse applications in horticulture and agriculture. Serving as an effective pest deterrent, soil conditioner, and fertilizer, frass is increasingly favored by producers for its natural and sustainable attributes, which enhance crop vitality and productivity while minimizing environmental repercussions [10].

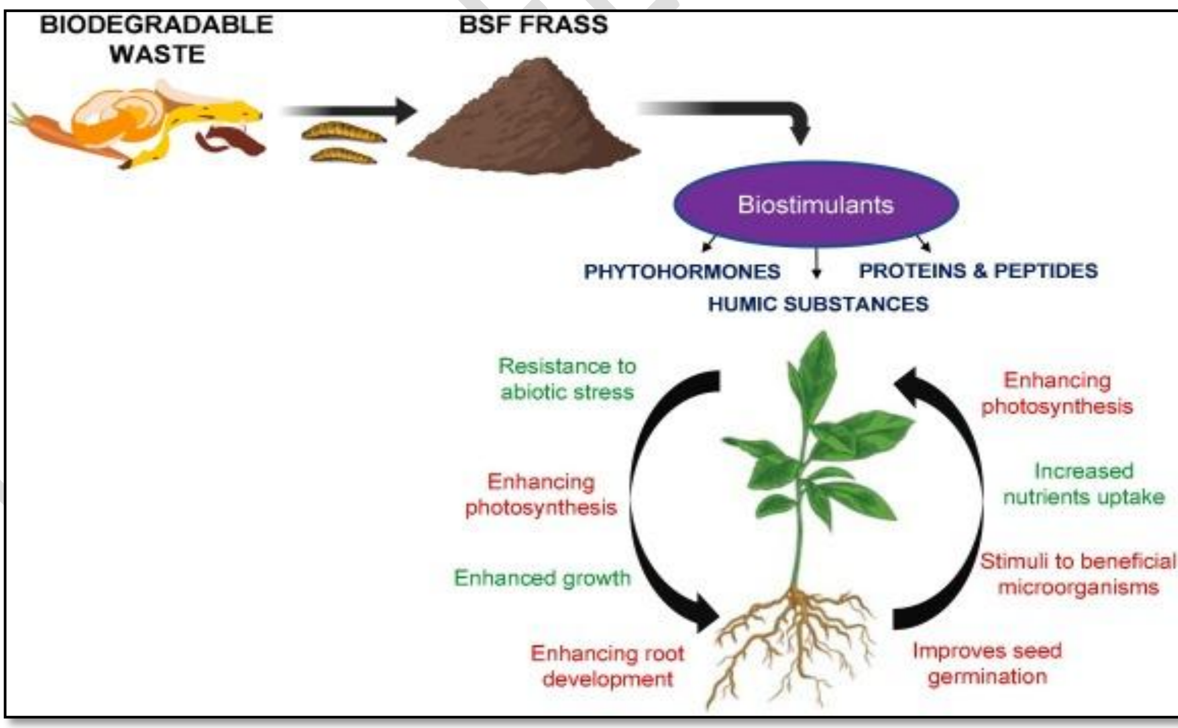


Figure 1:Bio stimulants of insect frass used for various developments

2. Use of insect frass as organic fertilizer

In response to the adverse effects of synthetic and chemical fertilizers on soil health and fertility, there's been a growing interest in adopting organic fertilizers and sustainable agricultural practices [11]. Utilizing insect frass as a natural fertilizer presents a promising solution to address these concerns. Insect frass, which comprises exoskeletons and waste residues from insect farming operations, can be repurposed as valuable organic manure, offering substantial benefits for soil enrichment and plant growth [12-13].Organic agriculture, encompassing the cultivation of vegetables, fruits, grains, herbs, and various other plant species, stands to benefit significantly from the incorporation of insect frass as a soil amendment [13]. Rich in essential nutrients such as nitrogen, phosphorus, and potassium (NPK), insect frass serves as an effective enhancer of soil quality and fertility. By integrating insect frass and exoskeletons into the soil, its physical properties can be enhanced [14], contributing to improved soil structure and nutrient availability. This not only promotes robust plant growth but also supports sustainable agricultural practices that prioritize environmental conservation and long-term soil health.

In addition to its nutrient-rich composition, insect frass offers ecological advantages by reducing reliance on synthetic fertilizers and minimizing the environmental impact associated with their use. As a natural and renewable resource, insect frass represents a valuable asset in fostering resilient and productive agricultural systems while preserving the integrity of natural ecosystems. By harnessing the potential of insect frass as an organic fertilizer, farmers can contribute to more sustainable and environmentally friendly agricultural practices, ultimately leading to healthier soils, increased crop yields, and enhanced food security [15].

2.1 Processing of frass before use as organic fertilizer

Concerns have always been raised about effectively using frass as fertilizer. Due to the application of frass directly to the soil, there is a possibility that some harmful organisms may survive in the digestive tracts of insects and be passed on to plants or people [16]. To ensure the safe use of frass after adequate sanitization and sterilization, the advantages of insect frass in agriculture as organic fertilizer are important. The frass has to go through several sanitization processes before it can be used as an insect fertilizer in agriculture to get rid of the dangerous bacteria present in the organic matter. With this, we can be confident that there are no longer any organisms that are dangerous to human health or unsafe for use in organic agriculture(Zewa Ecosystem) [17].

Table 1. Comparison between frass and chemical fertilizer

FRASS AS FERTILISER	CHEMICAL FERTILIZER
Requires more time for the nutrients of these fertilizers to reach the plant.	Work faster than organic fertilizers as they get immediately dissolved in water and supply nutrients to plants
Renewable source.	Non-renewable source.
Makes the soil healthier and more fertile	Soil life will not be enriched or stimulated.
It ensure an airy soil structure.(COMPECTION)	Chemical fertilizers lead to soil acidification.
It is biodegradable, sustainable, and environmentally friendly.	Repeated applications affect microbial ecosystems and the soil's pH, a toxic buildup of chemicals in the soil.
It supports the growth of nitrogen-fixing bacteria.	Destroys the growth of the nitrogen-fixing bacteria as it contains high acid content.
It is more expensive as compared to chemical fertilizers	It is less expensive compared to bio-fertilizers.

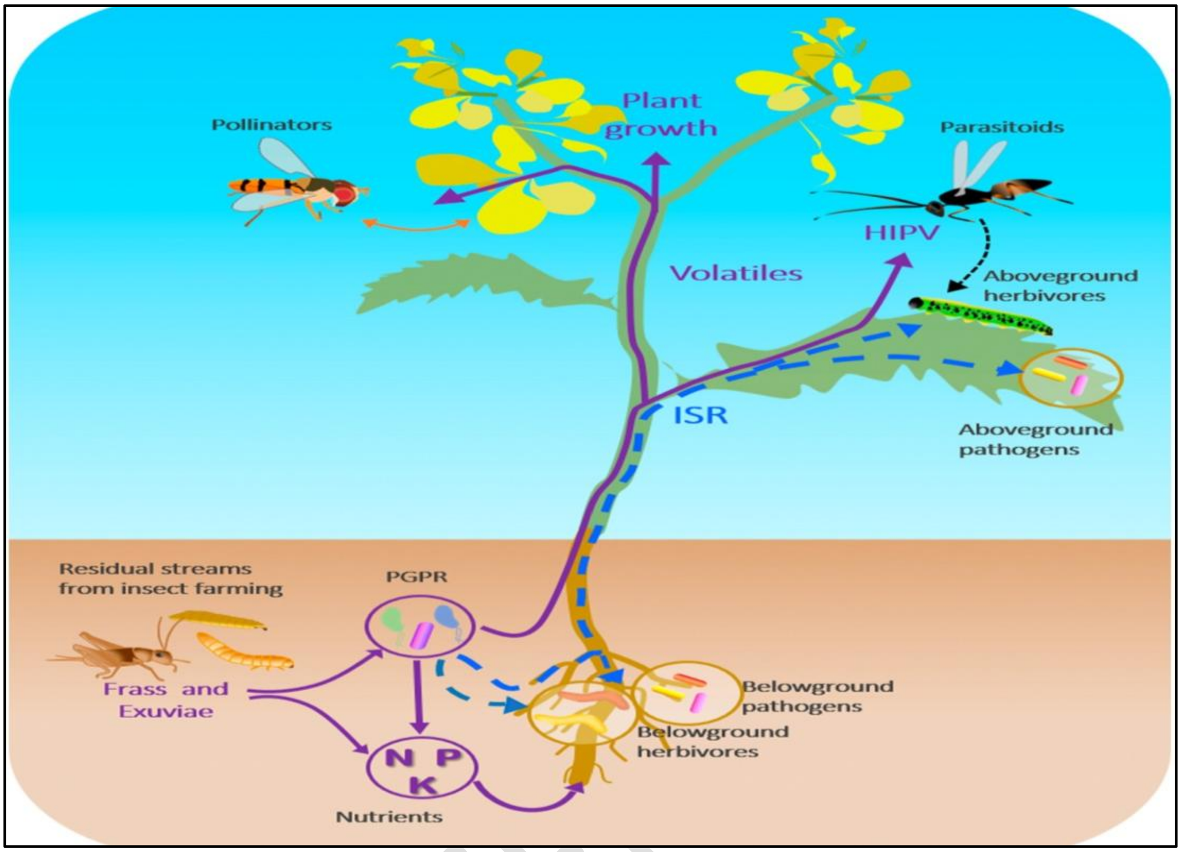


Figure 2: Circular economy of insect frass

3. Industry of mass insect breeding

In recent years, there has been a notable surge in interest surrounding the utilization of insects as both food and feed, leading to a proliferation of scientific research publications and the emergence of numerous businesses specializing in insect-based products. According to recent data, the global landscape now boasts over 250 enterprises dedicated to insect production for food and feed purposes, a figure that excludes industry associations [18]. This growing interest has spurred a substantial body of scientific literature, with hundreds of articles being published annually on the subject.While there are common themes elucidated across these studies, such as those identified by different researchers, the successful establishment and operation of large-scale insect breeding facilities necessitate the adaptation of industrial processes to accommodate the unique lifecycle of insects. Central to this endeavor is the production of frass, the excrement generated by insects, which has emerged as a significant end product within these systems [19].

Recognized within industrial frameworks as an organic fertilizer and even as animal feed, frass plays a pivotal role in the mass rearing process.Studies have shown that yellow mealworms (Tenebrio molitor), for instance, can consume substantial amounts of food, such as corn and carrots, with an accompanying production of insect biomass and frass. For instance, it has been estimated that for every 220 grams of food consumed by yellow mealworms, approximately 4 grams of insect biomass and 180 grams of frass and residues are generated [20]. This underscores the significant potential for frass accumulation in such industrial operations on a daily basis.

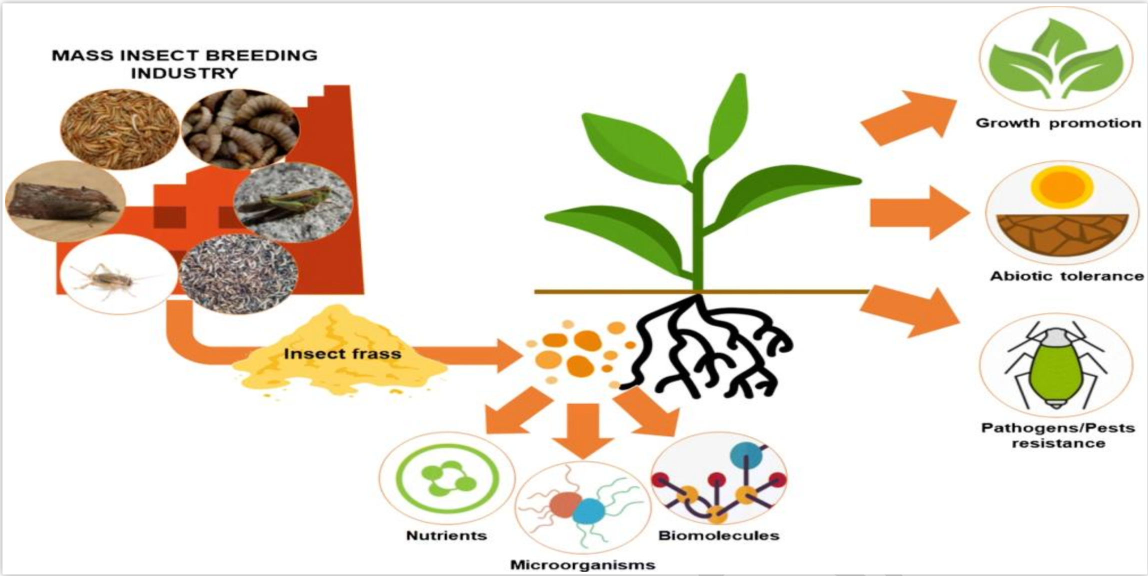


Figure 3:Production of insect frass in mass breeding inustry

4. Advantage of insect frass in agriculture as organic fertilizer

4.1 Nutrient quality and maturity status of frass fertilizer

1. The quality of frass fertilizer produced by insect species and its practical application for enhanced soil health and agricultural yield
2. The different frass fertilizer products' high nutrient contents, fertilizing indices, and prospective nutrient supply capabilities suggest that they are suitable as sustainable substitute sources of plant nutrients.
3. Utilizing the circular economy concept, there is significant interest globally in recycling organic waste into high-quality frass fertilizer by applying insect larvae.
4. All insect species had sufficient levels of the macronutrients potassium, phosphorus, and nitrogen
5. Soil degradation and improper waste management; seriously threaten global food and nutritional security, as well as environmental health.

In sub-Saharan Africa (SSA), nearly 40% of soils exhibit deficiencies in essential crop nutrients, presenting significant challenges for agricultural productivity. Moreover, a quarter of soils are burdened by aluminum toxicity, while 18% are prone to leaching, and 8.5% are characterized by phosphorus fixation [21]. These soil constraints hinder crop growth and yield potential, exacerbating food insecurity in the region. Smallholder farmers, who form the backbone of agriculture in SSA, often face barriers to accessing and affording mineral fertilizers due to their high costs and limited availability. Consequently, many farmers apply minimal amounts or no mineral fertilizer at all, further exacerbating soil nutrient deficiencies. Additionally, the efficacy of mineral fertilizers is compromised by factors such as low soil organic matter, micronutrient deficiencies, and soil acidity, which diminish their impact on crop growth even when used [22-23].

While organic fertilizers offer a viable alternative, their adoption in SSA has been limited by challenges such as low quality, lengthy production processes, and insufficient on-farm organic matter supplies. In this context, exploring alternative sources of organic fertilizers, such as insect frass, becomes imperative. Insect farming presents a promising avenue for bio-converting low-value organic materials into valuable products, including food, feed, fiber, and organic fertilizer. Insect frass stands out as a readily available, cost-effective, and high-quality organic fertilizer source that merits further investigation for its potential to enhance soil fertility and agricultural productivity in SSA [24].

4.2 As sources of nutrients and compound interest for plant growth

In nature, insect frass plays a vital role in the soil-plant nutrient cycle, serving as a key component of the ecosystem's nutrition cycle. Beyond its ecological significance, insect frass holds practical value in various agricultural and environmental contexts.Due to its nutrient-rich composition, insect frass finds multiple applications beyond its role in natural ecosystems. It can serve as a valuable indicator of insect diversity in specific areas, aiding ecological studies and biodiversity assessments. Moreover, the nutrient content of insect frass makes it a suitable option for use as fish feed, contributing to the nutrition of aquatic species such as hybrid tilapia and channel catfish [25].

In agricultural settings, insect frass provides readily absorbable nutrients to plants, facilitating their growth and development. Through physiological processes within insects, nutrients like nitrogen and phosphorus are concentrated in frass, making them highly accessible to plant roots. This nutrient transfer is especially significant in ecosystems where plants face challenges in accessing nitrogen, such as in soils with low nitrogen levels or prone to denitrification [26].Studies have demonstrated the efficacy of insect frass as a natural fertilizer in enhancing soil fertility and promoting plant growth. Frass from various insect species, including the yellow mealworm and cabbage moth, has been shown to enrich soil with essential nutrients, leading to increased crop yields and improved plant health. Additionally, insect frass contributes to the soil's carbon and nitrogen content, supporting microbial activity and overall soil health.

The nutritional value of insect frass extends beyond traditional fertilization benefits. Frass derived from specific insect species contains sugars, alkaloids, and phenols, which can stimulate seed germination and seedling development in various plant species [27]. Furthermore, ongoing research explores innovative applications of insect frass, such as utilizing frass from mealworms to recycle plastics in agriculture, highlighting its potential for promoting sustainability in agricultural practices.Overall, insect frass represents a natural and sustainable resource with diverse applications in agriculture, ecology, and environmental management. As research continues to unveil its potential benefits, incorporating insect frass into agricultural practices holds promise for enhancing soil fertility, improving crop productivity, and fostering ecological balance [28].

4.3 Frass as an aspect of abiotic stress resistance and abiotic stress tolerance for plants

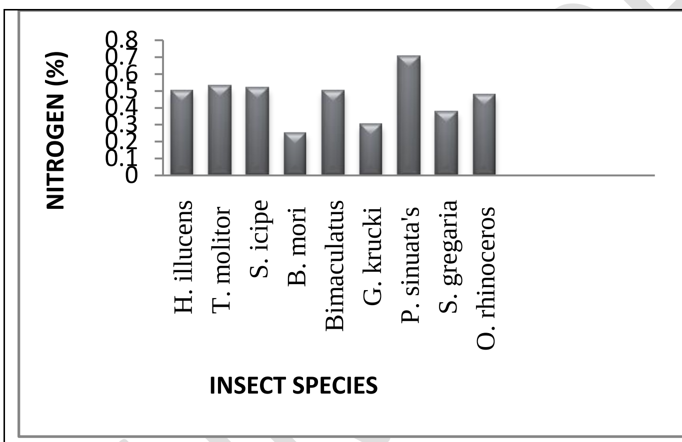
Insect frass has emerged as a potential enhancer of plant resilience against various abiotic stressors. For instance, a study applied mealworm frass to bean plants and observed an increase in seedlings' resistance to salt, drought, and floods. The enhanced tolerance was attributed to the presence of numerous bacterial and fungal isolates in the frass capable of fixing atmospheric nitrogen, solubilizing phosphates and potassium, and producing beneficial compounds like siderophores, auxins, and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminize, which stimulate plant growth and stress tolerance [29].Moreover, research indicates that insect frass can activate plant defense mechanisms against pests and diseases. The microorganisms and compounds present in frass play a crucial role in initiating plant systemic resistance via pathways such as salicylic acid (SA) and jasmonic acid (JA)/ethylene (ET). These pathways are triggered by the recognition of chemical patterns by cellular receptors linked to microbes and herbivores, such as chitin [30].

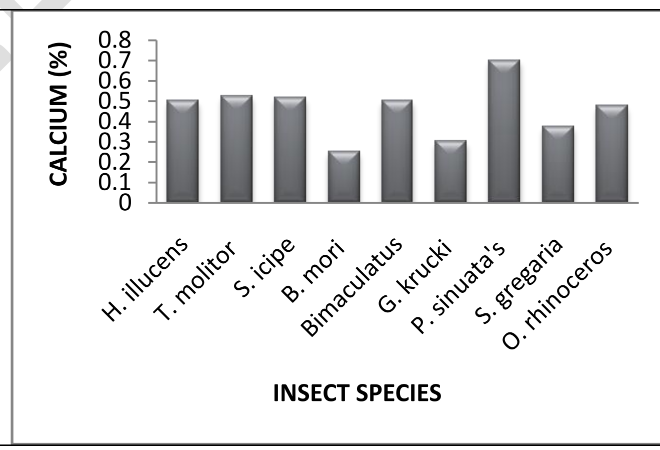
Studies have demonstrated the induction of pathogenesis-related (PR) defense genes in plants exposed to insect frass, leading to increased resistance against pathogens. Compounds like chitin present in frass have been shown to activate plant defense mechanisms and reduce disease severity, as observed in cowpea plants exposed to brewery waste-fed frass from *Hermetiaillucens*. Additionally, chitinase enzymes found in insect frass can enhance pathogen defenses in plants while reducing herbivore defenses [31].However, the effectiveness of insect frass in activating plant defense responses may vary depending on the crop and the specific pathogens or pests involved. For instance, while frass from *H. illucens*did not reduce disease severity in sugar beetroot and staff seedlings infected with *Rhizoctonia solani*and *Pythium ultimum*, respectively, it may exhibit different outcomes in other plant species or under different conditions [32].

5. Compression of the nutritional value and maturity status of some edible insects as fertilizers

Frass fertilizers derived from various edible insect species contain essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as secondary nutrients like calcium, magnesium, and sulfur, and micronutrients including manganese, copper, iron, zinc, boron, and salt [33]. Notably, black soldier fly (BSF) frass fertilizer demonstrated significantly higher levels of potassium (K) and nitrogen (N) compared to other insect-based fertilizers, with Gryllusbimaculatus frass exhibiting notably higher phosphorus (P) content.Seed germination rates and indices were notably higher in seeds treated with BSF frass fertilizer, showcasing its efficacy in promoting seedling growth [18-20]. The total organic carbon content of frass fertilizer samples varied, with Tenebrio molitor and Oryctes rhinoceros frass showing the lowest and highest values, respectively.

Ammonium content in frass fertilizer samples ranged widely, with the highest levels observed in frass produced by *Prosopocoilussinuatus*. Frass fertilizer derived from *Hermetiaillucens* exhibited significantly higher total nitrogen content compared to other insect-derived frass fertilizers.Variability was also observed in phosphorus (P) concentrations among different insect species, with *Gryllusbimaculatus* and *Bombyx mori* generating frass fertilizer with the highest and lowest P contents, respectively [34]. Additionally, potassium (K) levels were notably higher in H. illucens-derived frass fertilizer compared to other insect sources.Manganese (Mn) concentrations varied across frass fertilizer samples, with *O. rhinoceros* and *B. mori* producing the lowest and highest Mn values, respectively. Furthermore, iron (Fe) concentrations were significantly higher in O. rhinoceros frass fertilizer compared to other insect-derived fertilizers [35]. These findings underscore the potential of insect frass as a valuable and nutrient-rich organic fertilizer for agricultural applications.





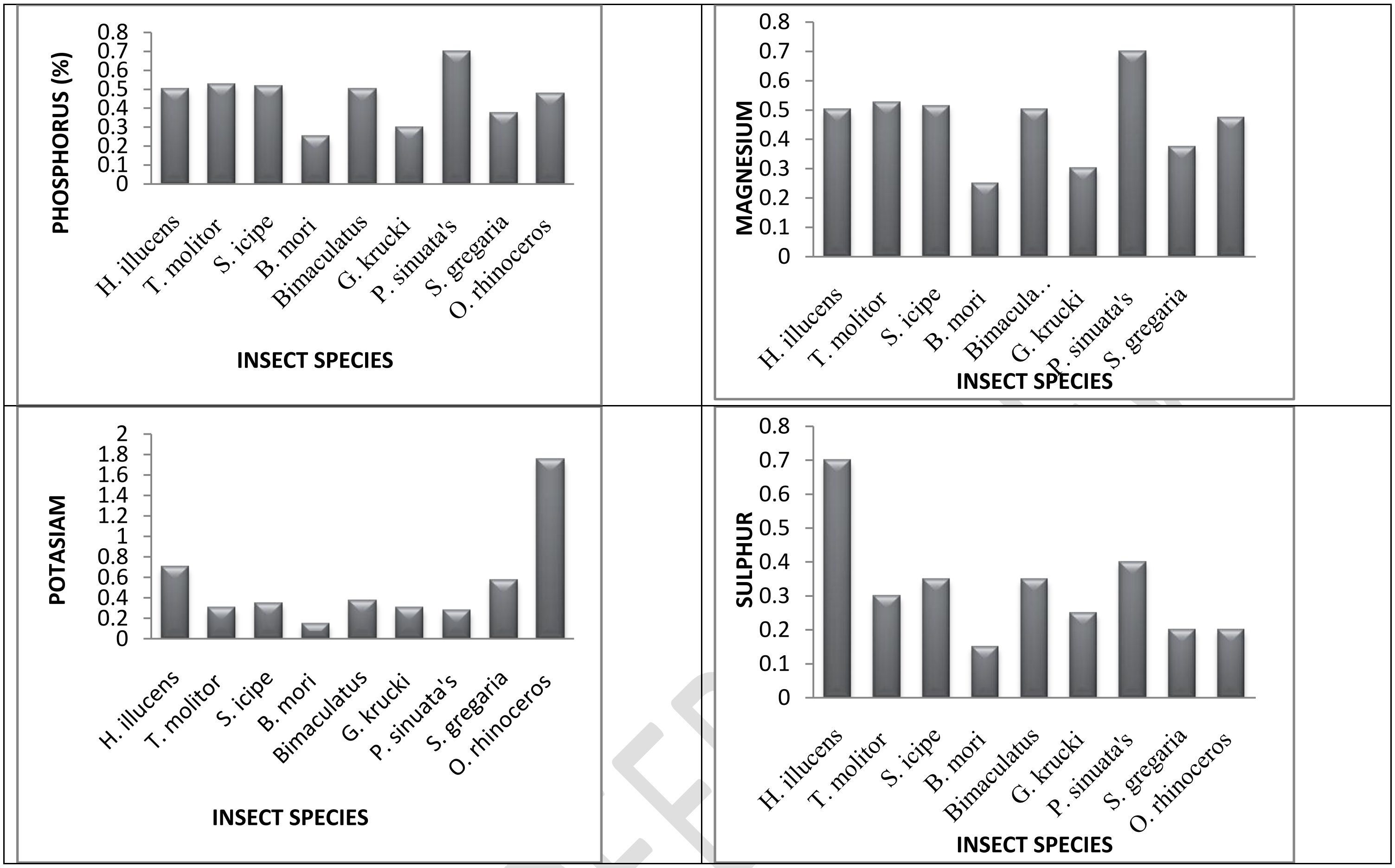


Figure 4: Total amounts of nitrogen, phosphorous, potassium, calcium, magnesium, Sulphur, and other nutrients were measured in frass fertilizer produced by various edible insects (nature portfolio).

The effectiveness of using frass fertiliser produced by various edible insect species to boost soil health and crop yield, along with precise directions for its use. Numerous frass fertiliser products are suitable as sustainable alternative sources of plant nutrients due to their high nutrient levels, fertilising indices, and potential nutrient supply capacities [23,24]. It is expected that the availability and use of insect frass fertilisers will greatly reduce the overreliance on expensive commercial mineral fertilisers and subpar organic fertilisers.In terms of nutrient content and prospective supply capability, frass fertiliser products from *H. illucens* and two cricket species (*G. bimaculatus* and *S. icipe*) were the best [2,3]. However, with the exception of *H. illucens*, the frass fertiliser from all of the insects would require further composting to increase their maturity and stability. More agronomic research is needed to determine the best amendment rates of different frass fertilisers to ensure high nutrient release and synchrony for crop absorption, better yield, and nutritional quality of food crops.

6. Beneficial effects of frass

Insect farming stands out as a highly sustainable method for generating alternative protein sources, with insect frass emerging as a valuable by-product that offers extensive benefits in agriculture, particularly as an organic fertilizer. The utilization of waste from insect rearing not only presents economic advantages but also aligns with ecological principles, fostering a zero-waste approach. Rich in essential nutrients like nitrogen, phosphorus, and potassium, insect frass serves as a vital source for promoting plant growth and development. Additionally, it provides sufficient quantities of micronutrients necessary for soil enrichment and improvement. Moreover, its application enhances microbial activity in the soil, facilitating better nutrient absorption by plants and thereby boosting overall plant health. With its high nutritional value available at cost-effective rates, insect frass emerges as a promising option for sustainable agricultural practices. Furthermore, it contains growth-promoting compounds such as insect exuviae and chitin, which contribute to improved plant productivity. Through frass treatment, crops exhibit heightened resistance to insects and increased resilience against various abiotic stressors. Overall, the use of insect frass contributes to the enhancement of soil fertility, structure, and water retention, underscoring its significance in promoting sustainable agriculture and ecological balance.

7. Frass application rates

Insect frass offers a multitude of applications in gardening, with its versatility determined by the specific needs of the garden. To maximize its benefits, it's advisable to incorporate insect frass into the soil or compost before planting, ensuring even distribution of nutrients [10-12]. For established plants, soaking insect frass in water for several hours and then using it to drench the roots proves effective in delivering essential nutrients directly to the plants. In raised beds, applying approximately a pound of insect frass per 20 square feet of plant space and thoroughly mixing it into the top half foot of soil ensures optimal nutrient distribution. For sustained benefits throughout the growing season, additional top-dressing of insect frass every few weeks can further enhance soil fertility.

When potting plants, incorporating one cup of insect frass per cubic foot of potting soil provides a nutrient-rich growing medium. Regularly sprinkling insect frass on top of the soil every few weeks ensures a continuous supply of nutrients to the plants [8].For a potent insect frass tea extract, mixing 12 cups of frass into a gallon of de-chlorinated water and applying it to drench plant roots within two hours of mixing is recommended. Any excess tea can be refrigerated for up to a week to prevent spoilage, as storing it at room temperature may lead to rapid deterioration. These various methods of utilizing insect frass in gardening practices highlight its efficacy in promoting plant health and enhancing soil fertility [6,12].

8. Conclusion

The escalating global population necessitates innovative solutions for sustainable food production, prompting a shift towards environmentally conscious practices like mass insect breeding. Insect frass emerges as a promising organic fertilizer, rich in nutrients and beneficial microorganisms, offering a sustainable alternative to conventional agrochemicals. Despite the promising potential, research on insect frass remains in its nascent stages, with a majority of studies conducted in the past few years. Future investigations should delve into the diverse compounds and microorganisms present in insect frass, exploring their roles in promoting plant growth and resilience against environmental stressors. While insect frass shows potential as a viable fertilizer, comprehensive studies in agricultural systems are imperative to ascertain its efficacy compared to mineral fertilizers. Embracing insect frass as a sustainable resource in farming practices could significantly mitigate reliance on costly mineral fertilizers and inferior organic alternatives.The nutritional composition of insect frass, encompassing various micronutrients and macronutrients, underscores its potential as a valuable fertilizer. However, the absence of regulatory frameworks specifically addressing the use of insect waste necessitates further scrutiny to ensure its safe and effective integration into agricultural practices.Moreover, insect frass presents a promising avenue for research into its role in enhancing plant nutrition, activating defense mechanisms, and fostering sustainable agricultural systems. As insect rearing experiences rapid growth, harnessing the potential of insect frass as an organic fertilizer holds promise for creating a circular economy and promoting sustainable agriculture in the face of global food security challenges.

9. References

1. Gupta GS, Vastag G. Sustainable Development and Relevance of Ancient Wisdom. PhD diss., PhD Dissertation, SzécheniyEgyetem English Doctoral School of Management. 2020.

2. Wu WB, Yu QY, Peter VH, YOU LZ, Peng YA, Tang HJ. How could agricultural land systems contribute to raise food production under global change?. Journal of Integrative Agriculture. 2014;13(7):1432-42.
3. Udeigwe TK, Teboh JM, Eze PN, Stietiya MH, Kumar V, Hendrix J, Mascagni Jr HJ, Ying T, Kandakji T. Implications of leading crop production practices on environmental quality and human health. Journal of environmental management. 2015;151:267-79.
4. Kumar A, Kumar R, Kumar S. Scope and Significance of Soil, Water, and Air Pollution Resulting from Agricultural Activities. SOIL, WATER.:12.
5. Trivedi P, Singh BP, Singh BK. Soil carbon: introduction, importance, status, threat, and mitigation. In Soil carbon storage 2018 Jan 1 (pp. 1-28). Academic Press.
6. Marousek J, Strunecky O, Vaníčková R, Midelashvili E, Minofar B. Techno-economic considerations on latest trends in biowaste valuation. Systems Microbiology and Biomanufacturing. 2023:1-9.
7. Deruytter D, Gasco L, Gligorescu A, Yakti W, Coudron CL, Meneguz M, Grosso F, Shumo M, Frooninckx L, Noyens I, Oddon SB. The (im) possible standardisation of insect feed experiments: a BSF case study. Journal of Insects as Food and Feed. 2022;8(Supplement 1):S144-144.
8. Rajendran K, Surendra KC, Tomberlin JK, Khanal SK. Insect-based biorefinery for bioenergy and bio-based products. InWaste Biorefinery 2018 Jan 1 (pp. 657-669). Elsevier.
9. Lopes IG, Yong JW, Lalander C. Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives. Waste Management. 2022;142:65-76.
10. Rassaei F. Chitosan as an organic amendment to improve soil properties and plant growth in the presence of polystyrene microplastics. Environmental Progress & Sustainable Energy. 2023:e14301.
11. Verma BC, Pramanik P, Bhaduri D. Organic fertilizers for sustainable soil and environmental management. Nutrient dynamics for sustainable crop production. 2020:289-313.
12. Asghar W, Akça MO, Akça H, Tarf OJ, Kataoka R, Turgay OC. Alternative strategies to synthetic chemical fertilizers: revitalization of soil quality for sustainable agriculture using organic-based approaches. InNew and future developments in microbial biotechnology and bioengineering 2022 Jan 1 (pp. 1-30). Elsevier.
13. Tripathi S, Srivastava P, Devi RS, Bhadouria R. Influence of synthetic fertilizers and pesticides on soil health and soil microbiology. InAgrochemicals detection, treatment and remediation 2020 Jan 1 (pp. 25-54). Butterworth-Heinemann.
14. Antoniadis V, Molla A, Grammenou A, Apostolidis V, Athanassiou CG, Rumbos CI, Levizou E. Insect Frass as a Novel Organic Soil Fertilizer for the Cultivation of Spinach (Spinacia oleracea): Effects on Soil Properties, Plant Physiological Parameters, and Nutrient Status. Journal of Soil Science and Plant Nutrition. 2023;23(4):5935-44.
15. Poveda J. Insect frass in the development of sustainable agriculture. A review. Agronomy for Sustainable Development. 2021;41(1):5.
16. Zahn NH, Quilliam R. The effects of insect frass created by Hermetiaillucens on spring onion growth and soil fertility. Undergraduate disertation. University of Stirling. Skotlandia. 2017 Apr 4.
17. Horrigan L, Lawrence RS, Walker P. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental health perspectives. 2002;110(5):445-56.
18. Megido RC, Francis F, Haubruge E, Le Gall P, Tomberlin JK, Miranda CD, Jordan HR, Picard CJ, Pino MJ, Ramos-Elordy J, Katz E. A worldwide overview of the status and prospects of edible insect production. ENTOMOLOGIA GENERALIS. 2024 Feb 20.
19. Menino R, Murta D. The insects as a workforce for organic fertilizers production–insect frass. New Generation Organic Fertilizers. 2021 Oct 3.
20. Abajue MC, Gbarakoro TN. Prospects of Insect Farming for Food Security, Environmental Sustainability, and as an Alternative to Agrochemical Use. InOne Health Implications of Agrochemicals and their Sustainable Alternatives 2023 Sep 4 (pp. 565-600). Singapore: Springer Nature Singapore.
21. Johannes BW, Paxton CB, Peter MK, Neal WM. Aluminum. InManaging Global Resources and Universal Processes 2020 Jul 29 (pp. 155-173). CRC Press.
22. Fageria NK, Nascente AS. Management of soil acidity of South American soils for sustainable crop production. Advances in agronomy. 2014 Jan 1;128:221-75.

23. Singh B, Ryan J. Managing fertilizers to enhance soil health. International Fertilizer Industry Association, Paris, France. 2015 May;1.
24. Place F, Barrett CB, Freeman HA, Ramisch JJ, Vanlauwe B. Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food policy. 2003;28(4):365-78.
25. Romano N, Yamamoto F, Rawles SD, Webster CD. Type of black soldier fly (*Hermetiaillucens*) larvae frass influences the nutritional value when included in a prepared diet for Mozambique tilapia (*Oreochromis mossambicus*). Aquaculture. 2024:740946.
26. Van Groenigen JW, Huygens D, Boeckx P, Kuyper TW, Lubbers IM, Rütting T, Groffman PM. The soil N cycle: new insights and key challenges. Soil. 2015;1(1):235-56.
27. Chou CH. Roles of allelopathy in plant biodiversity and sustainable agriculture. Critical reviews in plant sciences. 1999;18(5):609-36.
28. Liu X, Floate KD, Gorzelak MA, Holman DB, Hrycauk S, Kubota H, Lupwayi N, Neilson JA, Ortega Polo R, Petri RM, Tran L. Prairie agroecosystems: interconnected microbiomes of livestock, soil and insects. Agriculture. 2023;13(2):326.
29. Singh S, Prasanna R, Pranaw K, editors. Bioinoculants: Biological Option for Mitigating Global Climate Change. Springer Nature; 2023 Jul 25.
30. Walling LL. Adaptive defense responses to pathogens and insects. Advances in botanical research. 2009;51:551-612.
31. Ray S, Alves PC, Ahmad I, Gaffoor I, Acevedo FE, Peiffer M, Jin S, Han Y, Shakeel S, Felton GW, Luthe DS. Turnabout is fair play: herbivory-induced plant chitinases excreted in fall armyworm frass suppress herbivore defenses in maize. Plant physiology. 2016;171(1):694-706.
32. Adegbeye MJ, Salem AZ, Reddy PR, Elghandour MM, Oyebamiji KJ. Waste recycling for the eco-friendly input use efficiency in agriculture and livestock feeding. Resources Use Efficiency in Agriculture. 2020:1-45.
33. Beesigamukama D, Subramanian S, Tanga CM. Nutrient quality and maturity status of frass fertilizer from nine edible insects. Scientific Reports. 2022;12(1):7182.
34. EFSA Scientific Committee. Risk profile related to production and consumption of insects as food and feed. EFSA journal. 2015;13(10):4257.