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EDITORIAL
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Editorial: Frass: The Legacy of Larvae – Benefits and Risks of Residues From Insect Production

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Editorial on the Research Topic

Frass: The Legacy of Larvae – Benefits and Risks of Residues From Insect Production

In November 2021, IPIFF (the International Platform of Insects for Food and Feed) produced a highly readable fact sheet on insect frass. Therein is a section detailing the benefits of frass, listed as its:

1. plant fertilization potential by supply of macro- and micronutrients to soil
2. positive effects on soil microbiological activity, and
3. provision of plant tolerance to abiotic stress and resistance to pathogens

Given that insect rearing is a rapidly growing sector in Europe (IPIFF in 2020 predicted 5 Mt larval protein production by 2030), such positivity regarding frass and its potential to make insect production a "zero waste" industry, is not surprising. Agriculture leads to the escape of reactive nitrogen and phosphorus rock reserve depletion (Rockström et al., 2009), while increasing soil carbon sequestration is a global warming mitigation strategy (Minasny et al., 2017). Using insect frass as a soil amendment could therefore contribute to tackling agricultural nutrient cycle imbalances and climate change.

Insect frass has been associated with a range of positive effects, including increasing the soil microbial biomass (Gebremikael et al., 2020), provision of macronutrients to plants (Houben et al., 2020), and supply of biomolecules and microbes promoting plant growth (Poveda, 2021). However, some experiments reveal negative effects of frass on soil processes, such as the marked build-up of nitrite observed by Watson et al. (2021), and on plant growth, for example, the inhibited germination of Japanese mustard spinach reported by Kawasaki et al. (2020). Therefore, how robust are the three claims listed above? Each of the papers in this Research Topic sheds light on some or all of them.

Regarding point (1), Houben et al. demonstrated mealworm frass (MWF) to be as effective as mineral fertilizer in the provision of P and K to Italian ryegrass but reported only the higher application rate could supply adequate N. They highlighted that N provision can be rapid from frass and recommended its application according to plant N demand. In contrast, Gebremikael et al. recorded N immobilization in an incubation experiment using black soldier fly frass (BSFF) and advised co-application of frass with a more readily available N supply to meet the requirements of their pot trial test plant, maize. Similar to Houben et al., these authors recommended the investigation of frass N mineralisation dynamics.

Of relevance to this, Watson et al. studied the N uptake of Italian ryegrass from soil amended with MWF and inhibitors of nitrification and/or urea hydrolysis. This work demonstrated that a substantial fraction of frass organic N is ureic; retarding this pathway by co-applying

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inhibitors could potentially allow frass to be applied as a slow-release fertilizer. Nevertheless, frass nutrient content, and those nutrients' availability to plants, is dependent on several factors, with Gebremikael et al. and Watson et al. identifying larval feedstock composition as one of the most important. It is likely that processing and storage further influence the nutrient availability of frass.

With reference to point (2), Houben et al., Gebremikael et al., and Watson et al. all reported stimulatory effects of amendment with frass on soil microbial biomass and microbially-mediated activities including C and N mineralisation. It must be acknowledged that the effects of these activities are not necessarily positive. Watson et al., for example, described in soil amended with a high application rate of MWF a build-up of nitrite that could only be prevented with co-application of a nitrification inhibitor. Considerable release of CO_2 from frass-amended soil is reported by Rummel et al., Houben et al., and Gebremikael et al.

Possibly of far greater environmental relevance is the observation of Rummel et al.: soil amendment with BSFF derived from larvae reared on a carbohydrate-rich diet induced strong initial nitric oxide and particularly nitrous oxide emissions amounting to between 5 and 9% of applied N. This was reported to be mainly due to its labile C and N contents. Thus, the rapid mineralisation of the organic soil amendment frass, while desirable with regard to plant nutrition, may have negative environmental impacts which have until now been largely overlooked.

Perhaps point (3) is the most questionable of the IPIFF fact sheet claims. Application to soil of an organic amendment such as frass can certainly improve properties such as water-holding capacity, but the results of Watson et al. should not be overlooked. They applied 1.5% MWF to soil in a pot trial (effectively double the highest rate used by Houben et al.) which proved to be an effective fertilizer for Italian ryegrass. At an application rate of 3% however, seed germination was inhibited. While it was unclear whether this was due to salinity or ammonia toxicity, it is apparent that high amendment rates of frass can cause the abiotic stress it is purported to alleviate.

Point (3) also encompasses the belief that certain pathogenic fungi may be suppressed by one constituent of frass, chitin. Nurfikari and de Boer reported an analytical breakthrough in quantifying this polymer in larval molting skins (exuviae) isolated from mealworm and black soldier fly production streams. Their method involved defatting, demineralising, and deproteinising exuviae. Subsequently, the obtained chitin was hydrolysed and its components glucosamine, *N*-acetylglucosamine, and acetic acid were quantified chromatographically. They assert that electrochemical detection of these compounds could replace more expensive and laborious mass spectrometry. Nurfikari and de Boer reported 8–18% chitin is recoverable from exuviae. While they maintain exuviae could be isolated from frass via vacuum separation or sieving, it remains to be seen whether this will become a production norm. More importantly, the incentive is unclear, as it is questionable how pathogenic fungi would be selectively suppressed by the chitin fraction of frass, when frass application to soil was reported by Rummel et al. and Watson et al. to stimulate general fungal abundance.

The studies in this Research Topic highlight the undoubted potential of frass to be a soil amendment of benefit to the microbial biomass. As an organic fertilizer it can stimulate plant growth and potentially ease some of the demand for mineral fertilizers, thus contributing to regional nutrient circularity and lowering the environmental footprint of intensive farming (van der Wiel et al., 2021). To this end, testing of various application rates on a further variety of crops, in particular under long-term field conditions, will allow elucidation of crop response to frass type and level. Crucially, a thorough understanding of the influence of larval feedstock on the frass generated, as well as the effect of sterilization measures (70°C for 1 h), should enable the targeted application of frass to meet crop nutrient demand. Before stressing the potential of frass to mitigate climate change and improve nutrient flows, further research on the mechanisms of C and nutrient release (particularly N) from it is needed to minimize their loss to the wider environment. Given the major upscaling of the insect industry currently taking place, this research is especially urgent to enable the efficient and sustainable use of the huge amounts of frass generated.

AUTHOR CONTRIBUTIONS

CW wrote the editorial. FW and DH made suggested changes and proof-read the editorial. All authors contributed to the article and approved the submitted version.

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