Vermiculture for Human Nutrition across Scales – Potentials and Limitations

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Abstract

With rapid population growth and limited land availability, food security is increasingly threatened in many parts of the world. To address these challenges, future food systems need to provide additional, affordable and healthy food, without adding pressure on limited resources, particularly farmland. A promising novel food that can be produced on little land are earthworms. They are traditionally consumed by different cultures around the world and recent studies support their value as a high-quality alternative protein source. Earthworms can be reared on organic wastes to produce protein-rich earthworm biomass and vermicompost, a high value organic fertilized, as a byproduct. Future food systems could utilize the ecological function of earthworms as decomposers to create economic value, food and fertilizer, from waste. However, the scale at which these benefits can be harnessed best is still unclear. Accordingly, in this study we performed a SWOT analysis to compare three model scenarios of vermiculture for human nutrition to elucidate the potentials and limitations present at different scales.

Introduction

Global population growth is expected to rapidly increase the demand for food in the coming decades and innovative and sustainable food systems will have to be developed in response. Current food systems rely largely on farmable land for food production. The area of farmland available per person, however, is drastically decreasing and agricultural productivity is furthermore jeopardized by climate change, soil degradation and biodiversity loss (Rahmann und Grimm 2021). Under these conditions, ensuring food security for all will be near impossible with today's primarily land-based food systems (Rahmann et al. 2020). To address these challenges, future food systems should produce affordable and healthy food, and reduce the environmental impact on land, water, biodiversity and the global climate, while restoring soil fertility (Willet et al. 2019).

The circular LandLessFood system has been developed as one approach to achieving these goals (Rahmann et al. 2020). It combines the following three steps to increase food production and nutrient cycling, while lowering land-use and environmental footprint: 1. Land-based agriculture produces staple foods and crop residues are removed at harvest as a resource for further food production. 2. Crop residues are utilized as a substrate for cultivation of edible oyster mushrooms and are partially degraded in the process. 3. Spent mushroom substrate is fed to earthworms to produce protein-rich earthworm biomass for human consumption. Residual vermicompost, a high-quality organic fertilizer, is returned to the field to improve soil fertility and agricultural productivity.

The present article focuses on the rearing of earthworms for biomass production, also known as vermiculture, in the context of the LandLessFood system. A number of recent studies have shown the potential of using spent mushroom substrate as feed for earthworm biomass production (Bakar et al. 2011; Nik Nor Izyan et al. 2009; Sailila et al. 2010; Sun 2003; Wang et al. 2019). Earthworm biomass is a valuable protein-source and has been traditionally valued as food by cultures around the world (Sun und Jiang 2017; Grdiša et al. 2013). Earthworms have a high protein content of 55 – 71 % dry weight (Sun et al. 1997), are rich in essential amino acids (Sun und Jiang 2017) and a good source of minerals and vitamins (Domínguez et al. 2017). Furthermore, vermiculture for human nutrition produces high-

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quality organic fertilizer as a by-product, which can be applied to improve soil fertility and crop productivity in the field (Dominguez and Edwards 2011, Lazcano and Dominguez 2012).

Vermiculture for human nutrition comes with varying potentials and limitations depending on the scale of application. Vermiculture can be practiced from small-scale, low-tech settings up to industrial-scale, high-tech facilities (Shermann 2018). It is currently unclear at which scale the use of vermiculture for human nutrition can most efficiently contribute to food system sustainability. In this study we therefore investigate potentials and limitation of vermiculture for human nutrition in three scenarios of different scale. Our main research questions with regard to these three scenarios are:

1. Is vermiculture technically feasible?
2. How does vermiculture contribute to food security?
3. How does vermiculture contribute to sustainability?
4. How does vermiculture create economic value?

Methods

Table 1: The application of vermiculture for human nutrition is described for three model scenarios of different scale.

Scenario A: Farming household	
Socioeconomy: • 7 people • 0.35 ha farmland • Subsistence farming • Vermiculture: low level of know-how, no or little capital & equipment	**Vermiculture Setup:** Earthworms are reared in small-scale vermibeds, open to the ground and surrounded by a low wall on the sides. Shade is provided by trees, a simple roof or net. Evaporation can be controlled by large leaves, a tarp or other cover. Feed is applied in the form of crop residues and food waste when available. Earthworm are utilized by controlled access of chickens or hand-picked for direct use in the kitchen. Vermicompost is directly applied to the field or kitchen garden.
Scenario B: Rural community	
Socioeconomy: • 500 households (7 people each) • 175 ha farmland • Mainly subsistence farming • Vermiculture: centralized with some market orientation, specialized workers, little capital & low tech equipment	**Vermiculture Setup:** Earthworms are reared in several large vermibeds with a cemented floor and surrounded by low brick-walls. Alternatively stackable boxes with ventilated lids can be used for more efficient space utilization. Shading and rain-protection are provided by a simple roof. Vermibed can be covered with tarps, large leaves or lids for evaporation control. Spent mushroom substrate and other organic community wastes are regularly added as feed in thin layers. Earthworms are harvested by sieving for direct consumption in community households or during application to the field by chickens. Vermicompost is stored and supplied to farmers when needed. Leachate, or vermitea is collected and can be used as a biostimulant.
Scenario C: Commercial enterprise	
Socioeconomy: • Large scale production facility linked to commercial mushroom production • Vermiculture: highly centralized production for the market, expert workers, high capital & high-tech equipment	**Vermiculture Setup:** Earthworms are reared in a box-system on multi-level conveyor belts with sensors for automated feeding, optimal humidity and temperature regulation and pH-control. Spent mushroom substrate and other N-rich organic wastes supplied regularly in thin layers for optimal earthworm biomass production. Mechanized harvest with trommel sieve for direct processing of fresh earthworms. Vermicompost is stored and supplied to farmers when needed. Leachate, or vermitea is collected and can be used as a biostimulant.

This study investigates the potentials and limitations of vermiculture for human nutrition at different scales, based on three model-scenarios. The three scenarios (Table 1) describe increasingly complex socio-economic situations within the LandLessFood framework (Rahmann et al. 2020). The availability of materials, investment capital and know-how to implement vermiculture increases from the level of a farming household (scenario A), over a rural community (scenario B) to a commercial enterprise (scenario 3).

Each scenario was subjected to a SWOT-analysis, a strategic planning tool used to evaluate a project (Paschalidou et al., 2018). Following this method identify internal and external variables that are supporting or inhibiting to the application of vermiculture for human nutrition.

Results

Table 2: The results of a SWOT-analysis are shown for the implementation of vermiculture for human nutrition in three scenarios of different scale.

	Scenario A: Farming household	Scenario B: Rural community	Scenario C: Commercial enterprise
Strengths	• No / low cost for building vermibed • No cost for feed materials • Low workload • Additional protein source • Easy harvest through chickens	• medium labour productivity of skilled workers • medium area productivity resulting from better rearing conditions and/or stacking of vermiboxes • regular availability of homogeneous feed • improved humidity regulation	• High productivity of labour, area and feed inputs • Automatization → reduced labour costs • Immediate processing → wide range of food- and medicinal products
Weaknesses	• Comparatively high land-use • Heterogenous feed quality • Seasonality of feed availability • Low level of know-how • Low humidity control • Hand-harvesting earthworms is work-intensive • Human consumption difficult with mineral particles in earthworm gut	• Medium investment costs • Labour cost of skilled workers • Organizational complexity / difficulties within the community	• High investment costs • High energy costs • Transportation costs • Automatization → high maintenance costs • Potentially reduced circularity if vermicompost is not returned to the source of crop residues
Opportunities	• Reduced need for fertilizer inputs • Improved soil health and crop productivity • Improved productivity in chickens • Commercialization of excess worms and vermicompost	• Reduced need for fertilizer inputs • Improved soil health and crop productivity • (Improved productivity in chickens) • Commercialization of earthworms and vermicompost • Reduced CO_2 emissions compared to burning of crop residues and traditional composting	• Access to new markets • Reduced need for fertilizer inputs • Improved soil health and crop productivity
Threats	• Damage by invading wild animals or insects • Drying out / flooding / overheating of vermibed • Possibility of nutrient leaching (= nutrient loss)	• (Damage by invading wild animals or insects) • Earthworm diseases • Lack of water	• Earthworm diseases / pests • Infestation with competing invertebrates • Economic competition for feed substrates • Energy shortage • Failure of equipment

Discussion

Is vermiculture technically feasible?

Technical feasibility becomes increasingly difficult and requires more financial resources from small to large scale vermiculture operations. While a simple vermibed (scenario A) requires almost no financial and material resources to implement and maintain, walled and cemented vermibeds (scenario B) require at least some degree of material inputs and financing to establish. Scenario B also requires some simple machinery for harvesting which could present challenges of maintenance. On a commercial scale (scenario C), vermiculture requires a larger amount of investment and, depending on the degree of automatization, may be difficult to maintain.

How does vermiculture contribute to food security?

In farming households (scenario A) direct consumption of earthworms by humans is difficult, but indirect utilization as chicken feed is a viable alternative. Vermibeds, which are open to the ground result in the presence of mineral particles from the soil in the earthworm gut. These particles create an unpleasant sensation to the teeth. Earthworms need to be kept for at least 24 hours in moist conditions without soil to empty their gut which complicates direct consumption of earthworms by humans. The indirect valorisation of earthworms as chicken feed is a practical alternative which eliminates the laborious hand-harvest of earthworms. Chickens are efficient at picking out earthworms when given controlled access to the vermibed. Alternatively, vermicompost containing earthworms can be applied to the field with access for chickens. This approach creates a synergy whereby the chickens harvest earthworms and spread the compost on the field.

In rural communities (scenario B) larger quantities of earthworms are produced and can be utilized either for direct human consumption or via chickens. The cemented floors of vermibeds allows to feed chickens with organic materials only, avoiding the necessity to empty the earthworm's gut before consumption by humans. Earthworms can be harvested using simple hand or trammel sieves and distributed to households for processing as food. However, the time between harvest and processing needs to be as short as possible to avoid decay of earthworms and potential health risks. Alternatively earthworms can be sun-dried and preserved for later use as food or feed. Another alternative is the abovementioned application of vermicompost and earthworms to fields with access for chickens.

A commercial enterprise (scenario C) holds the greatest potential for utilization of earthworms for human nutrition. A well-controlled production process, mechanized harvest and direct processing ensures high quality and safety of earthworm biomass for human nutrition. Freeze-drying and removal of lipids can be applied to produce protein-powder with high storability, which can be used to improve protein content in a number of products, especially with regards to essential amino acids. The production of feed is still possible, but unlikely to be economically viable.

How does vermiculture contribute to sustainability?

In farming households (scenario A) resource use efficiency of vermiculture is likely to be comparably low. Organic wastes are not optimized for earthworm rearing but fed when available, resulting in seasonal variations in feed quality and earthworm production. Nutrients may be lost to leaching, possibly limiting the value of vermicompost as a fertilizer to improve soil fertility. However, application of this vermicompost is still preferable to commonly practiced burning of crop residues. Greenhouse gas emissions may be high due to limited control of humidity during the vermiculture process.

Rural communities (scenario B) are likely to show a higher degree of resource use efficiency due to a more controlled vermiculture process managed by trained staff. Feed materials can be stored and mixed for optimal rearing conditions resulting in high productivity of earthworm biomass. Optimal feed and prevention of leaching improve the value of vermicompost as a fertilizer. Vermicompost can be stored and redistributed to fields to strengthen nutrient cycling and maintain soil fertility in the community. Collection of leachate, or vermitea, provide an additional option for improving crop production in the community. Greenhouse gas emissions can be maintained at a low level when the vermiculture process is managed well.

A commercial enterprise (scenario C) will likely show the highest degree of resource use efficiency to optimize economic returns from organic wastes. Accordingly, feed materials will be selected and mixed, and the vermiculture process controlled for optimal earthworm biomass gains. Fertilizer value of vermicompost will be high and contribute well to soil fertility. However, a market driven distribution may lead to redistribution of nutrients to financially strong farms and therefore disrupt nutrient cycling. Leachate, or vermitea, is collected and can further improve crop production in farms with the financial capacity to purchase these products. Greenhouse gas emissions will be kept at a minimum and can even be captured and utilized, e.g. for CO_2 fertilization of greenhouses. However, the transport of organic waste to the production site and vermicompost back to farms is likely to produce more emissions than in the other scenarios.

How does vermiculture create economic value?

Farming households (scenario A) are likely to generate little economic returns from vermiculture, except for substitution of expensive chicken feeds. For these households the main benefit of practicing vermiculture may lie in the production of organic fertilizer as a low-cost substitute for chemical fertilizers. This could improve economic resilience and soil fertility.

Rural communities (scenario B) may benefit economically by efficient utilization of organic wastes for local production of protein-rich earthworm biomass and organic fertilizer. Selling of various products such as fresh or dried earthworm biomass, vermicompost and vermitea will generate a diversified income. Returns should be sufficient to make a profit after buying organic wastes at a low price and paying staff. A number of qualified jobs would be created.

A commercial enterprise (scenario C) would be able to generate the highest revenue from vermiculture due to high resource use efficiency and a diversity of products. A range of food, pharmaceutical and fertilizer products would help such a business to diversify its income options and contribute to economic resilience. Highly qualified jobs would be created. However, it is likely that returns would be privatized and not benefit the poorer population as much as in scenarios A and B. Processed food products would also be more expensive and may not be accessible for all.

Conclusion

While vermiculture is easily implemented at the level of a farming household, the potentials for food security, sustainability and economic value creation are not fully utilized. On the level of a rural community, vermiculture can be practiced at an efficient scale and contribute significantly to food security, sustainability and economic value creation. However, the needs for investment, communal organization and trained staff may hinder implementation. A commercial enterprise is likely to practice vermiculture most efficiently and generate the highest economic returns. However, needs in terms of investment, maintenance of facilities and highly qualified staff are potential barriers to implementation. While resources are efficiently used, circularity and benefits for low income populations are limited in this scenario. Overall, a medium scale vermiculture operation appears to produce the most convincing results.

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