Mushroom cultivation and its challenges at different scales

DANIEL GRIMM[1,2], GEROLD RAHMANN[1], AND ENNO SONNTAG[1,3]

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Abstract

This text analyses the societal, ecological and economic advantages and disadvantages of mushroom cultivation at different scales, from a farming household, to a rural community, to an industrialized, commercial enterprise. For this we use SWOT analysis in three model-scenarios. The results of this analysis show increased productivity and product-diversity going from the small to the large scale, but mixed results in terms of ecological sustainability and societal benefit. The most sustainable and socially beneficial approach seems to be a rural community farm, although it is not as productive as a commercial enterprise.

Introduction

With the world population predicted to increase to 11 billion people by the year 2100, according to medium estimates of the United Nations (2017a), and most of this growth taking place in the global south, land scarcity will become a major problem in many regions of the world (Rahmann et al. 2020). According to the medium estimates, and assuming that available cropland remains the same, only 629 m2 of land for crop production will be available per person in Africa and in more extreme scenarios only 458 m2 would be available (Rahmann et al. 2021). Landless food production, such as mushroom cultivation, could play an important role in overcoming the problem of land-scarcity and help transition towards a circular economy, in which food is produced on crop residues without additional land use (Grimm et al. 2021).

While mushroom cultivation has a history of many centuries, the last four decades have seen the most significant scale-up, with a more than 30-fold increase in mushroom production (Royse et al. 2017). A large part of this growth has been driven by China, which in the years from 1978 to 2002 went from producing 5,2% to 70% of all mushrooms cultivated globally (Shu-Ting Chang 2005). In his account as a first-hand witness of that remarkable growth-period, Prof. Shu-Ting Chang remarks how mushroom production in the 1980s was taking place in rural areas at a small scale, while 20 years later it had moved to urban areas and was being done at an industrial scale. This development, he notes, was mostly due to improvements in technology, which also enabled the cultivation of a more diverse set of mushroom species. The development of markets and the productivity increase through economies of scale are likely to also have played an important role.

This leads to the question, how mushroom economies can and should be established in developing countries that currently produce very few mushrooms. Is a grassroots-approach, with workshops for small farmers and subsequent "organic growth" of the sector the right way, as it was done in China in the 1980s (Shut-Thin Chang 2005), or should these steps be left out, to move directly to industrialized production, since the technologies for this scale have already been developed?

To answer this, and to better understand which are the societal, ecological and economic advantages and disadvantages of mushroom cultivation at different scales, we perform a SWOT-analysis of three different model-scenarios: a household, a rural community and a commercial enterprise. In the discussion we compare the results of this analysis.

[1] Thuenen-Institute of Organic Farming, Germany, www.thuenen.de/ol/en/, gerold.rahmann@thuenen.de
[2] University of Kassel, Faculty of Organic Agricultural Science, Germany
[3] Wageningen University, The Netherlands

Methods

We perform a SWOT-analysis of three different model-scenarios (table 1). The SWOT-analysis is a strategic planning tool used to evaluate the strengths, weaknesses, opportunities, and threats of a project (Paschalidou et al. 2018). The method begins with stating the project objective and then identifies internal and external variables that are favourable or unfavourable to achieving it.

To define the framework for the three scenarios, we use the boundaries defined by the LandLessFood project (Rahmann et al. 2020), focusing on the African continent and assuming an area of 500 m^2 of cropland per person.

For the first scenario we assume a household size of 7 people, which is in the medium to high range: an average household in Africa consists of 3.2 (South Africa) to 8.3 (Senegal) people (United Nations 2017b). In this scenario, a family of subsistence farmers produces mushrooms with the objective of producing food and some income by selling at local markets.

For the second scenario, we look at a rural community consisting of 500 such households (a village of 3.500 people), where crop residues from the village farm land are used for mushroom production in a special mushroom house, by specialized workers, with the objective of producing food and income for the community.

In the third scenario, we look at a commercial enterprise, which is not strictly limited to a certain area of farmland, but rather can buy substrate ingredients from farmers and food- or wood-processing industries as needed. The main objective of this enterprise is to make a profit by achieving high productivity.

A more detailed overview of the model-scenarios is given in table 1. Here we list differences in the cultivation set up, looking at

1. The mushroom species that can efficiently be cultivated at that scale,
2. The substrates that will be used,
3. The pasteurization or sterilization methods used,
4. The way mushroom spawn is obtained,
5. The way the production system is set up,
6. The labourers that do the work,
7. The markets where the mushrooms are to be sold and
8. Aspects of nutrient circulation

Table 1: The application of mushroom cultivation is described for three scenarios at different scales

Socio-Economic Information:	**Objective of Mushroom Cultivation:**	**Mushroom Cultivation Setup:**
Scenario A: Farming household		
7 persons, 0.35 ha farmland, subsistence farming. Mushroom production on self-produced straw. Low capital and low investment	Food and income for family and biomass for composting	**Mushroom species**: Oyster mushrooms **Substrates**: Grain and bean straw **Pasteurization/sterilization**: Hot water pasteurization **Mushroom-spawn**: bought from large supplier **Production system**: in small shack next to family house on shelfs, in plastic bags **Labour**: household members **Market**: local **Circularity**: spent mushroom substrate/compost for fertilizing household fields

Scenario B: Rural community		
500 households, 175 ha farmland, mainly subsistence farming. Mushroom and compost production: centralized with some market orientation, specialized workers, little capital & small equipment	Food and income for community and biomass for composting	**Mushroom species**: Oyster mushrooms and button mushrooms **Substrates**: straw, sawdust, chicken and horse/donkey manure **Pasteurization/sterilization**: Hot air pasteurization in oven **Mushroom-spawn**: G1 spawn bought from large supplier but increased by sterilizing grain in a small autoclave **Production system**: shelf and column systems in a specialized house with three cultivation rooms (one colonization room and one fruiting room for oyster, one room for button mushroom. Area outside for pre-composting button mushroom substrate. **Labour**: trained community members, outside experts for help and planning **Market**: local, national **Circularity**: spent mushroom substrate is composted for fertilizing village fields
Scenario C: Commercial enterprise		
Crop residues supplied by many farms other substrate ingredients from wood- and food processing industries. Mushroom production: highly centralized production for the market, expert workers, high capital & high-tech equipment	Profit. High productivity and efficient biomass usage.	**Mushroom species:** Large number of mushroom species **Substrates:** Cultivation on straw, sawdust, manure and side-products of food processing industry **Pasteurization/sterilization:** in large autoclaves **Mushroom-spawn:** self-produced spawn from self-kept and bred stem culture strains. Spawn also sold to other mushroom producers **Production system:** Shelf and column systems, many rooms **Labour:** trained, specialized workers and engineers **Market:** local, national, international **Circularity:** spent mushroom substrate is composted and sold. Not necessarily returned to the same fields from which the substrates came.

Results

Table 2: **Strengths** Analysis of the three different model scenarios

Farming household	Rural community	Commercial enterprise
Mushroom species: Only one, robust species which requires low skill level Substrates: No costs, no transport Pasteurization/sterilization: Easy method. Very low investment cost Mushroom-spawn: high quality Production system: cheap and simple Labour: some work, such as pasteurization, can be overseen while doing field work Market: not reliant on market but opportunity for extra income Circularity: Most nutrients in spent mushroom substrate returned directly to the field	Mushroom species: more than one species, tailored to available substrates Substrates: No costs, short transport Pasteurization/sterilization: More sustainable, energy and water-saving. Medium to high investment cost Mushroom-spawn: reduced cost by using spawn, which is bought, for producing more spawn on sterilized grains or sawdust Production system: good hygiene and climate conditions Labour: Well-trained and specialized on mushroom production Market: Profit from selling at markets can be invested in mushroom facilities or other community projects. Surplus production is distributed for free among community members. Circularity: Most nutrients in spent mushroom substrate returned directly to the fields	Mushroom species: wide range of species, some of which are more profitable Substrates: Wide range of substrate ingredients. These can be analysed in laboratory and mixed for maximum productivity Pasteurization/sterilization: highly reliable substrate sterilization Mushroom-spawn: self-reliant by using pure cultures, hight quality, low cost, opportunity to sell spawn and to breed and license new strains Production system: ideal hygiene and climate conditions Labour: specialized staff and experts with increased productivity through division of labour and through automation Market: nearby and distant markets, large and niche products, food and medicine, mushrooms and compost Circularity: compost can be sold to farmers or exchanged for substrates.

Table 2: **Weaknesses** Analysis of the three different model scenarios

Farming household	**Rural community**	**Commercial enterprise**
Mushroom species: oyster mushroom is a relatively low-profit species and there could be a lot of competition on the market Substrates: variable quality. Not analysed in laboratory and mixed accordingly. Dependent on seasons, no storage space Pasteurization/sterilization: uses a lot of fuel and energy. Substrate needs to drain after pasteurization, leaving time for pests to enter Mushroom-spawn: dependence on spawn makers and the prices they set Production system: low hygiene and no climate control Market: restricted access. Short shelf-life of mushrooms, no access to cooling Circularity: Plastic use for growing containers and high fuel use for pasteurization	Mushroom species: some species too difficult to cultivate Substrates: variable quality Pasteurization/sterilization: medium investment costs Mushroom-spawn: partly dependent on spawn makers Production system: medium investment cost. Limited number of cultivation rooms Market: restricted access Circularity: plastic use for growing containers and medium fuel use for pasteurization	Mushroom species: more expertise, more investment, more labour necessary Substrates: substrates are not for free and need longer transportation Pasteurization/sterilization: high investment, high energy need Mushroom-spawn: high cost of building and maintaining sterile work environment and specialised staff Production system: high investment costs Market: marketing and advertising costs Circularity: spent mushroom substrate is not returned to same fields from which it came. Transport of substrates leads to higher emissions. Plastic use for growing containers and medium fuel use for pasteurization

Table 4: **Opportunities** Analysis of the three different model scenarios

Farming household	Rural community	Commercial enterprise
Mushroom species: increasing demand Substrates: using substrates from neighbours Pasteurization/sterilization: buying a solar oven Mushroom-spawn: using spent mushroom substrate as spawn Production system: investing in better cultivation rooms, pasteurization and substrate chopping machinery Market: direct marketing to customers Circularity: investing in reusable cultivation containers, to reduce plastic pollution	Mushroom species: growing different species in different seasons, to optimize for weather Substrates: using substrates from neighbouring villages Pasteurization/sterilization: investing in solar panels to make pasteurization more climate-friendly Mushroom-spawn: become a spawn producer by investing in autoclaves and sterile work rooms Production system: investing in better climate control and Market: expand past local market Circularity: investing in reusable cultivation containers, to reduce plastic pollution	Mushroom species: Substrates: Pasteurization/sterilization: investing in solar-panels, to make sterilization climate-friendly Mushroom-spawn: become a spawn supplier to smaller mushroom cultivators Production system: investing in solar-panels, to make sterilization and other processes climate-friendly Market: export to other countries Circularity: investing in reusable cultivation containers, to reduce plastic pollution. Investing in greenhouses, to use air from mushroom facilities for CO2 fertilization and reduce emissions

Table 5: **Threats** Analysis of the three different model scenarios

Farming household	Rural community	Commercial enterprise
Mushroom species: none Substrates: bad harvests and pests Pasteurization/sterilization: fuel shortage (fossil fuels/timber) Mushroom-spawn: difficulty of obtaining quality spawn, rising spawn prices Production system: Hot and dry weather could stop production Market: competition driving down prices Circularity:	Mushroom species: none Substrates: bad harvests and pests Pasteurization/sterilization: rising energy prices Mushroom-spawn: difficulty of obtaining quality spawn, rising spawn prices Production system: Market: competition driving down prices Circularity:	Mushroom species: cheap imports Substrates: rising prices Pasteurization/sterilization: rising energy prices Mushroom-spawn: high demand for specialized staff Production system: worker shortage Market: competition driving down prices Circularity:

Discussion

As the SWOT-analysis showed, all three scenarios have their own strengths and weaknesses, opportunities and threats. Some of these have to do with the scale at which the mushroom cultivation takes place, some have to do with competition and other outside factors, so that in practice, mushroom cultivators at different scales are likely to affect each other business success. For the discussion we will have a short look at each scenario separately and then make a comparison.

Farming household:

Low investment and running costs the biggest advantages of this scenario. The household members can use straw and wood from their own land for mushroom cultivation and use the spent mushroom substrate for composting, which will in turn help maintain their soil fertility. Various activities of the farm can be interlinked with mushroom cultivation. For example, if the family has chickens or pigs, these could forage the compost for worms and even leftover mushrooms as feed. These sustainability factors are however somewhat undermined by the relatively ineffective hot-water pasteurization, which needs a lot of fuel and water.

Also, due to the lack of expensive machinery and specialized labour (the household has to perform all farming tasks, rather than only mushroom cultivation), the work hours that have to be put in per kilo of harvested mushroom are quite high. Chopping straw with a cheap leave cutter takes a lot of time, as does pasteurization and spawning. This, together with the fact that less hygienic and climate-optimized growing conditions reduce mushroom yields, means that the profit from selling mushrooms might be relatively low. Considering the cost-factor of spawn, which a family household cannot produce itself, reduce the possible profit-margin further. Using part of the spent mushroom substrate as spawn can reduce costs but cannot completely reduce spawn costs, as insect larvae, moulds and bacteria would accumulate in the substrate over time.

If the household is able to invest in better machinery and cultivation room, as well as reusable growing containers, the profitability and competitiveness might be enough to have success at local markets even if there are competing farmers. Otherwise, the main benefits at this scale are the mushrooms produced as food for the household members and the improved circularity of their farm, which reduces costs (such as for fertilizer and feed) at other points and keeps the farm fertile.

Rural community:

A mushroom farm run by a rural community can produce more mushrooms in terms of amount and number of species. In order to make an impact and be able to process large amounts of the ligno-cellulosic biomass that grows on the village land, some machinery for chopping and pasteurizing straw have to be bought and cultivation rooms have to be built. This means that several thousand Dollars have to be invested. A large-scale oven for pasteurization is cheap, compared to an autoclave, but expensive compared to a simple barrel for hot-water pasteurization. It also uses less fuel and water than either an autoclave or the hot-water method, which improves the circularity. Since in this scenario there would be specialized staff and better machinery, the efficiency of labour would be relatively high and the losses due pests relatively low. The cost of spawn could be partly reduced by sterilizing grain in a pressure cooker or small-scale autoclave and multiplying the stem cultures or spawn bought from a supplier. This would lead to some independence, though it also requires extra work and investment. There are many opportunities for circular agriculture that would benefit the whole community in this scenario. Dung from animals could be collected and co-composted with spent mushroom substrate. Some dung, such as horse or sheep manure, could also be used for growing button mushrooms. If wood is available, even species such as shiitake could be cultivated. However, all this depends on good cooperation within the village.

Commercial enterprise:

In this mushroom farm, the efficiency of the production process and of labour can truly be optimized. The amount of mushrooms produced, as well as the number of species, is greater than in other scenarios. This is however only possible due to large investments in machinery, cultivation rooms and qualified staff. To sell the mushrooms that are produced, marketing costs might also limit the profit margin. By investing in large-scale autoclaves and hygienic facilities, the pest load of substrate will be minimal, while the energy and water cost would be medium. By producing spawn and selling it to smaller cultivators, additional profit can be made and costs can be reduced. The transport of substrates over long distances reduces the sustainability, as does the fact, that spent mushroom substrates is not necessarily returned to the same fields where the substrates came from. The accumulation of large amount of substrate in a small area can lead to environmental problems such as eutrophication, if the waste disposal is not handled correctly. The amount of food produced per kilo of substrate is greatest here, especially if the substrate ingredients are mixed optimally after analysing their chemical composition. By investing in solar panels and greenhouses or photobioreactors into which the CO2-rich air from mushroom production is pumped, the circularity of the approach could be improved.

Conclusion

The trend towards larger mushroom production facilities that has been taking place for example in China, can be explained by the higher effectiveness and productivity due to scale-effects and better machinery and production facilities. However, only where there is a large enough market, large enterprises can cover the costs and make good on the high initial investment. Also, large-scale facilities need more transport of substrates as well as the products that are sold and can cause more environmental problems. The household scenario is relatively unproductive but, except for fuel and (depending on the local conditions) water-use in pasteurization is also sustainable. The more productive, as well as more sustainable rural community approach might however be the better one. In a country, where mushroom cultivation is not yet common, it might be best, to foster this communal approach to mushroom cultivation as a part of local recycling schemes. In this way the benefits of mushroom cultivation can be shared in the whole community. A crucial part of growing a mushroom economy in this way would be easily and cheaply available spawn and workshops to have trained labout. Other than this, few obstacles seem to be in the way. In the long term however, commercial enterprises could outcompete smaller farms. At this point it will be crucial to either make sure these enterprises make the necessary investments, to be sustainable despite the weaknesses of the large-scale approach, or to protect small- to medium scale mushroom cultivators from competition through government action.

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Germany
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