Scandinavian Journal of Forest Research

ISSN: 0282-7581 (Print) 1651-1891 (Online) Journal homepage: https://www.tandfonline.com/loi/sfor20

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Martin Pavlík & Daniel Halaj

SCANDINAVIAN JOURNAL OF FOREST RESEARCH
https://doi.org/10.1080/02827581.2019.1584639

Production and investment evaluation of oyster mushroom cultivation on the waste dendromass: a case study on aspen wood in Slovakia

Martin Pavlík and Daniel Halaj

Department of Forest Economics and Management, Faculty of Forestry, Technical University in Zvolen, Slovak Republic

ABSTRACT

This paper addresses the processes and investment evaluation of utilizing available dendromass in an easy and close-to-nature way under Central European conditions in Slovakia. Wood of the European aspen (*Populus tremula* L.) that has generally been considered of little economic value was efficiently used as a growth medium for the oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm.). The production of the fruiting bodies of this mushroom were evaluated for 5 years under natural forest conditions. The evaluation focused solely on aspen wood, specifically, the most valuable part – the trunk. The investment assessment revealed the high economic value of the fruiting bodies of the oyster mushroom inoculated into aspen wood blocks for the period of five years. In particular, the results of the net present value (NPV = 347.78 €/m^3) as well as the profitability index (PI = 1.63) and discounted payback period (DPP ≈ 2 years and 8 months) point to the high profitability of such a project under the given conditions. The results could be helpful and inspiring for forest and garden owners when deciding how to utilize low-value waste dendromass, low-quality aspen wood and other tree species in small-scale forest management.

ARTICLE HISTORY
Received 21 August 2018
Accepted 14 February 2019

KEYWORDS
Aspen; oyster mushroom; biological efficiency; investment; efficiency

Introduction

Long-term meteorological measurements along with the scenarios of climate change confirm the rise in atmospheric temperature and summer temperature differences over the years. This topic is especially significant in Central and Eastern Europe, where climate changes are expected to have a larger effect compared to other areas (Hlásny et al. 2012). From the plethora of actions proposed to mitigate the negative results of climate change, using more resilient tree species seems very viable. A sensible and close-to-nature approach could support their ability to capture as much moisture as possible while leaving an appropriate amount of deadwood. One of the most resilient tree species is the aspen. As climate change advances, the numbers of aspen in the Atlantic climate zone should decrease, as this species will move towards Northern Europe (Puhe and Uhlrich 2001). Therefore, the forest owners of Central, Eastern and Northern Europe are interested in aspen. The physiological attributes of the aspen allow it to resist upcoming climate changes quite well (Benčať 2009), which makes research concerning this tree species highly attractive.

Aspen, especially European aspen (*Populus tremula* L.) is widely spread across all European countries, from Iceland to Turkey and from the Pyrenees to Urals. It is the second most common tree species on the Earth after pine *Pinus sylvestris* (Caudullo and de Rigo 2016). In Slovakia, it occurs from lowlands to approx. 430 meters above sea level (Benčať 2009), mostly as a part of mixed forests, as it is not dependent on nutrient-rich soil; even though it grows the fastest in deep, nutrient-rich soils, it also occurs in areas with poor gravelly substrate and peat (Pagan and Randuška 1987). Additionally, it is not climate-dependent, as it grows in both oceanic and continental climates and in clean or highly polluted air (Benčať 2009).

Aspen is of crucial ecological significance despite its lower commercial value. It provides food for various species of herbivores and saprotrophic invertebrates, places for growing mushrooms and moss, and a good hideout for birds. It is an irreplaceable part of the diversity of boreal forests and is a pioneer tree in the moderate temperate zone of Europe (Kouki et al. 2004; Latva-Karjanmaa et al. 2007; MacKenzie 2010; Savill 2013). However, the qualitative properties of the wood make it rarely suitable for anything more than cellulose production, matches or simple wooden packaging materials (Caudullo and de Rigo 2016). The reasons for seeking new uses for the wood are its low value and high abundance.

Wood-destroying fungi are a very important part of nature, especially in forests where they are irreplaceable as decomposers. Their utilization is profitable for both nature and humans. Although cultivation of wood-destroying fungi does not have a long tradition in Europe, it does have a promising future. Out of the large variety of naturally occurring wood-destroying species, the oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm.) is the most well-known and used. Growing of the oyster mushroom is popular worldwide, taking second place in mushroom cultivation after button mushrooms (Wasser 2017). The research is focused on evaluating the use of various kinds of substrate and conditions that ensure the

CONTACT Martin Pavlík mrtnpavlik1@gmail.com Department of Integrated Forest and Landscape Protection, Technical University in Zvolen, T. G. Masaryka 20, Zvolen 96053, Slovak Republic
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highest yield (optimal growing conditions) in Asia (Mandeed et al. 2005; Vetayasuporn 2007; Naraian et al. 2008), South America (Sales-Campos 2008), Africa (Obodai et al. 2003; Familoni et al. 2018) and Europe (Gregori et al. 2007; Myronycheva et al. 2017). However, research on the biological efficiency (B.E.) of mushroom cultivation and an investment evaluation of such a venture are currently missing for Central European conditions. There are few mentions of using wood as a substrate for mushroom growth in European countries in the late half of the twentieth century.

In the 1970s and 1980s, research focused on using the oyster mushroom to decompose waste dendromass to suppress undesirable tree species in forest stands (Kodrík 1979, Gubka 1989). The Faculty of Forestry at the Technical University in Zvolen conducted research on decomposing waste and unused dendromass with the oyster mushroom (Kodrík and Vaník 1989). At the beginning of the twenty-first century, new trends in silviculture and forest protection, along with the principles of sustainable forest management including the complex utilization of dendromass, brought back the utilization of wood-destroying mushrooms for the purposes of forest management. Research has shown the viability of growing and utilizing wood-destroying fungi under the natural conditions of forest stands (Pavlík 2005, 2006; Pavlík et al. 2008; Hraško et al. 2014). Therefore, the aim of this research is to evaluate the production and investment potential of using aspen wood for growing oyster mushrooms.

Materials and methods

Materials

As a part of this research, we used aspen wood procured at the end of winter. The oyster mushroom naturally grows on stumps and larger logs that contain sufficient amounts of moisture, mainly with the bark still attached. The research included manual manipulation of the inoculated logs; they were cut to lengths of 44–53 cm, with widths of 20–35 cm. This size was chosen following previous research experiences (Pavlik 2005; Pavlik et al. 2008; Hraško et al. 2014).

The oyster mushroom inoculum was made by using mushroom cultures provided by the company MYKOFOREST Velčice (Slovak Republic). The production strain was registered as MFTCCA042/102017. Wheat grain was chosen as the growing medium for the mycelium. It provided plentiful nutrition for the inoculum and subsequent better growth of fungus in dendromass during the adaption period.

Substrate inoculation methods

For the most effective and intensive inoculation, it was important to use an appropriate amount of quality inoculum, good quality wood and the proper method of securing and storing the logs after inoculation.

The method of inoculation depends on the substrate and the environment. Based on the evaluation of previous research (Pavlik et al. 2008), the most effective method for log inoculation was by using a newly invented applicator made from galvanized metal. It had the shape of a hollow triangular prism with a top opening that is 20 × 10 cm large and an opening at the bottom that narrows down to 10 × 0.5 cm. This applicator was filled with inoculum and was then forced by a wooden wedge down through an opening into a previously cut (using a chainsaw) longitudinal notch in the log. The notch was 2–4 cm deep and 10–40 cm long, depending on the log size. The notches were cut all over the circumference of the log to ensure even growth and thorough decomposition of the wood and a better yield of mushrooms. Inoculation using the applicator along with a thorough preparation of the logs is a very effective way to ensure high biological efficiency (Pavlík et al. 2008; Hraško et al. 2014; Pavlík and Pavlík 2016). The inoculation was performed in May to ensure optimal temperatures for growth. The logs were packed into solid plastic bags, the bag was bound, and a bunch of paper wool was embedded in the shutter of the bags. This ensures gas exchange and protection against insects and loss of moisture. The bags were stored in a shady place until the middle of September. Thereafter, logs were unpacked and partially buried in the forest soil in a place protected against direct sunlight. They were buried 15 cm deep at least 30 cm apart from each other to allow growing space. After washing, the plastic bags were suitable for further use.

The applicator used for inoculation of the wood is registered as a utility model at the Industrial Property Office of the Slovak Republic (Vestnik 2015).

Evaluation method for the production results

Production of the fruiting bodies is definite proof of successful inoculation and overgrowth. The mushrooms were gathered, and their quantity was evaluated (Pavlík 2005).

Based on the results of previous research on growing mushrooms on various tree species under natural conditions (Kodrík 1979; Pavlík 2005; Pavlik et al. 2008), the monitoring of oyster mushroom growth was considered to take five years.

To evaluate the efficiency of mushrooms growing on various substrates, the biological efficiency must be calculated (Stamets 2000). The ability of mushrooms to convert substrate materials into fruiting bodies was measured using a simple formula known as the "Biological Efficiency Formula" (B.E.). This formula states that one pound of fresh mushrooms grown from one pound of dry substrate represents 100% biological efficiency (Stamets 2000). Our biological efficiency was calculated based on the actual weight and humidity of the logs at the beginning of the experiment and the actual weight of the fresh fruiting bodies growing from the logs for 5 years. The humidity of the fresh aspen wood was 50%.

The research was conducted in the forest stand, shaded by adult deciduous trees (oak, beech, hornbeam) in Borová hora Arboretum. This research area was situated 370 meters above sea level with an average temperature ranging between 8.7–9.8°C over the last five years with a minimum temperature of −22.2 °C and a maximum temperature of 37.9°C. Generally, the annual precipitation was measured between 490 and 650 mm. However, it reached an extraordinarily high level at 973 mm in the last year of the study. Temperature and humidity conditions were standard overall during the research period, compared with long-term observations (Lukáčik and Sarvašová 2017).

Investment evaluation methods

One of the key elements of the research was the investment evaluation of oyster mushroom growing efficiency. All the costs and yields for each log were meticulously monitored and recorded. The results were calculated for a cubic meter of dendromass. One cubic meter represents 44 aspen logs, where one log has a 44–53 cm length and 23–35 cm width.

The amount of saleable fresh fruiting bodies expresses the biological efficiency from the annual amount of dry matter. The revenues of the oyster mushroom production depended on its market price, the biological efficiency concerning the wood species used and the length of the fruiting period.

The calculation of the revenues in each year was as follows:

$$\begin{aligned}\text{Revenues}() &= \text{amount of dry matter (kg/log/year)} \\ &\quad *\text{biological efficiency } (\%/100) \\ &\quad *\text{local price}(/\text{kg})*\text{number of logs}(n)\end{aligned} \tag{1}$$

The calculation of profitability followed the conversion of expected costs and revenues to the present value with a discount rate in the amount of 2% (discount rate used in forestry projects, Tutka 2003). The profitability has been assessed by so-called dynamic indicators of the investment project evaluation, namely, by the net present value, profitability index 1 and 2 and the discounted payback period (Brealey and Myers 1992).

The calculation of discounted costs and revenues is given by the discount factor (DF):

$$d_i = \frac{1}{(1+p)^n} \tag{2}$$

where: r – opportunity costs (2%); t–year

Net present value (NPV) is given by the difference between the sum of discounted revenues and discounted costs.

$$\text{NPV} = \sum_{i=0}^{n} \text{Discounted Revenues} - \sum_{i=0}^{n} \text{Discounted Costs} \tag{3}$$

The rule for the Net Present Value (NPV) is as follows:

- *NPV > 0–the project may be accepted*
- *NPV < 0–the project may be rejected*
- *NPV = 0–the project adds no monetary value; the decision should be based on other criteria.*

- *Profitability index (PI) 1* and *2* are determined by the following:

$$\text{PI 1} = \frac{\sum_{i=0}^{n} \text{Discounted Revenues}}{\sum_{i=0}^{n} \text{Discounted Costs}} \tag{4}$$

$$PI\ 2 = \frac{\textit{Net Present Value}}{\sum_{i=0}^{n} \textit{Discounted Costs}} \tag{5}$$

The rule for the Profitability Index (PI) is as follows:

- PI > 1–the project may be accepted
- PI < 1–the project may be rejected
- PI = 1–the project adds no monetary value; the decision should be based on other criteria.

The discounted payback period (DPP) is given by (Drábek and Pittnerová 2001):

$$\text{DPP}: \sum_{t=1}^{\text{DPP}} \frac{\text{Discounted Revenues} - \text{Discounted Costs}}{(1+r)^t} = \text{Investment Capital}. \tag{6}$$

The rule for the discounted payback period (DPP) is as follows:

- DPP > t–the project may be accepted
- DPP < t–the project may be rejected,
- where t = expected period of economic viability, according to the project.

Results

Our research was conducted under real conditions of forest management. This study focused on the cultivation of oyster mushrooms on low-value wood of aspen trees. Additionally, our study was monitored by evaluating the mushroom yields along with the substrate changes. The evaluation was focused solely on the aspen wood, especially the most valuable part – the trunk.

Evaluation of oyster mushroom production on aspen logs

All logs were individually evaluated over the whole period of 5 years. The data were used to calculate the mean biological efficiency. The average biological efficiency per log was 21.69% (Table 1).

During the whole research period, the mushroom production reached 157080 g of fruiting bodies per cubic meter of aspen. The highest production was recorded during the

Table 1. Mean values of fruiting body yields (g), minimal (Min) and maximal (Max) values per one log (g, %) and biological efficiency (B.E.) on all aspen logs over 5 years.

	Year					Overall	
	1 (g)	2 (g)	3 (g)	4 (g)	5 (g)	Yield (g)	B.E. (%)
Mean	48	1 345	1 488	245	10	3 570	
Min – Max/1 log	0–920	410–2380	100–5800	0–2360	0–160	1640–10640	7,79–45,10
B.E. (%)	2.93	8.17	9.04	1.49	0.06		21.69

third year. During the fourth and fifth years, the production was markedly reduced, which confirmed the advanced stage of wood decomposition.

Investment evaluation of oyster mushroom production on aspen logs

The growing costs consist of the cost of material and labor. Table 2 shows the time required to manage one log, from cutting the wood logs through inoculation and stabilization in the terrain to harvest. The table shows that the overall time needed to manage one log was 1 h per year. Labor costs were 4 € per hour.

Table 3 shows the costs overview of growing the oyster mushrooms per 1 cubic meter during the first year. The overall costs were 245 euros per cubic meter.

The overall costs of production along with the processing of the fruiting bodies and securing the growing area are shown in Table 4. In the case of this research, the overall costs of oyster mushrooms growing on aspen logs reached 394.10 € per cubic meter in the first year.

The care of the logs (44 logs = 1m^3) presents only the maintenance costs in amount of 44 €/m^3/year (1 €/log/year) during the next years. These are the only expected costs taken into the consideration in the following 4 years (Table 5).

The investment evaluation of growing oyster mushroom on aspen wood proves its high profit. Under the growing conditions of our research area, the process became profitable in 2 years and 8 months (Table 6). Knowing that the DPP (direct product profitability) is shorter than the research time, this project is economically viable. Based on the net present value (NPV) being 347.78 €/m^3, growing oyster mushrooms is recommended to forest owners and managers because the invested resources have a high return rate (profitability index of 1.63 –Table 6). This means that the investment brings 63% profit over five years. In other words, for each € invested in this project, the investor receives 1.63 € back.

Table 2. Length of individual working operations.

Four cuts by chainsaw, pushing of the oyster mushroom inoculum, securing of the inoculated place by protective latex paint, carrying the log	15 min
Stabilization of the inoculated log: • Carrying (after inoculation), wrapping (after inoculation) and unwrapping (after 4 month), measuring and marking the log • Carrying and planting the inoculated log into the soil	30 min
Care of the log during the first year (as necessary) Shielding, flow, gathering of the fruiting bodies	15 min
Care of the one log in the 1st year (total)	60 min

Table 3. Production costs of oyster mushroom in the 1st year.

Purchase price of aspen saw log (€/m^3)	40.00
Cutting the wood on logs (€/m^3)	7.00
Grain spawn (1 kg of inoculated substance – grain spawn – costs 3 € it is enough for inoculation of 6 logs) for 44 logs	22.00
One working hour in the 1st year (4 €/log/year) for 44 logs (1 m^3)	176.00
Production costs in the first year (€/m^3/year)	245.00

Table 4. Total production costs of oyster mushroom in the first year.

Production costs of oyster mushroom on 1 m^3 of aspen logs (€)	245.00
Game protection (- fencing) (€)	46.50
Containers for fruiting bodies (€)	100.00
Purchase price of agricultural land in the research location (€)	2.60
Total production costs (€/m^3)	394.10

Discussion

A vast amount of data on oyster mushrooms growing on various substrates in different parts of the world under different conditions does not provide enough information needed to evaluate the success rate of growing oyster mushrooms under our conditions. Many authors describe the results of growing oyster mushrooms on wheat straw enriched by wheat bran or even grain. The substrate was always sterilized at 121°C and achieved B.E. values of 25% (Kalmis and Sargin 2004), 29.26% (Obodai et al. 2003), 31.7–39.77% (Sainos et al. 2006), and even 50% (Kalmis and Sargin 2004).

Cultivation on a mix of corn husks with various kinds of bran, cotton seeds and urea resulted in a B.E. of 93.5% (Naraian et al. 2008). The highest B.E. values of 103.56% were recorded when growing oyster mushroom on cut sugar cane (Vetayasuporn 2007) and 125.6% using sugar cane enriched by rice and wheat bran with the addition of calcium carbonate (Sales-Campos 2008). Even though the growing costs are unknown, the authors state that it was economically viable.

From the very limited number of research results, it is possible to compare our research with that in Nigeria because it focuses on growing oyster mushrooms on waste wood. The highest yield was recorded with *Pleurotus ostreatus* growing on *Terminalia ivorensis* and *Triplochiton scleroxylon* (B.E. values 48.83% and 48.40%, respectively). In this case, the research was focused not only on mushroom production but also on ecological decomposition of the waste sawdust (Familoni et al. 2018). The results from African and South American countries, which use waste products from agriculture or wood, are very promising even though the whole process is energy and time consuming (the substrate must be sterilized or at least pasteurized). However, these results do not include an investment evaluation.

The biological efficiency values calculated from growing oyster mushrooms on aspen logs can be practically compared only with results presented by Pavlík (2005). He has dealt with evaluating the production of fruiting bodies on the logs of five different tree species (beech, aspen, hornbeam, birch and alder). Our research provided much higher values of biological efficiency (21.69%) than the research conducted 20 years ago (14.84%), which can be explained by the use of a different innovative method of inoculation.

A study conducted in the beginning of the twenty-first century focused on growing oyster mushrooms on beech logs using an optimized method of inoculation using the applicator, resulting in an average B.E. of 29.05%. This proves that growing oyster mushrooms on beech logs can be ecologically effective and economically profitable (Hraško et al. 2014).

Table 5. Profitability assessment by net present value (€/m^3).

Year	Discounted Factor ($r = 2\%$)	Revenues	Disc. Reve-nues	Cumulative Disc. Rev.	Cost	Disc. Costs	Cumu-lative Disc. Costs	NPV
1	0.9803922	127.32	124.82	124.82	394.10	386.37	386.37	−261.55
2	0.9611688	355.02	341.24	466.06	44.00	42.29	428.66	298.95
3	0.9423223	392.83	370.17	836.23	44.00	41.46	470.13	328.71
4	0.9238454	64.75	59.82	896.05	44.00	40.65	510.78	19.17
5	0.9057308	2.61	2.36	898.41	44.00	39.85	550.63	−37.49
Total			898.41		570.10	550.63		347.78

Table 6. Dynamic indicators of the profitability assessment for the whole project.

NPV [€/m^3]	PI 1	PI 2	DPP [year/month]
347.78	1.63	0.63	2 years and 8 months

The social aspect of utilizing aspen wood to grow oyster mushrooms in a simple and, if possible, close-to-nature manner is extremely significant as it brings a new viewpoint for forest management, utilizing the forest and its products, such as the fruiting bodies of the mushrooms. A study focused on the social value of forests in Sweden (Haugen et al. 2016) showed that forest owners are much more interested in using new products and discovering new ways to utilize the forest, with wood production no longer being the sole purpose. Haugen et al. (2016) also mentioned that using forests for recreation, animal observation and foraging are among the priorities.

Non-industrial private forest (NIPF) owners focus more on maintaining the landscape scenery, means of recreation, and biodiversity and helping the overall ecosystem. Even mycophobic Swedes are interested in mushroom foraging in forests (Bjärstig and Sténs 2017). This makes the simple process of growing mushrooms under forest conditions attractive in European countries, with a positive effect on both the forest economy and biodiversity (Pykäläinen and Kurtilla 2009). According to research by Stryamets et al. (2012), non-wood forest products have potential for economic and sustainable rural development in Ukraine, Russia and Sweden.

Forest management provides a large amount of dendromass, which can be a suitable, inexpensive and, most importantly, natural substrate for growing oyster mushroom in Slovakia. There is a large amount of waste wood after large calamities caused by strong winds, which does not have any economic viability and may even be an obstacle for forest regrowth; however, it can provide good quality substrate for mushroom growth (Pavlík and Pavlík 2003).

Considering the need for innovation in utilizing the low-priced wood and waste dendromass of soft deciduous trees, which is currently used mostly for cellulose production or in heating plants, we conducted research focused on aspen, the most abundant low-value tree species. Experiments proved that even this kind of wood can be used for growing mushrooms profitably. Our results showed that, under the conditions of real forest stands or other unused areas without any terrain augmentations, it is possible to use wood of lesser quality to grow quality mushrooms while providing nutrients for the soil and profit for the forest manager.

Acknowledgements

We thank two anonymous reviewers for their valuable comments to the first version of the manuscript. The authors are grateful for the support of the project Profitability of Mushroom Cultivation using locally available agricultural waste, and Mrs. Peace Byandusya personaly. The study was supported by grant of the Slovak Grant Agency for Science VEGA 2/0049/18. The article was created in connection with the preparation of the KEGA (Cultural and Educational Grant Agency) project no. 013TU Z-4/2019, and the Slovak Research and Development Agency (project no. APVV-17-0644).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The study was methodically supported by grant of the Slovak Grant Agency for Science VEGA 2/0049/18. The article was created in connection with the preparation of the KEGA (Cultural and Educational Grant Agency) project no. 013TU Z-4/2019, and the Slovak Research and Development Agency (project no. APVV-17-0644).

ORCID

Martin Pavlik http://orcid.org/0000-0001-9839-9061

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