2019 BIOAg Project Report

Report Type:
Progress Report

Title:
Evaluating Commercial Specialty Mushroom Production Feasibility for Diversified Farms and Small Woodland Owners in Western WA

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Abstract:
Forest-grown specialty mushroom production may be an economical, low-impact, ecologically-appropriate enterprise for diversified farms and small woodland owners in western WA and the greater western Pacific Northwest (PNW). Nonetheless, to date, there has been little Extension research, publications, or formalized programs in the PNW on this subject as a commercial enterprise. In contrast, several northeastern and midwestern agroforestry Extension initiatives have developed commercial-scale, forest-grown specialty mushroom production systems and enterprise budgets. These systems use harvested hardwood as a substrate and mushrooms are cultivated under existing forest canopy. In contrast to the environments that these systems were developed in though, the western PNW environment has 1) markedly milder winter temperatures, 2) more limited choices of native hardwoods, and 3) patterns of markedly drier, lower-humidity summers. Nonetheless, our densely-forested, high-precipitation environment should be naturally-conducive to producing mushrooms. This project evaluates the adaptability of production systems developed by Extension in the eastern US for several species of specialty mushrooms to the western PNW. Using three research sites in two distinct regions of western WA, we aim to evaluate 1) multiple species of locally available hardwoods for their potential to sustain mushroom production 2) production systems that mitigate potential negative effects of sustained low-humidity in summers, and 3) estimate commercial forest-grown mushroom production potential for the western PNW context. Project results will be disseminated to farm and forest owners and educators on Extension websites and educational events in year two, to agroforestry researchers via a journal publication, and provide a foundation to substantiate needs for future research and development.

Project Description:
Over the past several decades, Extension researchers in the eastern US (including the eastern-midwest) have refined several systems for diversified farmers and forest owners to produce forest-grown specialty mushrooms on hardwood log substrates. To date though, there is a marked absence of institutional, research-based knowledge about the viability of commercial, forest-grown specialty mushroom production in the western Pacific Northwest (PNW), despite a potentially favorable production climate, proximity to premium markets, and interest from PNW farm and forest owners. Potentially foreseeable aspects affecting these systems' viability in the PNW are 1) differing and relatively limited species of locally-sourceable hardwood substrates, 2) common dry spells during PNW summers that could compromise critical thresholds of log moisture needed for sustaining mushroom vitality, and 3) potential effects resulting from mild winters (commonly wet, and with limited periods of freezing weather) and potentially competitive native fungal species.

In light of this, the aim of this project is to:

1) Establish baseline, research-informed estimations of the viability of adapting current forest-grown commercial mushroom production systems to western PNW environments;
2) Investigate economically feasible, regionally-appropriate management practices for commercial mushroom operation development in the region;
3) Increase awareness of forest-grown mushrooms as a commercial enterprise for forest owners and diversified farms, potential pitfalls, and current knowledge gaps;
4) Develop foundational, research-based information for stakeholders and researchers to use in future decisions about the potential for commercial forest-grown mushroom enterprise development in the western PNW.

To begin to address these objectives, the project includes research trials designed to produce foundational information regarding the viability of current eastern-US-developed commercial mushroom production systems in PNW environments. The trials aim to clarify 1) best practices for maximizing production regarding substrate choice, 2) substrate moisture management, and the 3) suitability of the most commonly cultivated forest-grown mushroom species for production in the western PNW. Three distinct trial sites in two western PNW regions were targeted with one location serving as the main trial site and the two others serving as satellite sites with truncated trials. The trials chiefly focus on "bolt" production systems for producing shiitake (*Lentinula*) mushrooms at all locations (see Figure 1). At the main site location, additional evaluations of 1) "Totem" systems for producing lion's mane (*Hericium*) and oyster (*Pleurotus*) mushrooms (see Fig 1, Appendix 5), 2) wood-chip bed production systems for producing wine cap (*Stropharia*) mushrooms are being conducted. Red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) are the primary mushroom log substrates being evaluated at all sites, with additional evaluations of wild sweet cherry (*Prunus avium*) and paper birch (*Betula papyrifera*) substrates are being conducted at the main trial location (see Appendix 2). Moisture management treatments focused on three methods of modifying humidity and evaporative potential to mitigate potential log moisture loss throughout the summer (see Appendix 6) with a combination of using breathable tarps with passive water diffusion (under tarps), active sprinkler irrigation (under tarps), or post-inoculation immersive log soaking (before tarping).

Figure 1. *Trial site illustrating bolt systems for shiitake mushroom production (horizontally stacked in foreground) and totem systems for lion's mane and oyster mushroom production (stacked vertically in background left). The figure shows a control treatment equipped with a weather data logger and two moisture-managed treatments under breathable tarps (background right) within a treatment block at the project's main trial site in Vancouver, WA.*

Because this is a nascent research area, a peer-reviewed journal publication is targeted as a core project output. Extension outreach products will primarily be web-based for purposes of conducting ongoing edits/updates as research progress is made. The project team will produce two major workshops featuring a guest speaker on commercial mushroom production from a different region, our trial results, and potential growth of future specialty mushroom markets. Trial sites will also dually serve as demonstration sites. Depending on project results and external circumstances, an Extension manual, presentations at conferences, invited talks to stakeholder groups, and press releases will also be targeted as a project output.

Outputs:

Overview of Work Completed and in Progress:

- In 2019, two replicated research trials were established in two differing western WA ecosystem regions- 1) the greater Willamette Valley (the main trial location, in Vancouver) and 2) the South Puget Sound (the satellite location, in using two sites in Lacey and McCleary). See Figures 2 and 3,

Appendix 1-6).

- Harvest of log substrates for trials began in mid-March 2019. Logs used in forest-grown mushroom production systems are ideally cut before trees break their winter dormancy. Winter dormancy in 2019 was just beginning to break in certain areas when the project was approved for funding, so timber cutting began immediately. Care was taken to avoid trees that were clearly breaking dormancy, so trees that were well-protected from southern exposure were targeted.
- Trials took much longer than anticipated to establish. Securing sufficient, quality timber was a challenge, as was capacity to move harvested timber to the inoculation and final field locations (see Appendix 1). Trees used for the Lacey and McLeary satellite trial sites were cut by mid-April, inoculated by mid-May, and placed in each trial site and under the influence of moisture management treatments by June. Trees used at the Vancouver Site were cut by the end of March. Shiitake bolts were inoculated by June, and placed in the final trial site and under the influence of treatments by July. Totem systems were inoculated and placed under the influence of treatments by the beginning of September.
- Several aspects of the final trial design were modified from the original proposed trial. Evaluations of bitter cherry and vine maple (Acer circinatum) substrates were abandoned due to lacking supply. Wild cherry and paper birch were alternatively chosen due to abundant local supply and because these feral non-native hardwood species are relatively abundant in urban and agricultural areas in the region (paper birch is also native in northwestern WA). The trial also added split-plots of differing shiitake strains at each site. A foreseeable issue with one of the original moisture management treatments inciting excessive feral fungal growth incited the project team to alter the treatment design (discussed below). The wine cap mushroom wood-chip bed trials at the main trial site were not established in 2019 due to capacity constraints, and will instead be established by spring 2020.
- Project information has been shared with stakeholders at three summer 2019 educational events, with two more project related events scheduled for winter 2020, to date.

Methods, Results, and Discussion:

The experimental design used at each trial site is a spatially-balanced complete block design with split-plots and four replications (see Table 1). At the main trial site, each replication contains a shiitake bolt production system and lion's mane/oyster totem production system, with 1) four moisture management treatments, 2) split-plots with four substrate species, and 3) split-split-plots with two different shiitake strains in the shiitake bolt system. The satellite sites each contain two of four total replications of an abbreviated trial containing only shiitake bolt systems, two moisture management treatments, split-plots of two species of substrates and split-split-plots with three different strains of shiitake (two wide range, one cold weather, and one warm weather strain). Moisture management treatments at all sites include 1)

Trial location	Replications	Mushroom species	Sample units	Main treatment plot	Sample units	Split-plot	Sample units	Split-split plot	Sample units
(Site)	*per site*	*(System)*	*per replication*	*Moisture management*	*per treatment*	*Substrate*	*per substrate*	*Strain*	*per strain*
Main (Vancouver)	4	Shiitake (Bolt)	64	Control (unmanaged moisture)	16	Red alder	4	Wide range shiitake strain	2
				Tarped + passive irrigation		Bigleaf maple			
				Tarped + active irrigation		Wild cherry		Cool weather shiitake strain	2
				24-hr immersive soak > tarped*		Paper birch			
		Lion's mane (Totem)**	16	Control (unmanaged moisture)	4	Red alder	1	NA	NA
				Tarped + passive irrigation		Bigleaf maple			
				Tarped + active irrigation		Wild cherry			
				24-hr immersive soak > tarped		Paper birch			
		Oyster (Totem)**	16	Control (unmanaged moisture)	4	Red alder	1	NA	NA
				Tarped + passive irrigation		Bigleaf maple			
				Tarped + active irrigation		Wild cherry			
				24-hr immersive soak > tarped		Paper birch			
Satellite (Lacey & McCleary)	4 (2 per site)	Shiitake (Bolt)	48	Control (unmanaged moisture)	24	Red alder	12	Wide range shiitake strain 1	3
								Wide range shiitake strain 2	
				Tarped + passive irrigation*		Bigleaf maple		Warm weather shiitake strain	
								Cool weather shiitake strain	

**Originally tarped + passive irrigation treatment using polyethlene tarp. Poylethlene trap replaced with breathable, spun polyester tarp in July 2019.*
***Production systems for lion's mane and oyster mushrooms are identical, but are not intended to be compared to one another in statistical analyses.*

***Table 1**. Trial treatment layout at each research site.*

un-managed controls (i.e. no moisture management) vs. 2) tarped + "passive irrigation" treatments using static water containers under tarps to modify relative humidity. Two additional moisture management treatments are being trialed at the main trial site, including 1) a tarped + "active irrigation" treatment using mist emitters on irrigation timers, and 2) a treatment where substrates were soaked for 24 hrs. post-inoculation, and then placed under tarps. A weather station was installed on each control treatment to log temperature, relative humidity, windspeed, and light intensity in the control (representing ambient conditions within a given trial block). Temperature and humidity loggers were installed under each tarp in the moisture-managed treatments (see Figure 3).

Figure 2. *Two different treatment blocks established at the main trial site in Vancouver, WA. Photos: Justin O'Dea, WSU.*

Response variables to be collected are temperature and relative humidity in controls and each moisture management treatment, log substrate moisture changes over time (see Appendix 3), total mushroom yield, marketable mushroom yield, and estimates of spawn run time (time from inoculation to first marketable harvest). Response variables will be used to estimate effects of substrate species and moisture management treatments on total and marketable yield, and to produce estimates of yield dynamics that can be used to inform enterprise budgets.

Figure 3*. A treatment block of the shiitake bolt system at a satellite trial site in McLeary, WA with data loggers. The bottom right photo shows the entire block with a polyethlene tarp before it was changed to a breathable spun polyester tarp in July (bottom left, also see below). Photos: Patrick Shults, WSU.*

Preliminary observations and results from the trial have already produced valuable information. The tarped + "passive irrigation" treatments originally used an impermeable polyethylene tarp (see Figures 3 and 4). The stagnant, perpetually moist environment under the polyethylene tarp in summer appeared to incite notable feral fungal growth on the logs by July at all trial locations (see Appendix 7). Because feral fungi are a known threat to these production systems (due to competition with the cultivated mushroom species), the project team chose to replace the polyethylene tarp with a permeable, breathable "tarp" of triple-layered spun polyester row cover (a.k.a. "reemay") for improved permeability and breathability.

While these spun polyester tarps may have some challenging aspects (they are challenging to manipulate over the logs in forest sites and tear easily), several aspects may be promising. While still being

Figure 4. *A treatment block in at a satellite site in Lacey, WA after switching to a spun polyester tarp in July 2019 from the original impermeable polyethlene tarp used in June. The Photo illustrates the benefit of the the white color of the polyester tarp in reflecting any direct sun that makes it through the forest canopy. Photos: Stephen Bramwell, WSU.*

breathable, preliminary data has indicated that they have been able to maintain a degree of elevated humidity in the air surrounding the logs without retaining excessive moisture. The tarps are assumed to also limit evaporative potential by inhibiting moderating wind speeds and reflecting direct sunlight due to their white color (see Figure 4). The degree of elevated humidity under the tarps appears to be affected by a given trial block's site's degree of natural ventilation (determined by the anemometer readings in each block). Two of the moisture management treatments are adjustable- the water surface area provided under the tarped + "passive irrigation" treatment, and frequency/duration of irrigation under the tarped + "active irrigation" treatment. Because we were able to monitor humidity levels in this trial, treatments in drier, more well-ventilated blocks were adjusted to attempt to raise the maintainable degree of humidity to levels closer to those observed in blocks with more limited ventilation. To date, average humidity levels do appear to be moderated by the moisture managed treatments, but the degree and the significance of the effect is still preliminary; effects on internal log moisture and marketable yields are yet to be determined. Tarps also have appeared to moderate the amount of free moisture under them because they inhibit rainfall. It is yet to be determined if this is detrimental or beneficial to the production system, but the aforementioned issues with the polyethylene tarps indicate this may be a beneficial aspect- lowered risk of inciting excessive feral fungal growth while still inhibiting moisture loss from the log via moderated, consistently elevated humidity levels.

Preliminary data on a small yield of lion's mane mushrooms collected from of the totem systems in October 2019 (premature, non-marketable levels) appear to support benefits of the moisture managed treatments and tarps also. The cherry wood substrates yielded significantly greater amounts of mushrooms, as did treatments where the logs were soaked (see Appendix 8). Observations of mushrooms collected from treatments under tarps appeared to have lower incidence of oxidation/weathering and desiccation than those collected from control treatments. This early yield of lion's mane is presumed to have fruited from the sawdust spawn rather from the log, as it typically takes this species much longer (≥ 1 yr.) to colonize substrates and begin fruiting with marketable levels of yield. It is unknown if the cherry wood substrate provided an additive effect to the spawn to increase mushroom yield, or conversely, whether this substrate incited the mycelium in the spawn to fruit more due to a limitation of resources.

Publications, Handouts, Other Text & Web Products:
No formalized educational materials have been made to date. Educational materials on these production systems would be premature at this point in time. They should first be informed by trial results to meet the information quality levels expected from Extension publications.

Outreach & Education Activities:
The project originally included a minimum deliverable of two educational events resulting from the project that intended to increase stakeholder knowledge on forest grown specialty mushroom systems in the PNW. We have already had three project-related educational events, with two more scheduled for 2020. Project Co-PI Shults presented a summary of the project at the National Agroforestry Conference held in Eugene, OR in June 2019, and showcased the satellite trials also at a field day held at the McLeary site in Summer 2019 (see Figure 5). Project PI O'Dea summarized and showcased the project at a field day at the Vancouver trial site in September 2019. O'Dea will also present project-related information in a session at WSU's 2020 Southwest WA Forestry School and at a mushroom workshop at the annual San Juan Islands Agriculture Summit in February, 2020.

Figure 5. *Project Co-PI Patrick Shults co-instructs a forest-cultivated mushroom session at a WSU Extension Forestry field day in McLeary, WA in summer 2019. Photo: WSU.*

Impacts:
Short-Term: At least 50 stakeholders have learned about the project and these mushroom production systems through the aforementioned educational events in 2019. Stakeholders included both local and national audiences. Post-event surveys from the field days in Vancouver and McLeary widely illustrated an increase in knowledge and interest in learning more about the project and these production systems. A number of attendees indicated an intent to incorporate the results into their farm businesses, depending on outcomes of the project trials. The project was also featured in a newsletter article published by PCC Community Markets: https://www.pccmarkets.com/sound-consumer/2019-10/mushroom-farming-and-cultivating-the-forest/. Readership statistics are unknown, but the newsletter is distributed to PCC members throughout the Puget Sound region and we were contacted directly by several stakeholders with inquiries after the article was published.
Intermediate-Term: The project is still too nascent to gauge intermediate-term impacts.
Long-Term: The project is still too nascent to gauge long-term impacts.

Additional funding applied for/secured:
No additional funding has been secured for the moment. A 2019 USDA-SCRI mushroom production project proposal that included WSU as Co-PD (primary institution: U of AZ) was expected to be re-applied for in 2020; the project team refrained from re-applying due to the prohibitively high match requirements required in the 2020 SCRI RFPs. Additional funding will be sought out in 2021.

Graduate students funded:
No graduate students are funded by this project.

Recommendations for future research:
1) Trialing additional native PNW hardwood substrates – especially Oregon oak and ash, and vine maple.

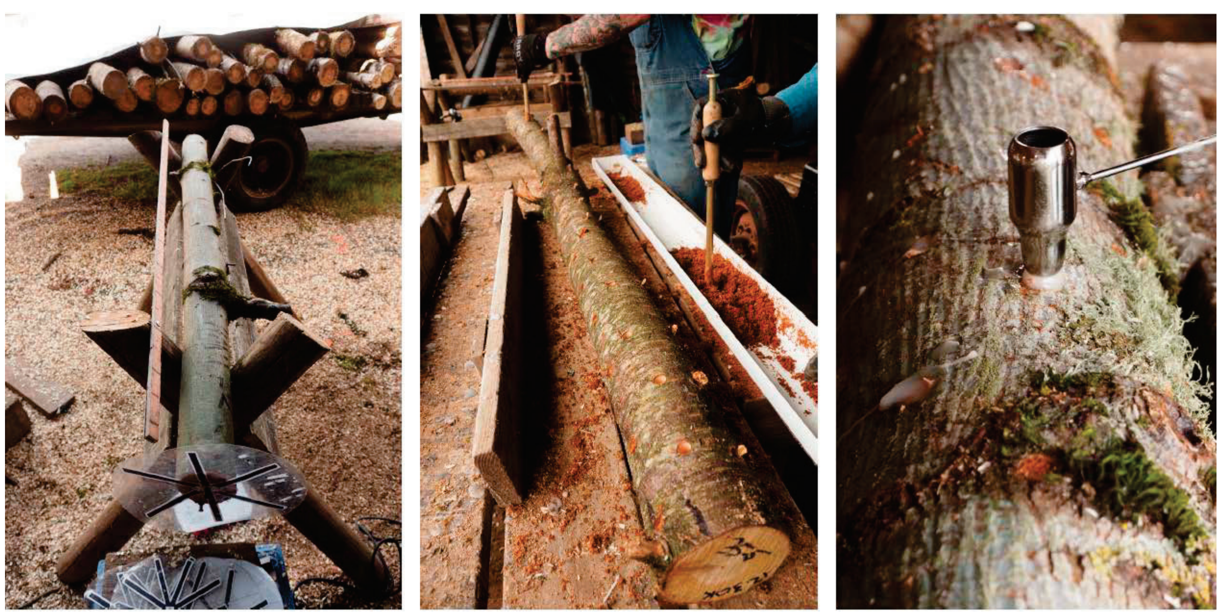
2) Trials examining mushroom strains best suited to the PNW climate, and whether well-suited strains can lengthen the mushroom growing season.
3) Effects of early-cut vs late-cut logs on production longevity.
4) Effects of soaking shiitake bolts immediately after inoculation on spawn run and moisture retention.
5) Identifying feral fungal species commonly found on a given substrate species, their degree of competition with the species of mushroom being cultivated, and control methods for any species shown to significantly compromise production.
6) Identifying insect and animal pests of these production systems, and control methods for any species shown to significantly compromise production.

Appendix:

1. *Bolt and totem cutting in spring 2019, and multiple iterations of moving log substrates from source locations to final trial locations throughout spring and summer 2019. Photos: Justin O'Dea and Stephen Bramwell, WSU.*

2. *All bolts and totems were indexed by source location, species, tree, size, and weight. Photos: Justin O'Dea, WSU.*

3. *Weighing log rounds used to determine initial log moisture content. Photos: Justin O'Dea and Stephen Bramwell, WSU.*



4. *Preparing shiitake bolts for inoculation, and inoculation with sawdust spawn, and sealing the inoculation holes with wax. Photos: Justin O'Dea, WSU.*

5. *Inoculating totems with lion's mane and oyster mushroom spawn. Photos: Justin O'Dea, WSU.*

6. *Figures illustrating moisture management treatments used in trials. From L to R: 1) "Active irrigation" treatment using mist emitters on timers; 2) post-inoculation immersive log soaking before tarping; and 3) "passive irrigation" with static water buckets placed under tarps (foreground, before tarp was placed). The active irrigation treatment used in the totem system can also be seen in the background of the picture on the right. Photos: Justin O'Dea, WSU.*

7. Potential issues with feral fungal growth, insect pests, and animal pests encountered throughout summer 2019. Photos: Justin O'Dea and Patrick Shults, WSU.

8. Premature fruiting of lion's mane mushrooms on totems. This fruiting is presumed to be from spawn, and was heaviest on the wild cherry substrates and the moisture-managed treatments where logs were soaked before tarping. Photos: Justin O'Dea, WSU