MycoRenew: Transforming landscaping waste into biodegradable mycelium plant pots

Abstract

The *MycoRenew* project investigated the development of biodegradable plant pots made from landscaping waste bound with fungal mycelium. Using local residues of wood, grass, and compost from JvEsch, researchers optimized substrate composition and moisture content to achieve structural integrity and biodegradability. The optimal mix composed of 75% wood, 12.5% compost, and 12.5% grass at 70% moisture showed the best balance of fungal growth, mechanical strength, and moisture behaviour. While mycelium pots remain weaker than plastic equivalents, they are still viable for use, offer full compostability and eliminate plastic waste in landscaping and reforestation. However, current small-scale production results in higher environmental and economic costs, primarily due to incubation and drying processes. The study validates the technical feasibility of waste-based mycelium composites and introduces an image-based method for quantifying mycelial colonization. Ongoing work includes field trials in a reforestation project of Rijkswaterstaat.

1. Introduction

Conventional plastic pots are widely used in horticulture, landscaping, and reforestation but contribute to significant plastic waste and microplastic pollution. Most are discarded after single use, adding to environmental burden and landfill accumulation. Furthermore, when planted in the ground, these must be removed after some time. or they will affect the soil, and for larger tree sapling species, anchorage is necessary. The *MycoRenew* project conducted by MNEXT in collaboration with JvEsch aimed to develop a circular and biodegradable alternative made from locally available organic waste bound with fungal mycelium.

MycoRenew sought to demonstrate that pruning and compost waste can be converted into strong, compostable plant pots suitable for planting directly into the soil by applying mycelium-bound composite (MBC) technology to landscaping residues. The main research question was "Can locally available landscaping waste be used to produce biodegradable MBC plant pots that are mechanically stable, compostable, and environmentally viable as an alternative to conventional plastic pots? The project combined applied material research with environmental and economic assessment to evaluate the feasibility of scaling up this concept toward practical use.

2. Materials and Methods

This section details the methodology carried out within MycoRenew. **Fig. 1** visualizes the flow of the research.

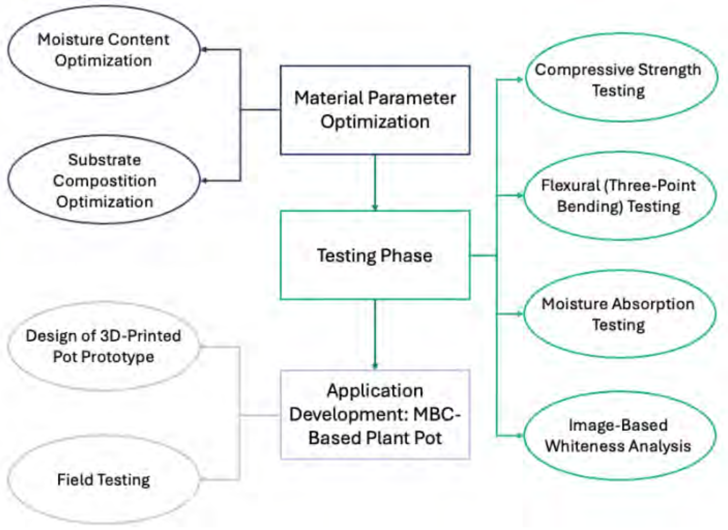

Figure 1 – MycoRenew methodology flowchart

2.1 MBC formulations

Three waste streams supplied by JvEsch, wood chips, grass clippings, and compost residues, were used as feedstock. *Ganoderma lucidum*, a white-rot fungus commonly used in MNEXT research, known for its extensive hyphal network and ligninolytic capacity, served as the binding organism. The fibres are shredded due to large and variable particle size.

A full-factorial experimental setup tested varying substrate compositions (25%, 50%, 75% wood) and moisture contents (50%, 70%, 90%). Mixtures were sterilized using an autoclave at 121 °C for 21 minutes, inoculated with a fixed 10% of the total weight *Ganoderma lucidum*-cellulose (inoculum media) spawn, and incubated for seven days at 30°C and 80% relative air humidity.

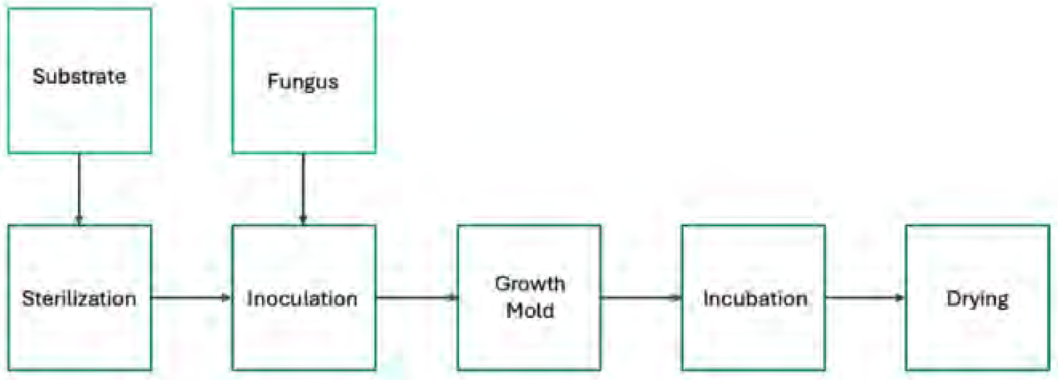

Figure 2 – MBC production methodology

2.2 Analytical methods

Several analytical methods were employed to identify the most suitable MBC formulation for pot production. Image-based growth analysis was combined with mechanical performance testing and moisture absorption measurements to determine the optimal substrate composition. These results were then used to guide pot fabrication and to support subsequent environmental and economic assessments.

2.2.1 Image-based whiteness analysis

To quantitatively assess mycelial colonization, a digital image-based analysis protocol was developed using *Fiji/ImageJ* software. Samples were photographed under controlled lighting (D65 illumination, 45° incidence angle) using an Epson Perfection V39 flatbed scanner at 600 dpi. Images were converted to 8-bit grayscale, cropped to standardized dimensions, and analyzed using threshold segmentation. The mean grayscale value (0 = black, 255 = white) was used as an indicator of mycelial coverage, referred to as the *whiteness index (WI)*. The method allowed non-destructive and repeatable quantification of surface colonization, reducing subjectivity compared to visual scoring.

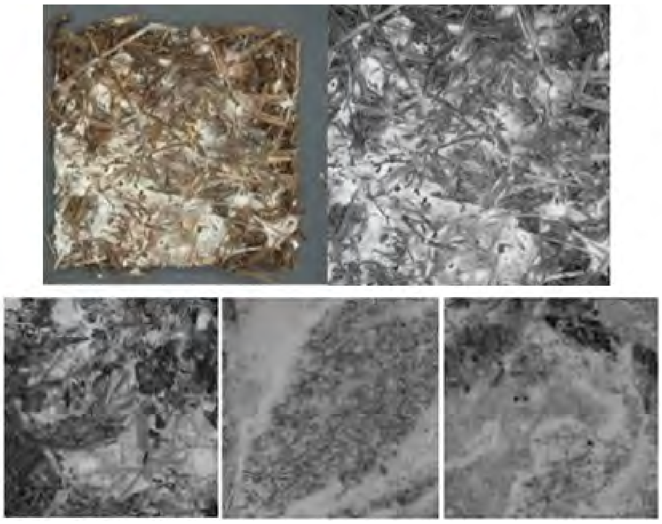

Figure 3 – Image-based WI analyses

2.2.2 Mechanical performance

Mechanical properties were determined using a Tinius Olsen 50ST universal testing machine.

Compressive strength was measured at 10% deformation, according to EN 29469:2022 on cubic samples (100 × 100 × 50 mm) at a loading rate of 1 mm/min [1]. The maximum stress before yield was recorded as the compressive strength ($\sigma_{(c)}$). The compressive strength at 10% deformation was calculated by:

$$\sigma_{10} = \frac{F_{10}}{A_0}$$

Where $F_{10}$is the compressive force at 10% strain (N), and $A_0$is the initial cross-sectional area of the specimen (mm²).

Flexural strength was evaluated using a three-point bending test following EN 12089:2013 [2]. Rectangular specimens (150 × 25 × 25 mm) were tested at a crosshead speed of 5 mm/min with a 100 mm span. The modulus of rupture ($\sigma_{(f)}$) was calculated using:

$$\sigma_f = \frac{3FL}{2bh^2}$$

where *F* is the load at failure, *L* is the span, *b* is the width, and *h* is the thickness.

Both tests were performed in triplicate, and mean values with standard deviations were reported.

2.2.3 Density and moisture absorption

The bulk density of each sample was calculated from dry weight and geometric dimensions according to EN 1602:2013 [3]. For hygroscopic behavior, water absorption was measured following ASTM D5229 [4]. Specimens were conditioned at 23 °C and 50% relative humidity for 24 h, immersed in demineralized water for 24 h, and reweighed.

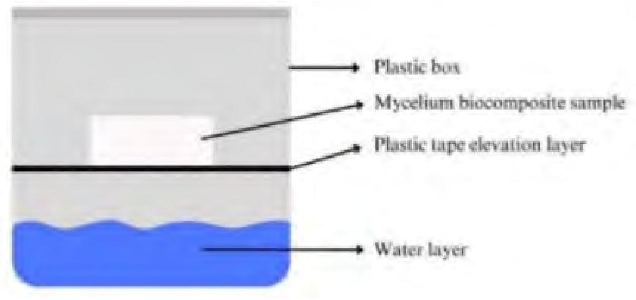

Figure 4 – Water absorption test set-up based on ASTM D5229 [4].

Moisture absorption (*MA*) was expressed as the percentage increase in mass relative to the initial dry mass:

$$MA = \frac{(m_t - m_0)}{m_0} \times 100\%$$

where m_0 is the initial dry mass and m_t is the mass after immersion.

2.2.4 Environmental and economic evaluation

A simplified environmental and economic analysis compared the mycelium pot production process to conventional polyethylene (PE) pot manufacturing in Microsoft Excel. Energy consumption during incubation and drying was measured using inline power meters, and CO_2 emissions were estimated using standard emission factors for electricity in the Netherlands [5]. Production costs included estimates of raw material handling, sterilization, incubation, drying, and labour. The impact of the pots on the soil was not included in either the environmental or the economic evaluation.

2.2.5 Field testing

Following laboratory development and mechanical validation, the produced mycelium pots were prepared for field evaluation in collaboration with Rijkswaterstaat as part of the Herplantplicht InnovA58 reforestation program. This national project involves large-scale tree replanting along the A58 highway corridor in North Brabant, aimed at compensating vegetation removed during infrastructure expansion. The pots are intended to hold European aspen tree saplings. 8 pots have been prepared for the purpose, including two other pots to be exhibited in the Avans Ambition 2035 stand at the Dutch Design Week.

3. Results

3.1 Mycelial growth assessment

Mycelial colonization was visibly influenced by substrate composition and moisture content. Samples with higher wood content (≥50%) and intermediate moisture levels (around 70%) exhibited the most uniform and dense surface coverage, characterized by a bright white mycelial mat and compact internal structure. In contrast, samples with low wood content or excessive moisture (90%) often showed incomplete colonization and, in some cases, localized contamination due to bacterial growth.

The image-based whiteness analysis confirmed these observations quantitatively. Although the results seem non-significant due to the low number of samples. The mean grayscale value, representing the *WI*, seemed to increase with wood fraction up to 75%. The formulation containing 75% wood, 12.5% compost, and 12.5% grass at 70% moisture reached the highest WI (≈195 on a 0–255 scale), indicating near-complete colonization. Lower wood ratios (25%) and high moisture (90%) seemed to reduce WI by more than 30%, confirming that excessive water content slowed hyphal propagation.

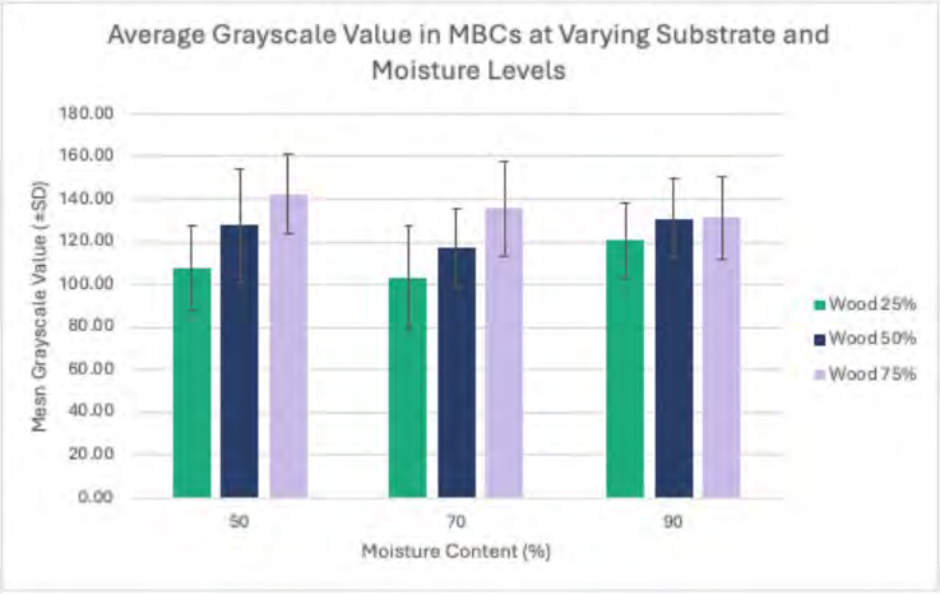

Figure 5 – Grayscale values for MBC formulations

These results demonstrate that wood provides a stable lignocellulosic structure promoting both mechanical interlocking and enzymatic binding, while compost and grass contribute nutrients necessary for mycelial growth. However, excessive nutrient-rich or moist conditions reduced overall uniformity and increased the probability of microbial contamination.

3.2. Mechanical performance

At 70% initial moisture, the 75% wood formulation achieved the best balance between fungal binding and fibre integrity, reaching an average compressive strength (σ_{10}) of 3.6 ± 0.3 kPa (at 10% deformation, and a flexural strength (σ_e) of 118 ± 9 kPa. These values represent a 25–30% improvement over formulations with lower wood content and were consistent across replicates.

In comparison, conventional polyethylene pots showed compressive strengths around 2100 kPa and flexural strengths near 17,000 kPa, highlighting the vast mechanical disparity between synthetic and biobased materials. Nonetheless, the MBC pots met the functional requirements for handling, potting, and short-term outdoor exposure before biodegradation.

The modulus of elasticity derived from the linear segment of the stress–strain curve was 80–110 kPa for the optimal formulation, reflecting a compliant yet stable structure suitable for seedling establishment.

3.3 Density and moisture absorption

The bulk density of the mycelium composites ranged from 72 to 128 kg/m³, depending on the formulation. Higher wood fractions yielded denser, more cohesive materials, while samples dominated by compost and grass were lighter and more porous.

Moisture absorption tests revealed significant hygroscopicity typical of biobased porous materials in all formulations. Most formulations did not show significant difference. The optimal formulation (75% wood, 12.5% compost, 12.5% grass) absorbed approximately 28.5% of its dry mass after 24-hour immersion. While this value is high compared to polyethylene (PE) reference pots (≈0.2%), it supports compostability and allows controlled degradation after planting. Samples with lower density and higher grass content showed up to 40% higher water absorption, suggesting greater open porosity and reduced dimensional stability.

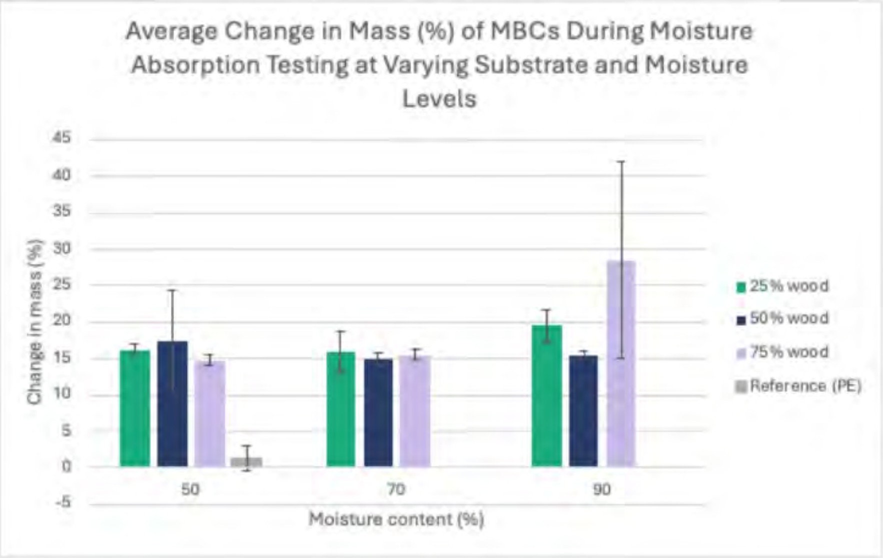

Figure 6 – Moisture absorption changes in weight values

3.4 Pot Fabrication and Physical Integrity

The optimized formulation was scaled up for pot production using a custom 3D-printed PLA mould designed to replicate the geometry of 30 cm height, with the upper diameter of 15cm and lower diameter of 10 cm. The resulting prototypes maintained dimensional accuracy with minimal warping after drying. Their texture was homogeneous, and surface colonization was complete, forming a continuous mycelial skin that provided rigidity without the need for additional binders.

Figure 7 – Prototype mould design (above) with the visualization of the MBC pots (below), produced in SolidWorks

During handling and simulated planting trials, the pots maintained integrity under manual compression and resisted crumbling under typical root ball insertion loads (~2–3 kPa). When immersed in water for 24 h, the pots showed surface softening but no structural disintegration, confirming that biodegradation would only commence under soil contact conditions.

Figure 8 – Example of MBC planting pot

3.5 Environmental and Economic Performance

A preliminary assessment comparing MBC and PE pots revealed that laboratory-scale mycelium pot production generated approximately four times more CO_2 emissions. This impact originated mainly from the energy-intensive incubation (temperature and humidity control) and drying stages, which together accounted for over 85% of total energy demand.

Economically, the production cost per mycelium pot was estimated to be ten times higher than that of an equivalent PE pot. Major contributors included energy consumption, sterilization of substrates, manual labour, and the absence of automated workflows. Raw material costs themselves were negligible, as all feedstocks were derived from local waste streams provided by JvEsch.

Both findings are consistent with other emerging biobased materials and highlight a problem of scale rather than fundamental inefficiency.

4. Discussion

The *MycoRenew* results confirm the feasibility of converting landscaping waste into biodegradable mycelium composites. The strong influence of substrate composition and moisture on fungal colonization and mechanical properties demonstrates the potential for optimization. High wood content enhanced material density and bonding, while compost and grass provided additional nutrients that seemed to accelerate mycelial growth.

The image-based whiteness analysis introduced in the project proved valuable for quantifying mycelial colonization and can serve as a reproducible, non-destructive monitoring tool in future bioprocess research and industrial production. Although several measurements showed no significant difference, this was due to a lack of samples. More samples should be produced to conclude the findings.

The environmental and economic limitations observed are not intrinsic to the material, but rather a problem of scale. Incubation and drying currently rely on small, energy-demanding laboratory setups. Transitioning to industrial-scale processes could enable:

- Energy recovery through heat exchange or compost heat utilization,
- Passive or solar-assisted drying,
- Continuous or modular inoculation systems to reduce labour and contamination risks.

When considering the entire product life cycle, biodegradable mycelium pots have key advantages: they avoid plastic pollution, integrate into the soil post-use, and valorize local organic waste streams that would otherwise be composted or discarded. These systemic benefits position the material as a credible sustainable alternative once efficiency gains are realized.

5. Conclusion

The *MycoRenew* project successfully demonstrated the technical feasibility of producing biodegradable plant pots from landscaping residues using mycelium as a natural binder. The optimal substrate formulation was identified, the pots were mechanically and biologically tested, and a successful proof-of-concept was achieved, two examples of which were showcased in the Dutch Design Week.

Figure 9 – Example of mycelium pots in the DDW showcase (right)

While current production results in four times higher CO_2 emissions and ten times higher costs than conventional plastics, these drawbacks stem from laboratory-scale inefficiencies. With process optimization and scaling, both impacts are expected to decrease substantially. Upcoming field trials with Rijkswaterstaat will test the pots under real planting conditions, while follow-up research.

The project represents a crucial step toward closing material cycles in landscaping and promoting circular, waste-based biocomposites.

6. Advice and follow-up research

The results of *MycoRenew* demonstrate that biodegradable mycelium pots can be a viable circular alternative to conventional plastics, but several steps are needed to enhance their environmental and economic feasibility. The most urgent recommendation is to scale up production. Laboratory-scale manufacturing currently limits efficiency and drives up both emissions and costs. Transitioning to pilot or semi-industrial scale would enable process automation, reduce manual handling, and make use of continuous production systems. Larger-scale incubation and drying facilities would also allow energy to be distributed more efficiently, reducing the per-unit footprint and improving consistency between batches.

A second priority is the optimization of energy use. A major part of the environmental impact stems from the incubation and drying stages, which currently depend on constant temperature and humidity control. Future development should focus on low-energy or passive incubation systems that utilize waste heat from nearby industrial processes, composting heat, or renewable energy sources. Similarly, replacing oven drying with prior deactivation stage and solar or ambient air drying could substantially lower total energy consumption without compromising material quality.

Another key improvement lies in the standardization of substrate quality. Variations in particle size, nutrient composition, and moisture content among waste feedstocks can lead to inconsistent material performance and increased contamination risk. Pre-processing steps after shredding such as such as sieving or controlled pre-composting can enhance substrate uniformity and lead to more predictable mechanical and biological results.

From a sustainability assessment perspective, future studies should include a full life cycle analysis (LCA). The current comparison to plastic pots only accounts for production-phase impacts, while overlooking long-term benefits such as biodegradability, carbon retention in the soil, and avoidance of plastic waste. A complete LCA would provide a more accurate reflection of the environmental advantages of mycelium pots once produced at scale.

MNEXT is searching for extending this collaboration to other waste producers, municipalities and construction companies to continue the research towards a construction-grade material. This is intended to support regional bio-based manufacturing and accelerate adoption of circular products.

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