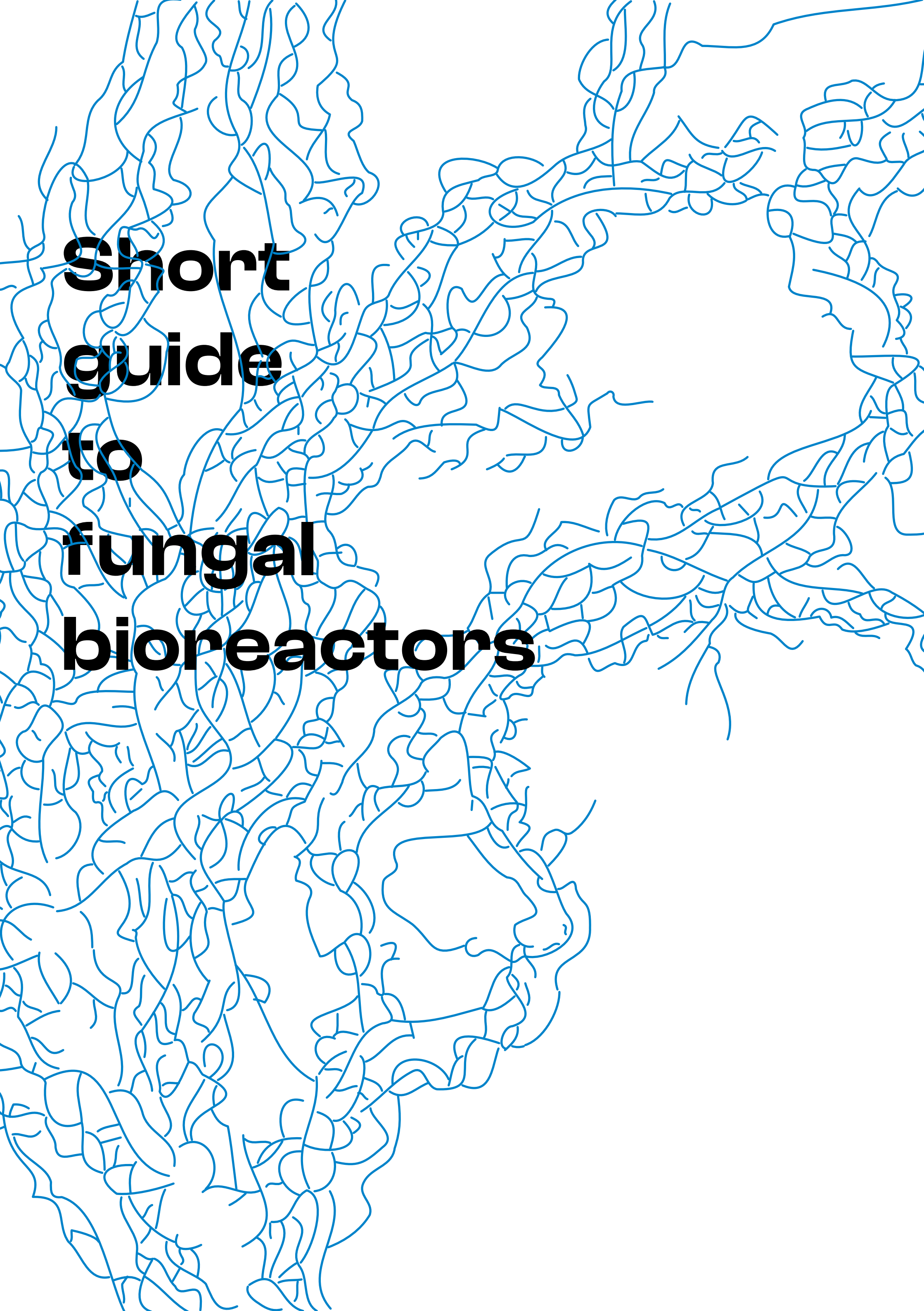
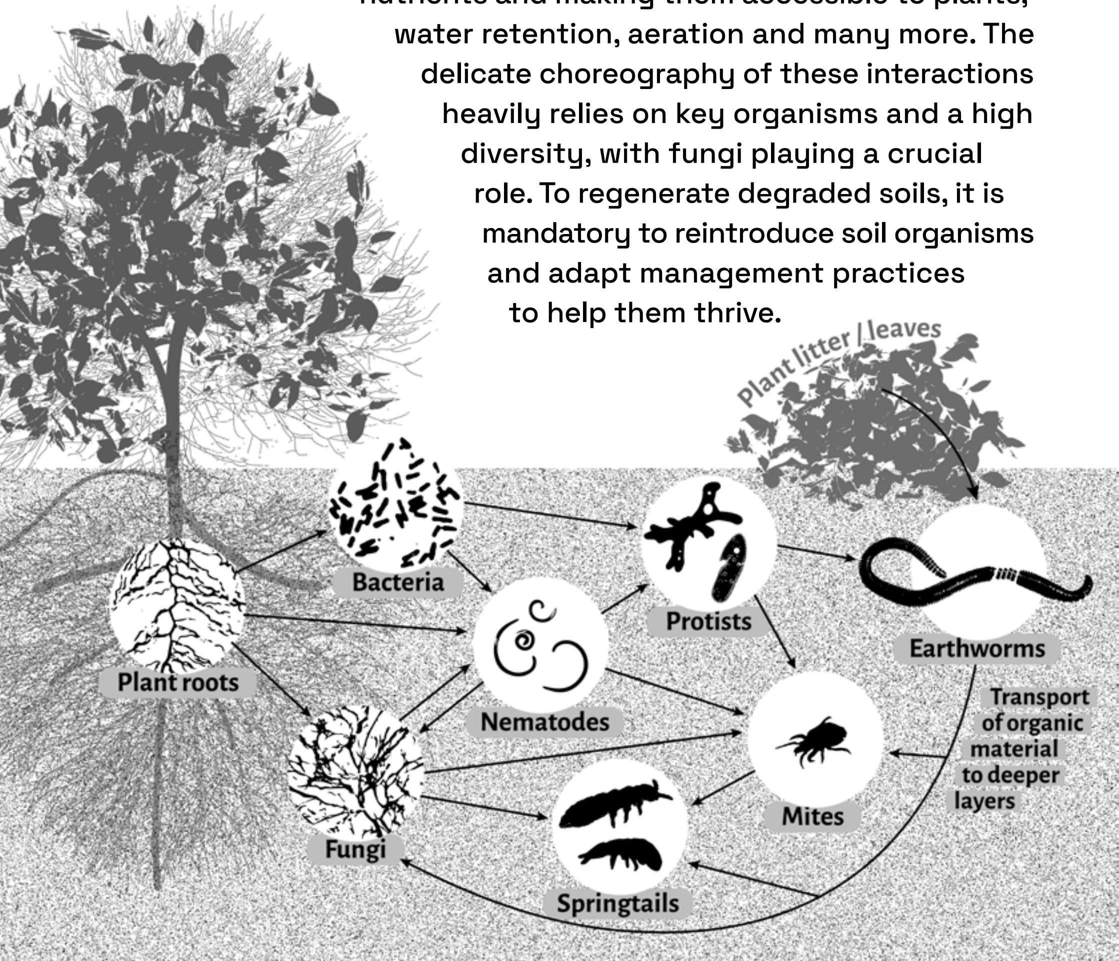


Short guide to fungal bioreactors

1. Introduction

Soils consist of a geographically unique composition of organic and inorganic material, air, water and complex ecosystems of mostly microbial organisms. This so-called ‘soil-food-web’ performs vital functions, such as recycling nutrients and making them accessible to plants, water retention, aeration and many more. The delicate choreography of these interactions heavily relies on key organisms and a high diversity, with fungi playing a crucial role. To regenerate degraded soils, it is mandatory to reintroduce soil organisms and adapt management practices to help them thrive.



Soils are threatened worldwide by human impact. The devastating consequences of inappropriate land management and degrading agricultural practices are further amplified by extreme weather events due to climate change. It is therefore one of the fundamental challenges of our time to restore the function of our soils and to implement regenerative methods to actively build humus - the foundation of long lasting civilisations.

With this 'short guide', we present a low-tech method for producing a soil inoculant with an extremely high density and diversity of fungi and bacteria that can be used for soil regeneration in rural as well as urban areas. Many early adopters of the method report miraculous yield increases, healthier plants and improved humus building - especially on highly degraded land. Research on the topic is slowly gaining momentum, while a worldwide community is testing and improving the design. Although promising, there are not enough results to allow clear statements about the long term effects of the method. This is why we want to encourage you to experiment and adapt the method to your local circumstances and contribute by sharing your experiences.

2. What is a fungal bioreactor?

The term “fungal bioreactor” is used to describe a specific type of compost pile - one that is not intended to produce fertilizer, but to create a soil additive that is especially rich in fungi. Throughout this guide, we will therefore refer to the product not as compost, but as ‘inoculant’ to highlight its purpose of introducing (inoculating) life into degraded soils. To understand the basic principle of this method, it is crucial to learn a few things about fungi. There are 3 major types: saprophytic, parasitic and mycorrhizae. For creating the inoculant only the saprophytic fungi are relevant, since their lifestyle is based on digesting plant biomass. They need woody material as a food source, darkness, humidity and enough fresh air. Because fungi are composed of long and frequently branching cells (the so-called ‘mycelium’), they can not thrive if their home is dug up, compacted or turned. Our job as caretakers is to build them a home that provides exactly those conditions and then leave them undisturbed for at least 12-16 months. As a reward for our efforts, the fungi will transform low-value material like leaves or wood chips into a vibrant inoculant bustling with life and containing billions of fungal spores.

3. Design principles

The bioreactor itself is a design concept that can take many shapes. It has to ensure the aforementioned conditions for fungal growth while being affordable, long-lasting and easy to build. The ideal place to set it up provides plenty of shade throughout the year and a water connection or - even better - the possibility to collect, store and distribute rainwater. In the second part of this guide, we present two tried and tested designs that use standard materials that can be found almost anywhere in the world. The first design is based on wooden pallets and wire mesh, while the second uses 1000 liter plastic containers (also called IBC-containers).

Both designs feature air channels for passive ventilation as well as a drainage and drip-irrigation system to ensure a stable humidity. To create aeration channels within the substrate, vertical sticks, pipes* or any other tube-shaped placeholder with a diameter of around 10 cm are positioned before the material is filled into the bioreactor. After letting the material set for 1-2 days, these sticks/pipes are removed to allow air circulation throughout the substrate. It is important that the channels have a maximum distance of 30 cm from each other as well as to the edge of the reactor and that the air can flow freely through them from underneath the structure.

* Due to their sturdiness and low cost, we often use PVC drainage pipes for this purpose. Although we never had problems with the material, it is important to note that this type of pipe should not be heated above ~60°C - a temperature commonly reached during the heat phase of the bioreactor. If using PVC or other heat susceptible plastics, make sure to remove the pipes as early as possible.

2.
The classic design

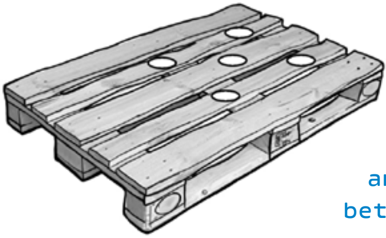
The following design was developed by Johnson and Su et al. (see “resources”) - we only added a door for more convenient harvesting of the material. Keep in mind that this is a design principle, and it can be adjusted, modified, and enhanced to suit your local conditions, available material and budget. Potential sources for materials include local scrap yards, hardware stores and agricultural shops.

Material

- Shipping pallet (standard, ideally EU norm) 120 cm X 80 cm
- Wire re-mesh (used for reinforced concrete) 150 cm X 300 cm
- Landscape fabric (woven, minimum 140g) 150 cm X 500 cm
- Pipes or other tube-shaped placeholder ⌀ ~10 cm, 5 pieces each 150 cm
- Sturdy wire (e.g. garden wire)
- Sticks/bamboo/or similar (to temporarily hold the pipes in place)
- Rubber band (only if you use pipes)
- Irrigation system

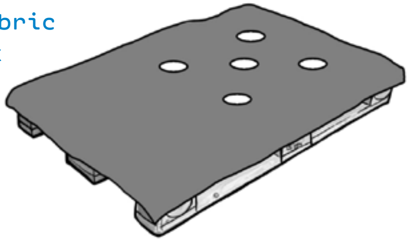
Tools

- Angle grinder/bolt cutter (to cut wire re-mesh)
- Pliers (to cut wire)
- Drill for wood
- Jigsaw with wood blade (to cut holes into the palette)
- Scissors/cutter knife (to cut landscape fabric)
- Pencil/marker

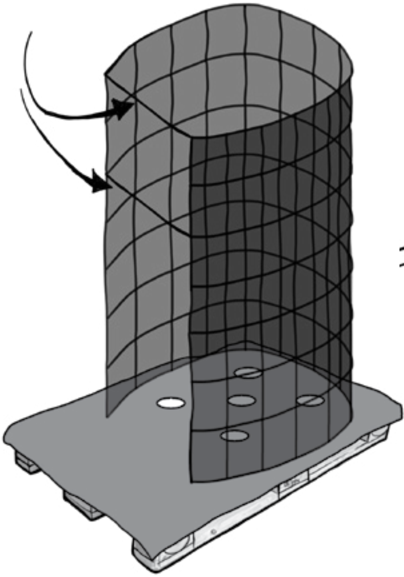


Use the pipes/sticks as a guide to draw 5 circles on the palette. Add some millimeters offset for easy sliding. Then drill holes into markings and cut with a jigsaw (distance between holes max. 30 cm).

Cut a piece of landscape fabric that fits the palette and fix with some nails. Cut holes for pipes/sticks.



~150 cm X 230 cm + door ~70 cm

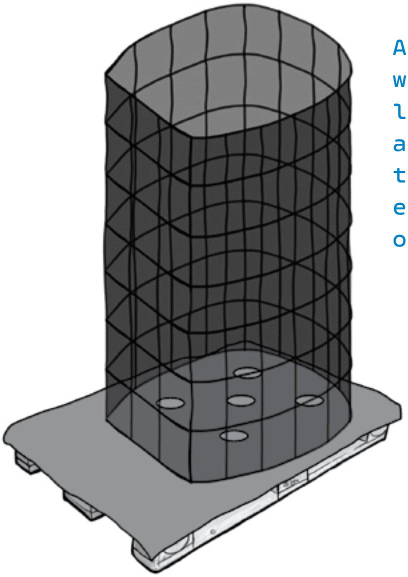


Cut wire re-mesh into dimensions. Add landscape fabric, cut to fit while still laying on the ground and fix it with wire.

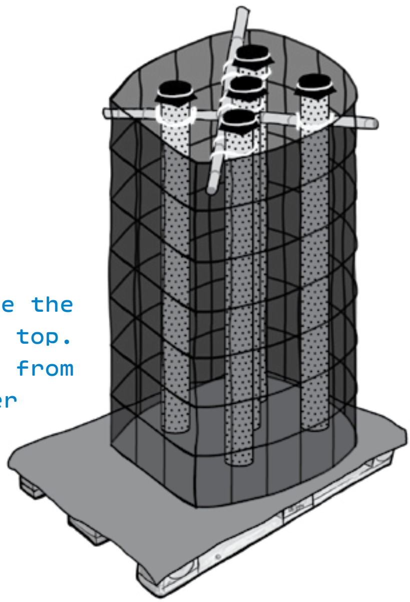
Nails are good to poke a hole into the fabric.

Then lift the wire re-mesh onto the palette and fix with 2 nails crossed.

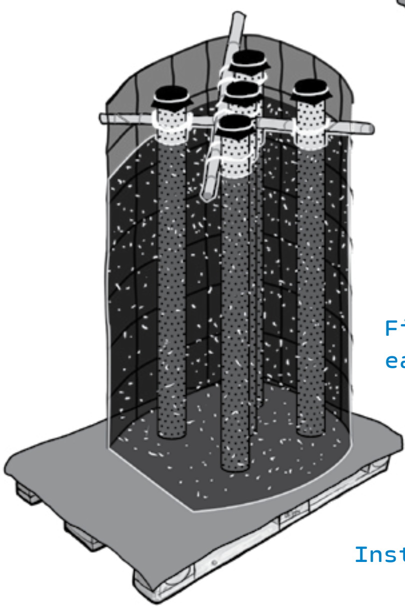
Before adding the door, fix the wire re-mesh with 2 wires or strings for stability.



Add the door by attaching wires as hinges and firmly lock it into place with additional wires. (Leave them visible, so you can easily find them when opening the door).



Place the sticks/pipes inside the bioreactor and secure them on the top. If you use pipes, cut small pieces from leftover landscape fabric and cover them. Fix with a rubber band.



Fill with substrate and water each layer thoroughly.

Install the irrigation system.

3.
IBC container design

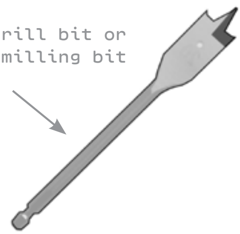
IBC containers are standardized, durable, easy to obtain and therefore often repurposed. The frame of the container can be used for the classical design instead of the wire re-mesh, but we would like to propose a way to also repurpose the plastic container itself. Feel free to make further adjustments and improvements.

Material

- IBC container (food grade, rinse well) ~1000 l; 100 X 120 X 116 cm
- Pipes or any tube-shaped placeholder 4 pieces each 100 cm (⌀ ~10 cm)
- Wire (to attach the irrigation system)
- Sticks/bamboo/or similar (to temporarily hold the pipes in place)
- Rubber band (only if you use pipes)
- Bricks/stones/wood blocks 6 pieces each ~10cm high
- Irrigation system

Tools

- Wrench (to unscrew the frame of the IBC container)
- Jigsaw (to cut the plastic canister)
- Electric screwdriver or drill with wood drill bit or flat milling bit
- Pliers (to cut the wire)
- Marker

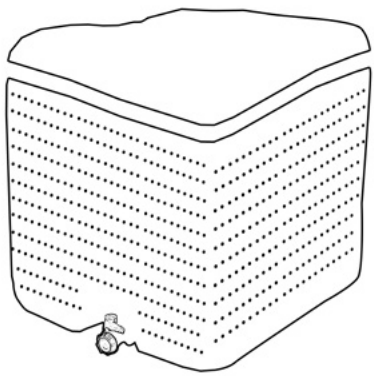


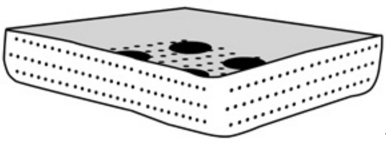
Unscrew the top of the IBC container frame and remove the plastic canister.

Drill 1-2 cm wide holes into the plastic canister from all 4 sides (not top/bottom) - with about 10 cm spacing.

A flat milling bit works great and does not create small plastic particles.

Cut off the top of the canister.



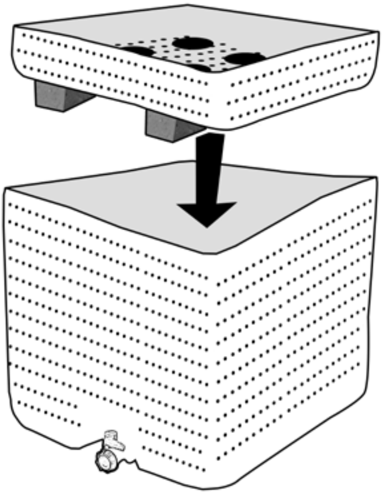


Use the pipes/sticks as a guide to draw 4 circles on it. Add some millimeters offset for easy sliding. Then drill holes into markings and cut with a jigsaw.

Distance between holes max. 30 cm.

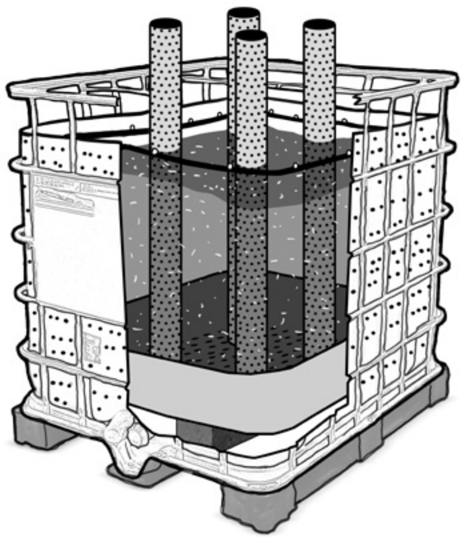
Also drill a few additional ~1-2 cm wide holes between the larger holes and on the sides.

Put the main part of the canister back into the IBC frame and place the bricks on the bottom. Place the lid upside down on the bricks, so that there is a ~10 cm gap between the bottom and the lid. Make sure that it is stable and the bricks do not cover the holes for the pipes. Also check if the holes on the sides of the canister will provide air to the space below the lid - if not, drill a few more.



Place the sticks/pipes inside the bioreactor and secure them on the top. If you use pipes, cut small pieces from leftover landscape fabric and cover them.

See classic design.



Fill with substrate and water each layer thoroughly.

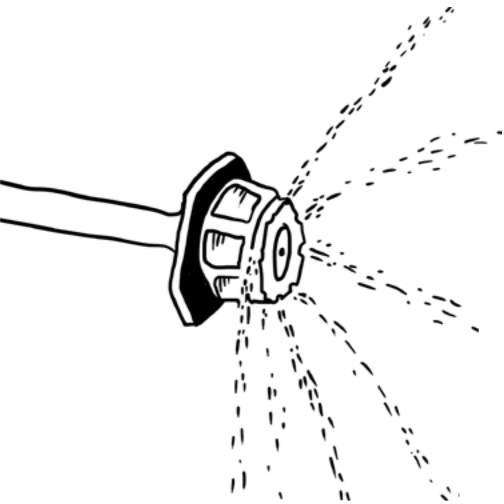
Install the irrigation system.

6. Loading the bioreactor

As food for the fungi ('substrate'), leaves, wood chips and other fibrous woody materials provide good yields. Substrates of similar size and texture ensure that the inoculant matures homogeneously. Kitchen waste has to be avoided and grass cuttings, coffee grounds or other material that is high in nitrogen should only be added in small amounts (< 15 %). It is important that the substrate is high in carbon/cellulose and can therefore also contain bark, straw, sawdust, corn stalks, hemp, jute, sisal, cotton, linen, bamboo, etc. leaves should not be shredded (otherwise air-penetration is affected), but for woody material the particle size should be around 2-4 cm. Everything has to be well moistened before or during loading of the reactor.

It is recommended to completely fill the bioreactor in one go, otherwise the onset of the heat phase and the stability of the aeration channels might be compromised. The substrate can either be submerged in a water bath or thoroughly sprayed with a garden hose (layer by layer) during loading. It is crucial to make sure that no dry pockets are created and that the material is not being compressed. After 1-2 days, the sticks/pipes are cautiously removed to create aeration channels.

7. Maturation & application



Other than irrigation, no maintenance is needed for the fungi to do their magic. Since keeping the substrate moist (but not wet) at all times is essential, we recommend installing an automatic irrigation system. Small sprinklers usually work better than 'micro-drippers' (hose with tiny holes) because of the water distribution. Make sure that the walls of the bioreactor get sufficient irrigation, especially for the "classic" design, because it is more prone to dry out. When using around 12 micro sprinklers (360° degrees, ⌀ 4,6 mm), 1 min of irrigation per day in summer should be sufficient. Especially during dry spells, it makes sense to check the substrate regularly and irrigate longer if necessary.

The maturation time is between 12 and 16 months, depending on temperature, climate, humidity, and substrate composition. The finished inoculant should have a clay-like consistency with little to no visible particles from the original substrate and a matte dark color.

For application on smaller areas, the material can be manually spread on the soil surface and is then ideally covered with mulch material (e.g. straw). For larger areas, a manure spreader can be used, or the inoculant can be liquefied with an 'extractor'. This is essentially a large bucket where water is added and the mixture is thoroughly stirred or bubbled with air. Thereby, spores attached to the soil particles are dispersed into the liquid phase. After filtering, the liquid can be applied with conventional spraying devices.

When you squeeze the finished product in your hand, it should feel moist and form a stable lump.

Resources

Websites & Videos

mikroBIOMIK project page (English & German)
mikrobiomik.org/en/projects/fungal-bioreactors

Instructional video for the IBC container design (German)
youtu.be/NAA7ES9uQd8

BEAM-Method by Johnson & Su et al. (English)
beamcompost.com

Instructional video for the ‘classic’ design (English)
youtube.com/watch?v=DxUGk161Ly8

Research on soil microbial communities (English)

Food and Agriculture Organization of the United Nations (2020) “State of knowledge of soil biodiversity”
fao.org/3/cb1929en/cb1929en.pdf

De Vries, et al. (2013) “Soil food web properties explain ecosystem services across European land use systems”
doi.org/10.1073/pnas.13051981

Morriën, et al. (2017)” Soil networks become more connected and take up more carbon as nature restoration progresses”
doi.org/10.1038/ncomms14349

Johnson, et al. (2015) - “Development of soil microbial communities for promoting sustainability in agriculture and a global carbon fix”
peerj.com/preprints/789v1.pdf

Acknowledgements

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(1) mikrobiomik.org
(2) mikrobiomik.org/humussapiens
(3) hackteria.org/wiki/UROS
(4) machbar-potsdam.de
(5) zukunftsstiftung-landwirtschaft.de

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