DOCTOR AGARICUS

"WHAT IS THE ACADEMIC/TECHNICAL KNOWLEDGE AROUND VENTILATION WITHIN THE COMPOST MATRIX DURING CROPPING AND ITS EFFECT ON MYCELIUM GROWTH AND MUSHROOM YIELD. WE KNOW THROUGH EXPERIENCE THAT THE 'RIGHT' STRUCTURE AND DENSITY OF THE COMPOST IN THE GROWING CONTAINERS IS IMPORTANT, BUT WE HAVE NO MEASURES OR EVEN CONSISTENT DATA ABOUT THE GOALS WE ARE AIMING FOR."

Balancing air and moisture within compost

This is an excellent, if complex, question!

The structure of the compost, together with moisture content, compression during filling and the degree to which the materials are already degraded, all affect the total air spaces – air filled porosity (AFP) – within the compost matrix. AFP is often estimated by measuring bulk density, recorded as kg/m^3.

For example, extending Phase I, using aged straw and finely chopping straw before composting can all increase bulk density and are likely to also reduce air spaces within the compost (Figure 1).

Maintaining air spaces within the compost matrix (Figure 2) is necessarily a balance between ventilation – which provides oxygen to growing mycelium and allows carbon dioxide and volatiles to escape – and providing the readily available moisture that the mycelium needs to grow.

Pore size distribution can be just as important as total air spaces. Small pores hold water, but *very* small pores may hold water too tightly for mycelia to easily access.

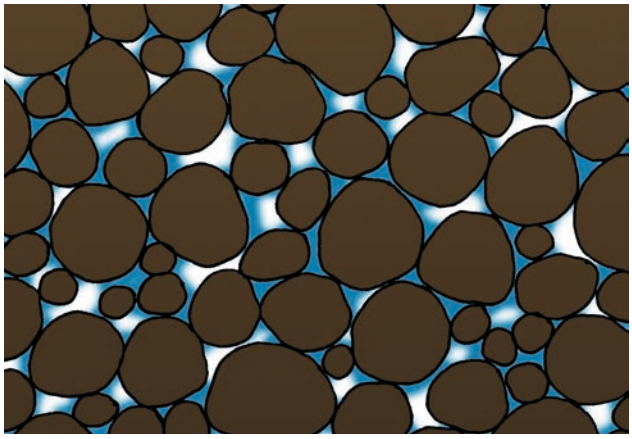

Figure 2. The compost matrix contains a mixture of large and small pores. While large pores drain more easily, the water they contain is readily taken up by *Agaricus mycelia*. In contrast, mycelia may have trouble extracting water held tightly in small pores.

Large pores increase aeration, but at the cost of water holding capacity.

Compost with low bulk density/high AFP is likely to to hold less water, even when fully saturated. For example,

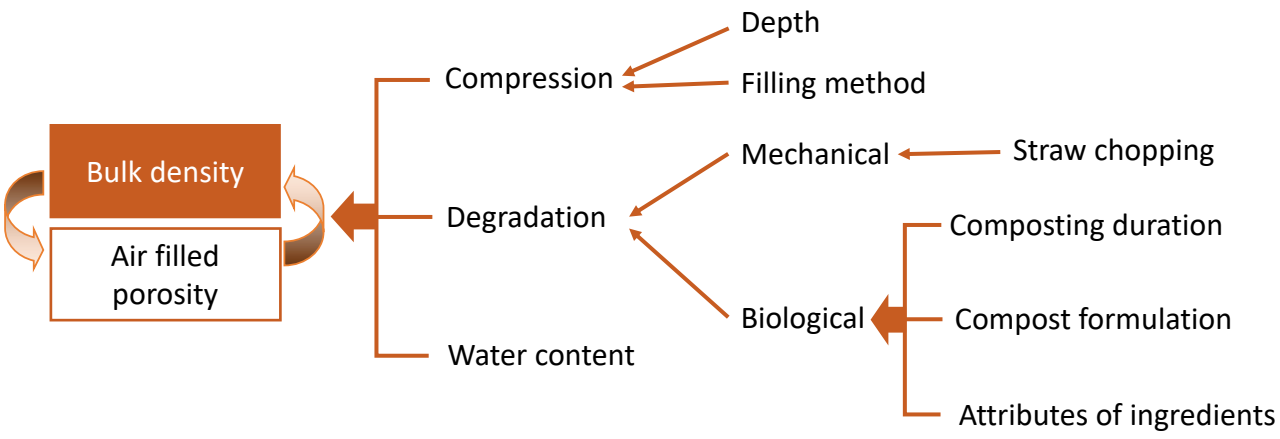

Figure 1. Summary of factors that affect AFP and bulk density of compost. Derived from Randle, 1981.

the study shown in Figure 3 sampled 39 commercial composts, measuring bulk density and moisture content at spawning. Despite considerable variability, it is clear that composts with high bulk density hold more water than those with low bulk density[1].

But how much water is needed in compost? A recent study from the Netherlands examined the water uptake mechanisms at play during mycelium growth and sporophore formation[2]. Water potential is a key factor. Water potential can be hard to visualise, as it ranges backwards from 0 (pure water) to negative values. Water potential depends on factors including the amount of dissolved solutes (osmotic potential), (hydrostatic) pressure and the attractive forces between the water and substrate (matric potential).

The osmotic potential of casing (-0.07 to -0.26 MPa) is much higher than that in compost (average -1.33 MPa) due to the lower concentration of solutes that it contains.

This means it is easier for the developing mushroom to extract water from casing than from compost. It is estimated that one-third of the water inside first-flush mushrooms is derived from the casing, increasing to approximately 50:50 by third flush.

However, the compost still supplies the majority of water found inside mushrooms. This water is mainly sourced from the top compost layer. Moisture content in the bottom layer of compost barely changes during cropping, with the centre showing an intermediate change in moisture content. Although *Agaricus* mycelia can transport water from wetter to dryer areas within the substrate[3], little vertical transport occurs within the compost. This is probably due to resistance in the fine hyphae found in compost compared to the thicker strands formed in casing.

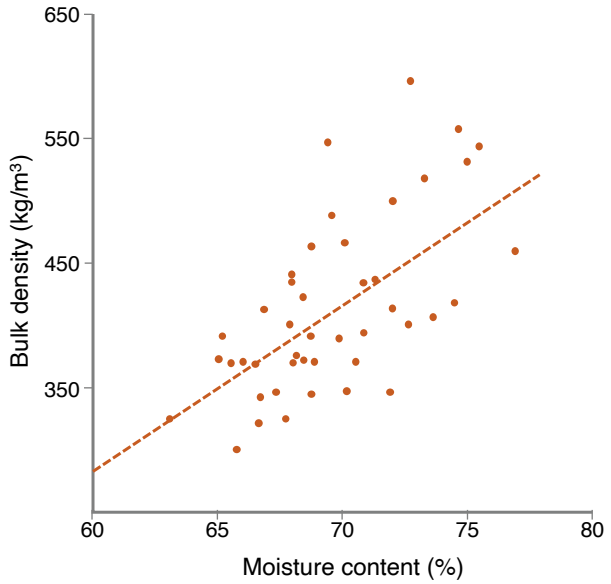

Figure 3. Relationship between bulk density and water content of 39 commercial composts. Derived from Randle, 1981.

In theory, the low osmotic potential in compost, compared to inside the hyphae, should make it impossible for *Agaricus* mycelia to absorb water. Not only is the osmotic potential within compost lower than that within the mushrooms (average -0.72 MPa), but it becomes increasingly negative with depth and as the cropping cycle progresses[4].

For example, nutrient levels are lower (and osmotic potential higher) in third compared to first flush mushrooms[5]. This may be related to the decreasing osmotic potential in the compost – which makes it more difficult for mushrooms to take up water and form.

It is believed that the fungus overcomes osmotic barriers to water uptake using a combination of hydrostatic and matric pressure. It is also thought that there is active absorption and transport of water within the rapidly expanding hyphae.

In addition, the fungal hyphae secrete water repellent compounds at the interfaces between air and water. It is these that allow *Agaricus* mycelia to escape the substrate, bridging air gaps and forming mushrooms.

These water-repellent compounds accumulate over time, which is why casing and compost become increasingly hydrophobic as the cropping cycle progresses. However, the benefit they provide is to lower the surface tension of water. This helps the mycelium to squeeze more water out of the substrate, even as moisture content drops during cropping.

The importance of well-structured compost

The structure within the compost matrix is strongly linked to the qualities of the wheat from which it is derived. Wheat straw has a highly porous structure. Not only is it hollow in the centre, it also has vascular bundles of various pore sizes within the plant tissue. Importantly, it is also strong, having been bred to resist lodging (falling over due to wind or rain). Growing conditions, use of irrigation, and variety will all contribute to the physical characteristics of wheat straw and, therefore, the AFP of compost produced.

The importance of mechanical strength can be shown by comparing wheat straw with barley straw. Wheat straw is 1.5 to 2.5 times stronger than barley straw, especially at the tops of the stems[6]. As a result, barley straw can hold a lot of moisture, but lacks the structural strength to maintain good AFP in compost.

Noble and Gaze reported that yield from barley straw was lower than that from wheat straw, despite similar initial bulk density and N content; it seems possible that declining AFP during cropping may have been a factor in this result.

The mechanical strength of straw depends on the composition of cellulose, hemicellulose and lignin, as well as the size of cell structures and vascular bundles. This in turn affects the AFP of compost. It is generally recommended that AFP should be maintained above 40%, and ideally higher, during composting itself to ensure the materials remain aerobic[7].

However, there is less guidance regarding ideal AFP during cropping.

What happens during cropping?

Compost AFP will inevitably fall during production. Growers will have observed the slumping and compaction that can occur between filling and third flush. How much AFP falls will depend on the qualities of the materials used to produce the compost.

For example, Wang et al (2021)[8] examined changes in AFP over time for composts prepared using wheat straw, rice straw and reed straw (Figure 4). Other ingredients (manure, gypsum, amendments) were adjusted so as to achieve similar initial carbon and nitrogen levels in the mix.

The rice straw was readily degraded by the mushroom mycelia. While the yield from flush 1 was similar to that from wheat straw, the compost subsequently collapsed. As a result, yield for flushes 2 and 3 was half that obtained in wheat straw.

In contrast, the large pores within the reed straw reduced its water holding capacity, so the compost tended to dry more quickly. The reed straw was not easily degraded so AFP remained high. However the mushrooms produced were soft and light, with elongated stipes and poor quality.

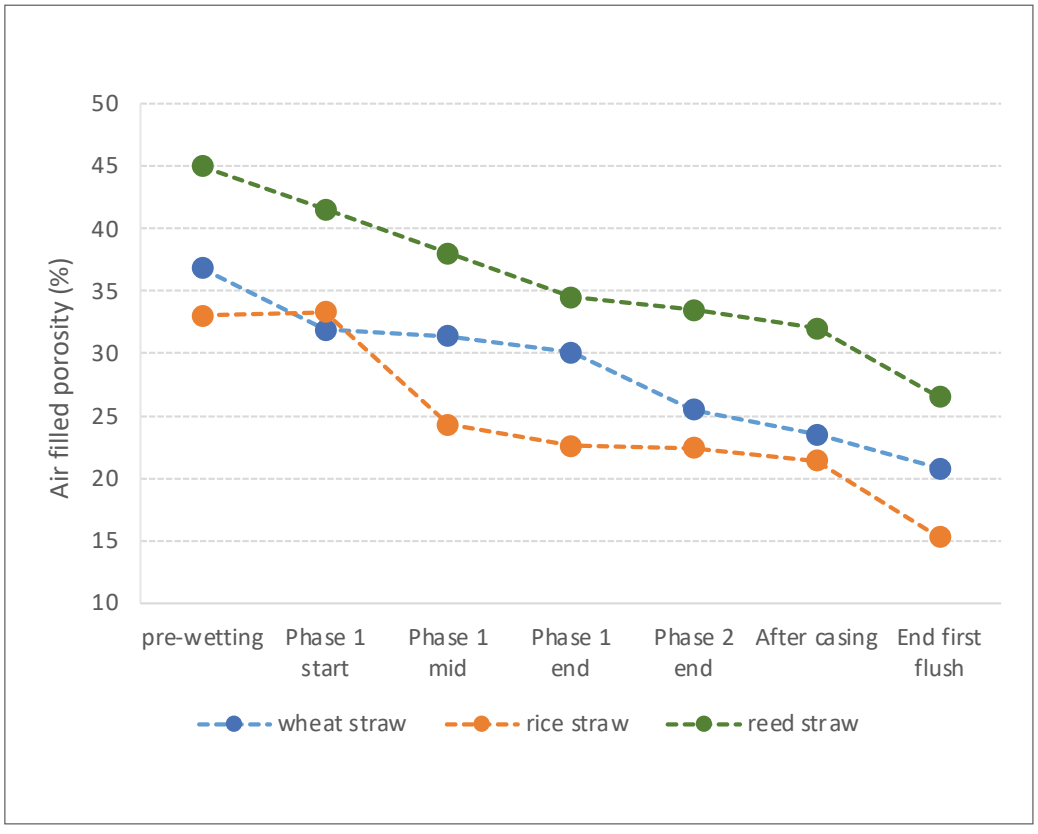

Figure 4. Changes in free air spaces within mushroom compost made from wheat, rice or reed straw, from pre-wetting to the end of first flush. Data derived from Wang et al., 2021.

Clearly, the AFP within the matrix was not the only difference between these materials. Nevertheless, the researchers concluded that the structure provided by wheat straw, being intermediate between these other substrates, is one of the key factors that make it ideal for *Agaricus* production.

Measuring bulk density and air spaces within the compost matrix

The AFP of compost can be measured by determining how much water is required to fill the air spaces within a known volume of compost. However, in the case of mushroom compost, changing moisture content is a complicating factor.

Despite this limitation, water displacement can provide information about the minimum air space volume when the compost is saturated. It can also be used to measure AFP at a point in time. Repeated measures during cropping, if combined with measurement of water content, could therefore provide information about stability or slumping within the compost matrix.

A tool some growers use to measure bulk density may be useful. This consists of a hollow tube of known volume with a cutting edge and a removable collar at the top end. In the example shown in Figure 5, the sampling tube has an internal diameter of 100 mm and a height of 255 mm, giving a total volume of 2.0 L. In this case it also has a tight fitting lid.

To measure bulk density:

- Tare a balance with the tube plus lid
- Add the removable collar
- Take a sample of the compost by forcing through the thickness of the bed, filling it up into the removable collar section
- Put the lid on
- Remove the collar and slice off any excess compost, gaining an exact volume
- Weigh the filled sampling tube plus lid, giving a weight per unit volume and convert to m^3 (e.g. 2L = 1.2kg; bulk density is 600kg/m^3)

To then measure air spaces within the matrix

- Tare the balance with the filled sampling tube
- Carefully and slowly fill the tube with water until water appears as a thin film at the top
- Re-weigh the sampling tube and convert to a percentage (e.g. 400g in 1.2kg = 33%

To measure *minimum* air space within saturated compost, repeat as described but thoroughly soak and drain the compost at least three times before re-taring and filling as previously.

How does AFP affect yield during cropping?

To answer this question MushroomLink turned Dr Ralph Noble, of Microbiotech UK.

Dr Noble has spent many years examining the relationship between compost attributes and yield. For example, Noble and Gaze (1994) reported that chopping straw before composting (compared to intact straw) increased bulk density from 470 to 548 kg/m^3, while also increasing yield in un-supplemented compost from 117 to 169 kg/tonne[9].

Subsequent trials[10] showed that increasing aeration during pasteurisation reduced bulk density of the final compost. However, in this case, low bulk density was associated with higher yields. A final experiment found that incorporating processed compost into fresh compost increased bulk density, but in this case yield was unaffected.

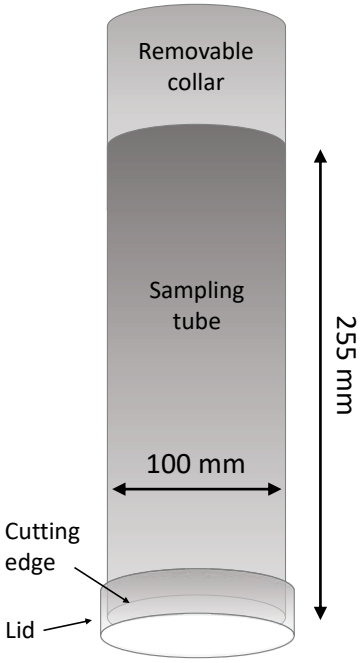

Figure 5. Device used to sample compost for measurement of bulk density and AFP

I discussed this with Ralph, and in response he has very generously taken the time to compile data from mushroom crops grown at the Wellesbourne Horticultural Research Institute between 1995 and 2008 (Figure 6). The compost was prepared the same way each time, using wheat straw, poultry manure, Sporavite and gypsum.

Phase I was conducted in windrows, whereas Phase II was in a bulk tunnel. Factors recorded included:

- Bulk density (recorded on phase II compost after filling trays with a high-pressure tray press – note that lower pressures will give different results)

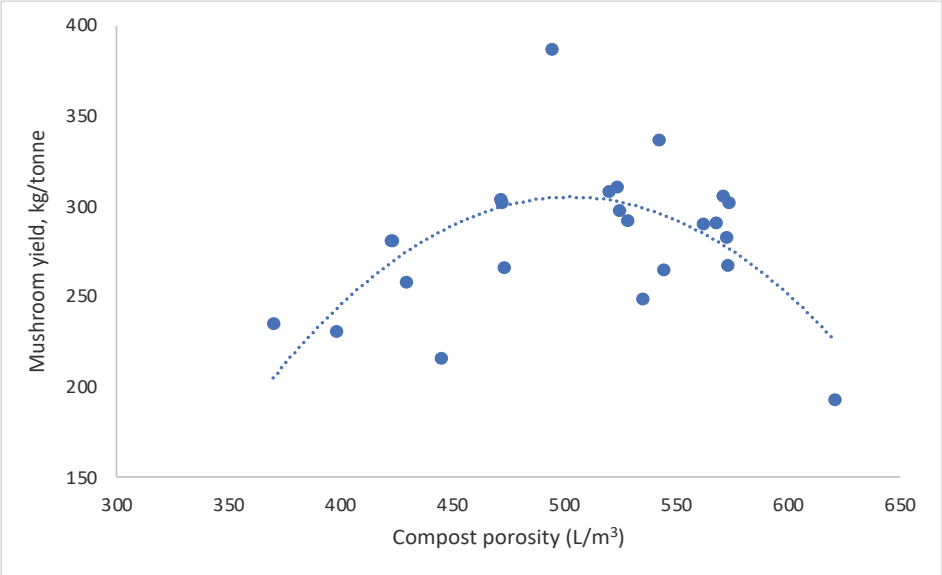

Figure 6. Relationship between compost porosity and yield for compost prepared at the HRI Wellesbourne between 1995 and 2008. N.B. Divide L/m^3 by 10 to convert to a percentage value.

- Moisture content (%)
- Ash content (%)
- Total yield (kg/tonne)

In these trials, bulk density ranged from 400 kg/m^3 to 650 kg/m^3. Bulk density, together with moisture and ash content, was then used to calculate the total AFP in L/m^3. That is, the volume of air spaces remaining that allow air movement during cropping. See the box out at the end of this article for the methodology Ralph used in this calculation.

Ralph plotted compost porosity against mushroom yield for 23 compost trials. While there are clearly many other factors that affect mushroom development and growth, the result seems to indicate that Phase II compost AFP of around 500 L/m^3 (50%) may help maximise yield.

Of course, this result applies only to compost prepared and bulk density measured using the method described. Not compressing the compost in the same way as Ralph's research team when measuring bulk density, or using a different composting technique, could yield different results.

Compost structural resilience - 'springiness'

This compost attribute is possibly one of the less well appreciated. However, the structural integrity of the compost over time is surely reflected in how well it can regain its former shape after deformation.

Dr Noble used a method to measure springiness based on compression with a standard force in Newtons. This would be equivalent to compressing 30cm^2 surface area of compost using a 100kg weight.

Ralph suggests that compost should return to approximately half its initial height after compression. Failing to spring back at all can indicate poor structure, whereas compost that fully returns to the original height may be 'fresher' than ideal.

There is no right or wrong answer to such measurements. However, they do allow different batches of compost to be compared. Measurements of springiness can then be compared to records yield, quality or other outcomes from the crop. Over time, this can help form a picture of what works best within the farm's system.

Conclusions

While there are reasonably good guidelines regarding AFP and bulk density during composting, less is known about optimal ventilation during cropping. The data that exists has tended to focus on bulk density rather than AFP, and while the two are frequently linked it cannot be assumed that they are always directly inversely related.

Drilling further into AFP, no information on pore size and distribution in compost was found, even though this is critical for ready uptake of water from the substrate. Indeed, the accessibility of water during the fungal life cycle, and even the mechanisms by which water is taken up by the fungal mycelium, are still poorly understood. Finally – it would be useful to better understand the relationship between resilience of compost and obtaining a good second flush, and preferably also a productive third flush.

Measuring AFP, bulk density and springiness of different compost batches could potentially improve understanding of critical tipping points for these factors, and what would truly make a good compost great.

CALCULATING PORE SPACE VOLUME IN COMPOST – METHOD USED BY DR RALPH NOBLE

First, calculate the amount of water contained in a cubic metre of compost:

Bulk density (kg/m³) x (% moisture ÷ 100) = Water (kg/m³)

Example:

550 kg/m³ x (78.9 ÷ 100) = 413 kg water/m³

Use this to calculate dry matter:

Bulk density (kg/m³) – Water (kg/m³) = Dry matter (kg/m³)

Example:

550 kg/m³ – 413 kg water/m³ = 137 kg dry matter/m³

We know that a percentage of the compost is ash, so we need a value in (kg/m³):

Dry matter (kg/m³) x (% Ash ÷ 100) = Ash (kg/m³)

Example:

137 kg/m³ x (25 ÷ 100) = 34 kg ash/m³

The part of the compost that is not ash will be organic matter (OM), so this is easily calculated

Dry matter (kg/m³) – Ash (kg/m³) = OM (kg/m³)

Example:

137 kg/m³ – 34 kg/m³ = 103 kg organic matter/m³

According to British standards for measuring physical properties of substrates, the average densities of ash and organic matter are 2.65 L/kg and 1.55 L/kg respectively.

To estimate their volume within a cubic metre of compost, weight needs to be divided by density:

Ash (kg/m³) ÷ 2.65 = Ash (L/m³)

OM (kg/m³) ÷ 1.55 = OM (L/m³)

Example:

34 kg/m³ ÷ 2.65 = 12.8 L ash/m³

103 kg/m3 ÷ 1.55 = 66.4 L organic matter/m³

Water weighs 1L/kg, so weight is equivalent to volume. Subtracting the volumes of water, ash and organic matter within a cubic metre of compost calculates the air spaces that are left, expressed as porosity:

1,000 – [Water (kg/m³) + Ash (L/m³) + OM (L/m³)] = Porosity (L/m³)

Example:

1,000 – (413 + 12.8 + 66.4) = 507.7 L/m³

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