RESEARCH PAPER SUBMITTED TO

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Title: Spent Mushroom Compost as a Growing Media Substitute for Peat

Submission Date: December 6th, 2021

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Abstract

Peat is commonly harvested for agricultural and horticultural transplant media purposes. Peat has very useful characteristics, but it is a finite resource and therefore, renewable alternatives should be considered. Spent mushroom compost (SMC) is locally available in the Fraser Valley and is often considered a waste product by many mushroom producers around the world. SMC should be taken advantage of by growers as it contains nutrients, has a good water holding capacity and porosity, and has shown to increase the yield of a variety of crops. While high salinity levels have been observed as an obstacle when using SMC, previous research has showed that aging the SMC has resulted in significantly lower salinity levels and more successful crops. In this paper, aged SMC, fresh SMC, and an organic peat mix were compared. The two main hypotheses were that (1) plants grown in the aged SMC will perform the same or better than plants grown in the peat mix, and (2) that the plants grown in the fresh SMC will be outperformed by both the peat mix and aged SMC. The data accumulated in this research supports the second main hypothesis and the secondary hypothesis that the soil blocker seeding method would produce seedlings with a similar dry matter to those grown in horticultural plastic trays. Onion (*Allium cepa*), lettuce (*Lactuca sativa*), and fennel (*Foeniculum vulgare)* have a low tolerance to saline soils, so these crops were chosen to study whether the aged or fresh SMC can replace peat as an environmentally friendly alternative in this region.

1. Introduction

Peat is a common ingredient for soilless growing media due to its wide availability, ideal physical and chemical properties, high organic matter content, and low cost (Kuepper and Everett 2004). Peat provides soil structure and excellent porosity to a potting mix while also being resistant to decomposition (Kuepper and Everett 2004). Unfortunately, peat harvest usually involves drainage of sensitive wetland habitats with tremendous capacity to sequester carbon, and peat is expensive and non-renewable (Unal 2015). Local and environmentally friendly solutions should be expanded on to grow healthy plants in an organic system without degrading the ecosystem (Unal 2015). An interesting growing media alternative to peat is spent mushroom compost (SMC). SMC is renewable and it is also commonly considered a waste product by mushroom producers. SMC's utilization as a growing media in the agricultural and horticultural sectors will hopefully allow for peat bog conservation and carbon sequestration.

1.1 Concerns regarding peat usage

Peatlands cover only 3% of the worlds land area, but they hold 30% of the worlds soil carbon (FAO 2019). Peat is a limited resource that when over-harvested can have environmental and economic challenges (Yan et al., 2020). Peatlands are often drained for agricultural and forestry purposes and when this happens, they become sources of greenhouse gas (GHG) emissions (FAO 2019). Peat is the third largest GHG emitter in the world because when harvesting peat there is the potential to disturb rare habitats that sequester carbon. Harvesting of peat can also affect water management, erode biodiversity, increase the frequency of fires, and more (FAO 2019). Due to the concern around the use of peat, experts have placed an increased emphasis on finding sustainable growing media alternatives.

1.2 Spent Mushroom Compost

1.2.1 The mushroom industry and SMC

The mushroom industry has expanded worldwide, and Canada alone produced 120.3 million kilograms of mushrooms in 2017 (Beaulieu-Fortin 2019) making Canada the eighth largest mushroom producing country in the world (Uzun 2004). The most produced mushroom is the white button mushroom *Agaricus bisporus*, which accounts for 32% of worldwide production (Uzun 2004). In 2017 British Columbia exported 27,212,940 kg of the *Agaricus bisporus* mushroom (Uzun 2004). This mass production of mushrooms has also led to an increased amount of available SMC. SMC, which is also often referred to as spent mushroom waste or spent mushroom substrate, is the material that provides mushrooms with nutrients during production (Sendi 2013). Annual mushroom production has led to massive amounts of SMC being distributed globally (Kwack 2012). For every 1 kilogram of mushrooms produced, approximately 5 kilograms of SMC is produced (Paredes 2016). SMC can have negative impacts on the environment if it is not disposed of properly (Kwack 2012) and at the end of the production cycle it is often discarded (Sendi 2013).

Many of British Columbia’s white and brown mushrooms are grown in the Fraser Valley (Ministry of Agriculture, 2014). The Fraser Valley consists of various farms that produce organic products, one of which is Highline Mushrooms in Langley, British Columbia. Highline Mushrooms sells SMC out of its facility in Ontario to farmers in that region. In Langley, there is plenty of SMC available but not yet a market to sell to (M. Bomford, personal communication). It is of value for Highline Mushrooms to promote the understanding of SMC’s valuable properties so that they can distribute their SMC to local farms and nurseries. At Highline

Mushrooms, mushroom compost goes through three phases of processing before it is useful, this processing takes approximately five weeks (L. Dodds, personal communication).

1.2.2 SMC as a growing media

Spent mushroom compost contains chicken manure, wheat straw, gypsum, water, and sometimes peat (Uzun 2004). There are many benefits to SMC and each of these ingredients contribute to the SMC's beneficial properties, such as a good water holding capacity, nutrient availability, and good structure for plant growth (Uzun 2004). SMC is already used in horticulture for various reasons, it is used as bioremediation of contaminated soil and water, to stabilize disturbed soils, to control plant diseases, and even as bedding for animals (Sendi 2013). SMC used in the proper proportions may replace peat as a growing media (Sendi 2013).

The main problem associated with using SMC is its high salt content as many crops are sensitive to high levels of salinity. Uzun (2004) recommended that fresh SMC should not be used as fertilizer or as a soil amendment in orchards due to its high salinity, which is usually above 4 dS/m. Uzun (2004) states that problems due to high levels of salinity occur when too much SMC is applied, or when plants are grown directly in SMC. The salt content of material like SMC will gradually be reduced through the process of leaching when exposed to rainfall. Uzun (2004) stated that for optimal results when using SMC as a growing media that the salt content should be reduced, and SMC should be stored for a total of two years before it is used. In contrast, Sendi et al. (2013) studied SMC as a growing medium for production of Kai-Lan (*Brassica oleracea* var. Alboglabra) and found that the salinity content of SMC was in an acceptable range, with electroconductivity (EC) values of only 1.33 dS/m. Despite this, Sendi et al. (2013) acknowledges that the high salinity of SMC often limits its usefulness as a growing media.

Uzun (2004) states that SMC has a low nitrogen, phosphorous, and potassium (NPK) content compared to commercially available fertilizers. However, Uzun (2004) states that SMC does serve as a slow-release fertilizer which is beneficial as plants can harness the nutrients more effectively. SMC has a good water holding capacity, promotes microbial activity, increases soil aeration, and adds organic matter to the soil (Uzun 2004). Uzun (2004) observed little benefit to an orchard in the first year after SMC application, but greater benefits in the second year. Sendi (2013) also found low levels of NPK in the pure SMC media, and reported improved that growth of Kai-Lan when NPK was added.

Unal (2015) studied the effect of peat and SMC combinations on tomato (*Lycopersicon esculentum* Mill.) seedling media, and found high levels of salt, organic matter, N, P_2O_5, K_20, and Ca in the SMC, with considerable variation between mixes. Unal (2015) concluded that the addition of the SMC has an overall positive impact on the growth patterns of tomatoes. According to Unal (2015) these results are consistent with other research that found that the media with SMC gave the best results when growing ornamental plants. Dura et al. (2000) found that SMC did not work as well as traditional compost when growing peppers, but Polat et al. (2009) did find positive results with SMC that had been weathered for six months before it was used to grow cucumber (*Cucumis sativus* L.). The variety of different results is most likely due to different salt content and chemical composition. Overall, Unal (2015) found that SMC can be used on its own or in combination with other growing media to grow seedlings. They also noted that salt content is a restricting factor when using SMC and that reducing the salinity before use should be considered.

1.2.3 Soil Blocking vs. Plastic Trays

In 2010 more than 265 million tons of plastic were used worldwide and 2% of it was used for agricultural purposes (Vox et al., 2016). The purpose behind using the soil block seeding method was to showcase that this method is a viable alternative to the commonly used horticultural plastic trays and pots. The soil blocker was designed by Eliot Coleman who has over 40 years of experience in organic farming (Coleman, n.d.). Coleman created this design to produce abundant seedlings that would quickly re-root after transplanting. Coleman claims that the use of soil blockers helps “eliminate expense, waste, and storage issues associated with plastic pots” (Coleman, n.d.).

1.2.4 Intended outcomes

This study evaluated the use of SMC as a growing media in an organic vegetable production system. Previous research acknowledges that SMC has a high salinity, which can reduce crop yields, but there is a consensus that SMC has valuable properties and is an environmentally friendly option compared to peat. Fresh and aged SMC were compared to determine whether the salinity content was lower in the aged compost and if this has any effect on the crops grown. Lettuce (*Lactuca sativa*), onion (*Allium cepa*), and fennel (*Foeniculum vulgare*) were chosen as test crops with low tolerance to salinity (Shannon 1999). The main hypotheses were that: (1) plants grown in the 1-year aged SMC will accumulate either the same amount of dry matter or more dry matter than the plants grown in the peat mix; and (2) the plants grown in the fresh SMC will accumulate less overall dry matter than the plants grown in both the aged SMC and peat. The secondary hypothesis was that the soil blocking seeding method will facilitate the growth of seedlings and produce plants with a higher dry matter mass than the plants grown in the horticultural plastic trays.

2. Materials and Methods

2.1 Materials

- 4 plastic plug insert trays (KPU)
- 60-block soil blocker (KPU)
- 4 open plastic trays (KPU)
- Seedling heating mats (KPU)
- Blood meal (KPU)
- One-year old spent mushroom compost (donated in 2020 by Highline Mushrooms)
- Fresh spent mushroom compost (donated by Highline Mushrooms)
- 80 organic fennel seeds (from [1]West Coast Seeds)
- 80 organic onion seeds (from [2]West Coast Seeds)
- 80 organic lettuce seeds (KPU)
- Watering can (KPU)
- Tables (KPU)
- Oven (KPU Soil Lab)
- Scale (in g) (KPU Soil Lab)
- EC meter (KPU Soil Lab)
- Popsicle sticks
- Vermiculite
- Pre-mixed peat growing medium, Sunshine Mix #1 Organic ([3]Sungro Horticulture)

[1] Organic Fennel Seeds from West Coast Seeds: https://www.westcoastseeds.com/products/preludio-organic
[2] Organic Onion Seeds from West Coast Seeds: https://www.westcoastseeds.com/products/cabernet-organic
[3] Peat growing Mix: http://www.sungro.com/professional-product/sunshine-mix-1/

Mushroom compost (both aged and fresh) was donated by Highline Mushrooms. The three test crops were lettuce (*Lactuca sativa*), onion (*Allium cepa*), and fennel (*Foeniculum vulgare).* Highline Mushrooms SMC contains mostly chicken manure and wheat straw but also contains gypsum and peat (M. Bomford, personal communication). The Highline Mushrooms' SMC was found to have high levels of potassium and very low levels of nitrogen (M. Bomford, personal communication). Due to this nutrient imbalance, blood meal, which is very high in nitrogen, was added to the SMC. 5 grams of blood meal for every 1 liter of SMC was added, so both the 1-year aged SMC and the fresh SMC received 25 grams of blood meal as the mixes were 5 liters each. The SMC that was mixed with the organic peat mix also contained blood meal.

2.2 Experiment site

The experiment was conducted at Kwantlen Polytechnic University's farm on the Garden City Lands in Richmond B.C. Seedlings were sprouted in a heated germination chamber and then moved to tables in a passively heated solar greenhouse. Seedlings were moved outdoors into a shaded area in June, in response to a 'heat dome' that raised temperatures in the greenhouse. Seedlings in two subsequent trials were germinated in the greenhouse, then moved into a shaded outdoor environment.

2.3 Experimental Design

The experiment was conducted using a completely randomized split-plot design. The main plots were either the horticultural plastic trays or soil blocks in an open plastic tray, with four replicates of each. Each tray contained 15 subplots (cells), which were randomly assigned to one of 15 factorial combinations of three crops and five growing media. The experiment was repeated 3 times, but only two repetitions had sufficient germination for data collection.

Three experimental factors:

- Growing media (5 levels)
  - Organic Peat Mix
  - One-year old SMC
  - Peat/One-year old SMC (1:1)
  - Fresh SMC
  - Peat/Fresh SMC (1:1)
- Vegetable crop (3 levels)
  - Fennel
  - Lettuce
  - Onion
- Transplant method (2 levels)
  - Soil blocker
  - Plastic trays

- Dependent variables:
  - Dry weight of each plant
  - Number of seeds that germinated

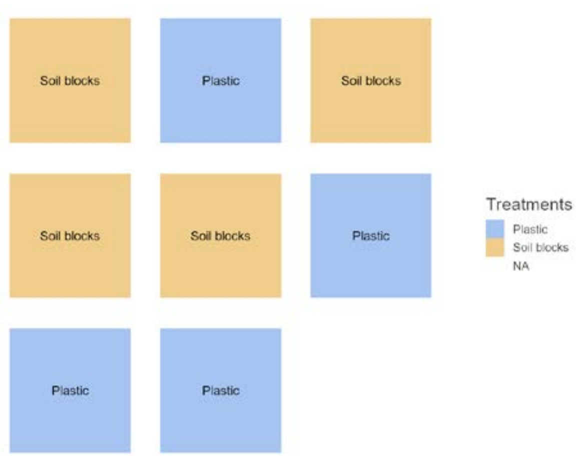

Figure 1. Completely randomized design for the transplant method treatment (soil block and plastic trays).

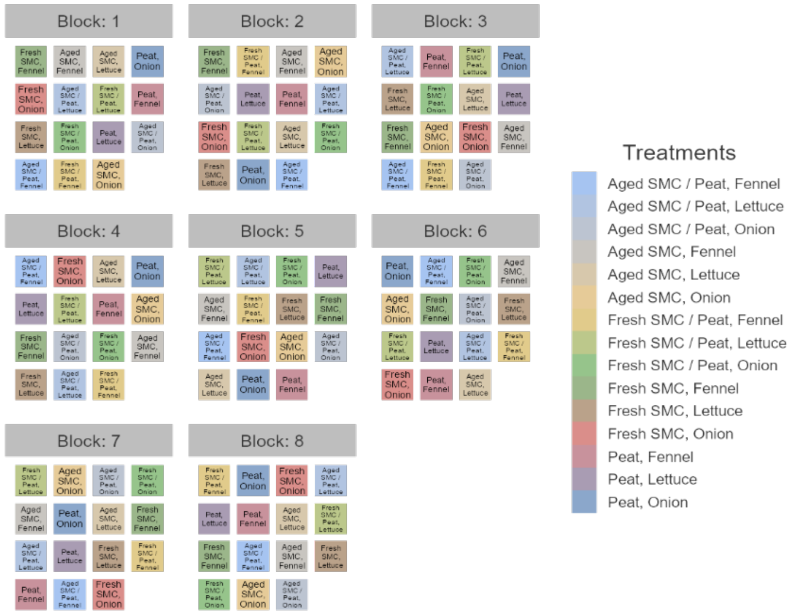

Figure 2. Randomized complete block design for the 15 factorial combinations of three crop treatments (fennel, lettuce, onion) and five growing media (peat, aged SMC, fresh SMC, peat/aged SMC, peat/fresh SMC).

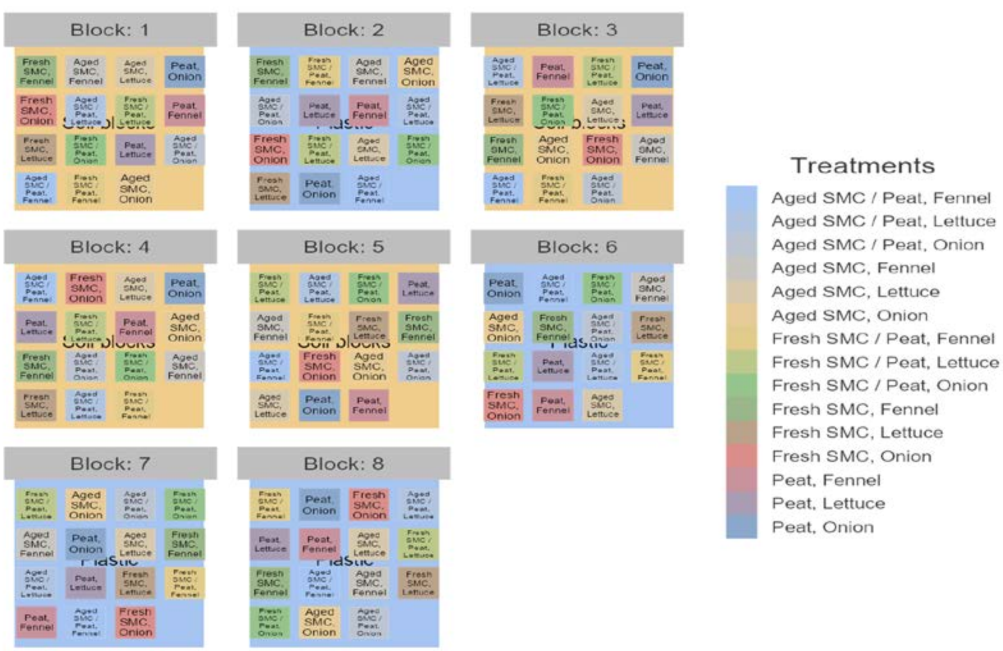

Figure 3. Completely randomized split-plot design with eight main plots and 120 subplots.

Each cell was seeded with two seeds and labeled with the growing medium, crop, and main plot number. The first round of seedlings sat in the germination chamber for one week and then they were moved onto a table with a heated mat. The seedlings were later moved outside when the conditions in the dome were too hot. The second and third round of seedlings germinated inside of the dome and then were moved outside into the shade for the rest of each trial. The seedlings were irrigated as needed and grown for six weeks (the second trial was terminated after five weeks due to poor germination).

2.4 Data collection

After six weeks the transplants were harvested and washed if necessary. The number of plants was recorded (germination rate), and the seedlings were dried in paper bags in an air-forced oven for 72 hours at 60 °C then weighed. Prior to seeding the salinity of each growing medium was measured (Field Scout Direct Soil EC Meter, Spectrum Technologies, Aurora, IL, USA).

2.5 Statistical analysis

A Shapiro-Wilk test determined that Log_{10} transformation of dry weight data was necessary to satisfy the assumption of normal distribution. Transformed data were analyzed by mixed model analysis, with seeding method, crop, and growing medium as fixed effects, and main plot as the random effect, in the GAMLj module of the jamovi interface for R (Gallucci 2019, The jamovi project 2021, R Core Team 2021).

3. Results

3.1 Treatment

Growing medium had a significant ($p < 0.01$) effect on plant dry weight (Figure 4). No difference was detected between the peat mix and the blend of peat and aged SMC ($p = 1.0$), or between the aged SMC and the blend of peat and fresh SMC ($p = 1.0$). Differences between other treatments were significant ($p < 0.05$).

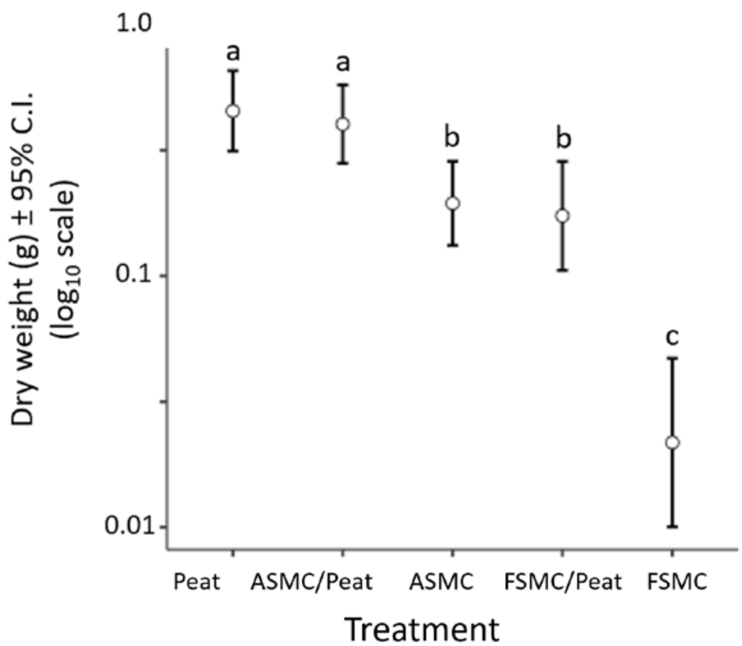

Figure 4. Plant dry weight by growing medium six weeks after seeding. Seedlings were grown in pure peat (Peat), aged spent mushroom compost (ASMC), fresh spent mushroom compost (FSMC), or a 1:1 blend of peat and aged or fresh spent mushroom compost (ASMC/Peat or FSMC/Peat, respectively). Error bars denote the 95% confidence interval around each mean. Means labelled with the same letter do not differ significantly (Bonferroni test, $\alpha = 0.05$).

3.2 Salinity & Nutrient analysis

Table 1. The electric conductivity readings of the five different experimental treatments.

Treatment	EC (dS/m)
Peat/1-year Aged SMC	2.30
Peat/Fresh SMC	8.15
Fresh SMC	11.35
1-year Aged SMC	5.38
Peat mix (control)	1.00

The data from two different samples of fresh SMC from Highline Mushrooms that donated the SMC for this experiment (Table 2).

Table 2. Nutrient analysis of two different (Lot A, Lot B) fresh SMC from Highline Mushrooms.

	Lot A	Lot B
Organic matter	56.9%	41.3%
pH	6.6	7.2
Electrical conductivity	12.9 dS/m	7.27 dS/m
Nitrogen (N)	130 ppm	320 ppm
Phosphorus (P)	1600 ppm	640 ppm
Potassium (K)	25900 ppm	10800 ppm
Sodium (Na)	675 ppm	438 ppm

3.3 Seeding method

No significant effect of try type was detected (p = 0.265) (Figure 5). Plants performed as well in soil blocks as in horticultural plastic trays.

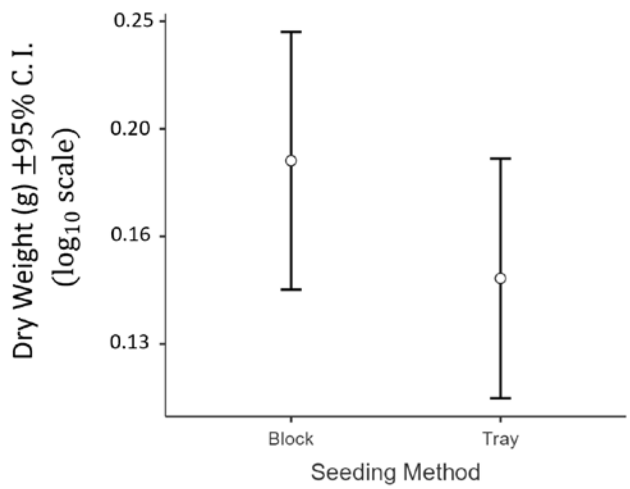

Figure 5. Plant dry weight by seeding method six weeks after seeding. Seedlings were grown in soil blocks and horticultural plastic trays. Error bars denote the 95% confidence interval around both means.

3.4 Crop

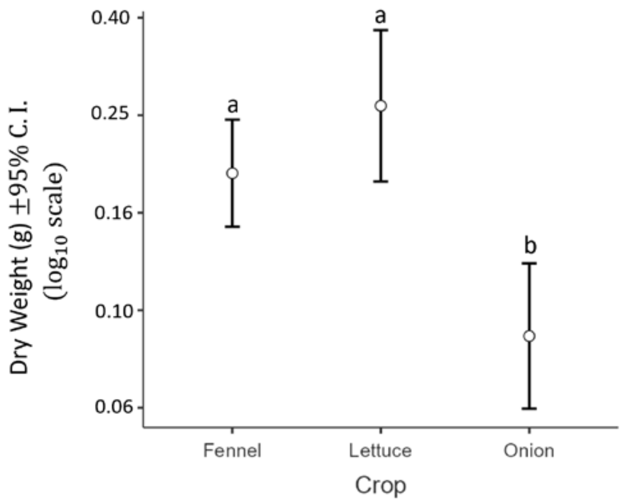

Figure 6. Plant dry weight by crop six weeks after seeding. The three crops grown were onion (*Allium cepa*), lettuce (*Lactuca sativa*), and fennel (*Foeniculum vulgare*). Error bars denote the 95% confidence interval around each mean. Means labelled with the same letter do not differ significantly (Bonferroni test, $\alpha = 0.05$).

*3.5 Seeding method*Crop*

There was a significant interaction between the peat treatment and the two seeding methods. The peat produced bigger plants in the soil blocks than those grown in peat in the horticultural plastic trays (Figure 7). The interaction between the crops and the different seeding methods were not significant ($p = 0.089$). The interaction between the crops and treatment could not be tested for because only the fennel survived the fresh SMC.

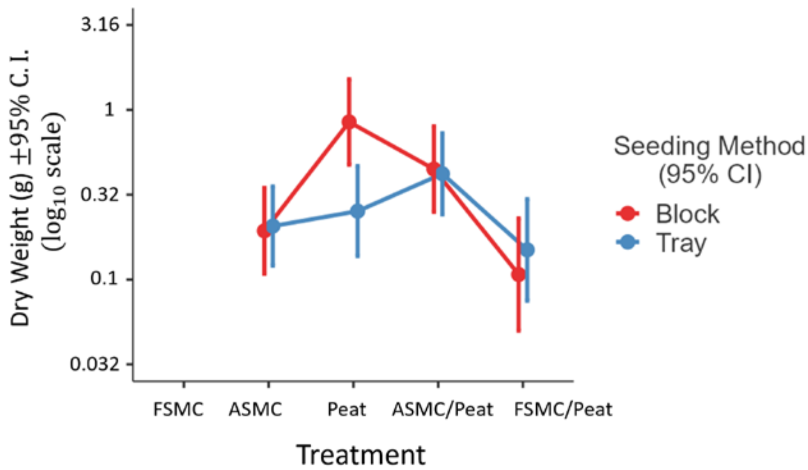

Figure 7. Plant dry weight by growing medium separated by seeding method to show the interaction between the two variables. Seedlings were grown in pure peat (Peat), aged spent mushroom compost (ASMC), fresh spent mushroom compost (FSMC), or a 1:1 blend of peat and aged or fresh spent mushroom compost (ASMC/Peat or FSMC/Peat, respectively). The seeding methods were soil blocking (Block) and horticultural plastic trays (Tray). Error bars denote the 95% confidence interval around each mean.

*3.6 Crop*Treatment*

The only crop to germinate in the fresh spent mushroom compost treatment was the fennel (Figure 8).

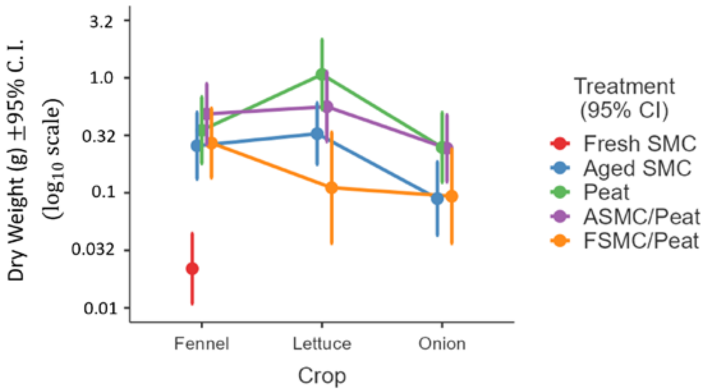

Figure 8. Crop dry weight by treatment 6 weeks after seeding. The three crops grown were onion (*Allium cepa*), lettuce (*Lactuca sativa*), and fennel (*Foeniculum vulgare*). Seedlings were grown in pure peat (Peat), aged spent mushroom compost (ASMC), fresh spent mushroom compost (FSMC), or a 1:1 blend of peat and aged or fresh spent mushroom compost (ASMC/Peat or FSMC/Peat, respectively). Error bars denote the 95% confidence interval around each mean.

4. Discussion & Conclusion

4.1 Primary hypotheses

The first primary hypothesis was that seedlings grown in the 1-year aged SMC would have either the same dry matter accumulation or a higher dry matter accumulation than the seedlings grown in the 100% peat mix. The null hypothesis cannot be rejected because the aged SMC on its own did not produce seedlings with a similar biomass to those seedlings grown in the peat mix. However, the data does support that the aged SMC combined with the peat mix can promote seedling growth and have similar results to the peat mix on its own. Therefore, in combination with the peat mix, 1-year aged SMC can successfully facilitate the growth of salt sensitive seedlings such as fennel, onion, and lettuce.

The second primary hypothesis was that the seedlings grown in the fresh SMC would have a lower total dry matter accumulation than those grown in both the aged SMC and the 100% peat mix. The fresh SMC seedlings had the lowest dry matter accumulation and had a significantly lower dry matter accumulation than the weight of the seedlings grown in both the aged SMC and the peat. This data supports the alternative hypothesis which means that the null hypothesis can be rejected.

4.2 Secondary hypothesis

The secondary hypothesis was that the soil block seeding method would facilitate the same amount of plant growth than those in the horticultural plastic trays. The seedlings grown using the soil blocker and peat treatment had a significantly higher dry matter accumulation than those grown using the plastic trays and peat mix. The overall data shows that there was no significant difference in the weight of the seedlings between the two seeding methods. This means that the data was in support of the alternative hypothesis. The soil blocks dried out very quickly which was not anticipated to be an issue. To randomize the blocks according to the experimental design, they had to be separated and moved which is not how a soil blocker is designed to work. Due to this, it is possible that the soil blocker would have been more successful if it was used as it was designed.

4.3 Salinity & Nutrient Analysis

One of the main problems associated with the use of SMC is its high salt content. Sendi (2013) acknowledged that this is the reason for the limited use of SMC as a growing media. The salt content of SMC gradually decreases due to leaching when it is exposed to rainfall. Uzun (2004) noted that SMC should experience leaching for about two years before it is used as a growing media. The aged SMC used in this study sat uncovered in Metro Vancouver for about a year. This area experiences a very high level of rainfall. Uzun (2004) discovered that fresh SMC usually has a salinity higher than 4 dS/m and that anything higher than 4 dS/m impedes vegetable crop growth. The productivity of most vegetable crops is reduced when they are exposed to excessive salinity (Machado & Serralheiro, 2017).

The treatment that resulted in the lowest dry matter weight was the fresh SMC. The only crop that accumulated dry matter weight in the fresh SMC was fennel, but the mean dry matter accumulated by the fennel seedlings were about one-tenth the amount as mean fennel biomass in all the other treatments. Due to this there was a lack of data and the interaction between the three crops and the five treatments could not be tested. According to Grieve et al. (2012) these three crops all have low thresholds for salinity, between 1.2-1.4 dS/m.

The full nutrient analysis provided by Highline Mushrooms shows that there is variability in the lots of SMC from their facility. Although neither of these analyses are the SMC that was used for the experiment, this information presents the range of salinity, pH, organic matter, and nutrients. This table shows that the fresh SMC is rich in nutrients and organic matter. It also shows that the material is likely to have medium to high salinity and a neutral pH.

4.4 Crop

As mentioned above, the fennel was the only crop that germinated in the fresh SMC treatment. The dry weight of the fennel seedlings and the dry weight of the lettuce seedlings were both significantly higher than the dry weight of the onion seedlings. There was no significant interaction between the crops and the seeding method. The fennel showed very similar results when grown in every material other than the FSMC. The onion although it did not germinate in the fresh SMC also had very similar results in dry matter accumulation when grown in the other four treatments. The lettuce had different results for all the different growing media.

4.5 Problems with the experiment

Three different trials were run for this experiment in the summer of 2021. Although the experiment was set up in the same way each time only the first trial resulted in usable data for analysis. The second round was discarded and not analyzed at all as there was very poor germination. The third trial was harvested, and the data was collected but it had very poor and inconsistent data, so it was not included.

Although the data supported the alternative hypotheses there were many things during the experiment that may have reduced the success of the seedlings. A week in to the first trial the blocks had been rifled through and flipped over. Due to problems with mice on this property in the past this is believed to be the explanation for the disturbance. Unfortunately, it was impossible to tell whether the blocks had lost their seeds. Instead of re-seeding the blocks were put back in place and recovered with vermiculite. The first trial and the proceeding two trials were then covered with green crates with small holes for air and light but not large enough to allow for mice to enter. These crates were taken off after a few weeks because the seedlings had elongated which is a sign of light depletion. The second and third round of seedlings were in a different location under shade and away from mice disturbances, but on one occasion birds were seen on top of the seedlings.

Additionally, the first round of seedlings experienced a heat dome, this heat dome lasted for 7 days in the end of June 2021 and got as high as 31.1 ℃, a week before the seedlings were harvested. According to Sanders (2001) although the ideal temperature is much lower, lettuce can handle temperatures up to 29.4℃ for a few days if night is cool. According to the Utah State University (2021) fennel also grows best in cooler climates. Onions prefer germination temperatures at around 13℃ and are not heat tolerant until later in development (Albert, 2020). All of these factors could have contributed to inconsistent data.

4.6 Conclusion

Using 1-year aged SMC in combination with peat is a possible alternative to a 100% peat mix. The three salt-intolerant crops (onion (*Allium cepa*), lettuce (*Lactuca sativa*), and fennel (*Foeniculum vulgare*)) all accumulated dry matter in the ASMC/peat material. Fresh SMC was able to facilitate the growth of fennel, but the mean dry matter accumulation was still low. Fresh SMC likely has too high of a salinity content to facilitate these plants, but because the 1-year aged SMC experienced leaching for a year it was able to provide a suitable environment to seedlings.

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