8 Hand-Mixed Substrate; Homogeneity of Crop Emergence in Peat-Free Substrate

8.1 Introduction

Potted plant production may be considered a industrialized process (Andersen 1983). Environmental conditions are fervently controlled, waste streams optimised and contracts filled. Going beyond this; working time requirements, production planning, resource management (space allocation, nutrients, water, light), and specific operating procedures all result in timely and predictable production. Standardisation is also a significant factor; Pot size, media composition, seed batches, treatments, irrigation and timings play into the industrial mechanics of glasshouse operations.

This importance of standardisation and production predictability may also be applied to growing media. Peat has long been the substrate of choice due to its relative homogeneity, availability and adaptability (Raviv 2014, 2014). Other considerations such as the physical characteristics of peat highlight it as a superior material for potted plant production; water holding capacity, bulk density, porosity and chemical stability often aid growers in the production of timely and consistent croppings (Bunt 1988; Papadopoulos et al. 2008; Neumaier and Meinken 2015).

The production of peat, as well as its availability will however, begin to dwindle over time. As a fossil fuel resource or “slow renewable” (as considered by the Finnish Government (Ylönen and Simola 2012)) with considerable environmental concerns regarding its extraction, peat use has begun to be phased out in favour of low peat, or peat-free alternatives (Neumaier and Meinken 2015), as demonstrated by white paper published in 2011 by the U.K. government, aiming to reduce domestic use of peat to 0% by 2020, followed by commercial sectors in 2030 (Alexander and Bragg 2014).

Peat-Free substrates offer a relatively distinctive media type for horticultural operations where adaptation and tailoring can be achieved to a much higher degree than conventional peat. This is apparent due to the number of components in these substrates and ability of suppliers to source specialist resources for each producer. Problems however, can be arise due to the sourcing of materials which may include contaminants and potentially subject to poor quality control at source. The main component in peat-free alternatives are organic (wood bark, compost etc.), which as a biological product will have inherent differences in physical and chemical characteristics from source to source. Substrate mixing may also produce issues, if procedures are not adapted to the characteristics of each new component batch (such as quantities), there may be noticeable differences in the growers crops.

As the importance of homogeneous croppings is so distinct in pot grown horticulture, the measurement and analysis of inequality between pots was assessed using unconventional methods typically applied to economic measurements, but may be adapted for approaching crop development and consequential treatment effect (Gange and Gadhave 2018).

The consideration in this study will be the homogeneity of peat-free alternative substrates and their effect on successful crop production using crop emergence (counts) as a proxy for efficacy.

8.1.1 Growing media Quality

Schmilewski 2008 notes the properties of growing media that influence "quality" (Schmilewski 2008) . One of the potentially overlooked elements of addressing growing media is the "Consitency of Quality". All elements of the table below factor into this consistency (see Table 27). Good consistency would therefore increase crop homogeneity. Establishing a measurement for this factor is therefore imperative for increasing the viability of both Peat and Peat-Free growing medias. Chemical elements such as Phenolic output from bark components may also demonstrate significant impacts on crop growth (Tanase, Cosarcă, and Muntean 2019), a particular concern regarding Peat-Free growing media, Indeed, even container/pot size can have significant impacts (Poorter et al. 2012) on the ability for substrates to effectively support crop growth.

Table 27: A table adapted from Schmilewski 2008 demonstrating important factors for Growing media selection

Structure	Chemical	Biological	Economic
Water Capacity	Nutrient Content and pH	Weed presence	Availability and Price
Air Capacity	Organic matter	Pathogens/pests	Consitency of Quality
Bulk Density	Noxious substances	Microbial Activity	Cultivation Technique
Wettability	Buffering Capacity	Storage Life	Plant requirements

8.2 Substrate characterization: Water retention and irrigation requirements

Water regulation is critical for crops and container plants are more fastidious in their need for consistent maintenance due to their limited water holding capacity. Adapting irrigation systems for specie crops can be complicated further by the use of unconventional substrates such as coir, wood fiber and composts, many of which are being studied by the sector due to heightened concerns regarding environmental impact, performance and potential cost-savings (Fereres, Goldhamer, and Parsons 2003). Several studies have demonstrated the need for modifying established irrigation systems in order to fully capitalize on yields and address a knowledge gap regarding peat-alternate medias (Grant et al. 2009; Knox and Hess 2014). The relative immaturity regarding commercial scale uptake of peat-free media for container grown crops further compounds the necessity in addressing the watering requires and establishing the characteristics of these substrates (Form 2015). This study provides a framework for setting up and establishing irrigation for trial work in container grown crops with mixed growth substrates.

8.2.1 Substrate Characterization: Physical attributes

Several physical attributes were assessed in order to quantify the suitability of Peat-Free growing media as a medium for pot grown herbs.

Adapted and summerised from Bunt 1988:

Bulk density (B_d): ‘The mass of dry material per unit of moist substrate (volume)’; A useful measurement that allows one to observe the level of compaction in a substrate or soil. This in turn gives a good indication of the substrates influence on water and air availability. Both factors have a significant impact on crop health. Shown as mass over volume (E.G : g/cm^3), bulk density ranges in typical growing medias between 0.09-1.5g/cm^3 for peat/mineral composite substrates.

Container capacity/water holding capacity (W_hc): ‘The amount of water left once the substrate has been soaked and allowed to drain off excess water’; Container capacity is highly important when discussing container grown croppings, due to the limited amount of water which can be found in the container, with no ability to naturally replenish this water which is lost through evapotranspiration.

Air porosity (A_p): ‘The volume of air remaining in the substrate post soaking/draining’; Air porosity is often used to establish how effective root growth will be.

Water porosity (W_p): The ability of water to penetrate and be absorbed by the volume of substrate within the container. This can be effected by other physical and chemical attributes. For instance, the periodic drying of substrates can result in a hydrophobic effect, thus reducing the ability for water to penetrate the substrate.

Total pore space (T_ps): The volume of substrate filled with air rather than mineral, organic material or water. This is similar to Air porosity before saturation.

8.3 Methods and Design

Two trials were used for this study. An initial small batch trial of n=140 pots was created with hand mixed batches of Peat-Free growing media (n=3). This trial assessed the homogeneity and rate of crop emergence . The large batch trial consisted of more pots (n=700+) and also consisted of x3 batches. The larger batch trial was performed in a commercial growing environment. Both Trials used untreated control pots.

Growing Environment

The initial small batch trial was performed at the RHUL glasshouse. This was kept at *ca.* 26^oC and 60% RH. Irrigation was performed with drip-stakes, maintaining substrate saturation to *ca.* 70-80%. The commercial growing environment was kept at *ca.* 19^oC minimum and 50-70% RH. Frequential fertigation occurred several times a day, with the aim to keep container capacity at *ca.* 60-80%. The trial conditions were different as the commercial facility is much larger in scale, thereby maintaining specific conditions becomes economically unsustainable, the glasshouse facility is however designed for research and therefor must cater to a wider range of plant types, hence the increased temperature.

Design

Randomized block design was used for both trials, with blind assessment achieved through anonymised labeling. The commercial trial required separation of biological treatments

(AMF) to prevent cross-contamination. This was maintained using a colour coding system.

Treatments

Various treatments were used for these trials, including AMF (Arbuscual Mycorrhizal Fungi) and standard starter fertilizer (NPK).

Homogeneity

The measurement of the gini index is a indication of inequality in a population, usually applied to economical data, most notably a countries GDP. Here this index is applied to the pot data and can be thought of as the value of each treatments homogeneity between pots. Thereby a value between 0 (perfect equality/crop homogeneity) and 1 (complete inequality/no homogeneity) gives a direct scale of the effectiveness for treatments to produce repetitive and consistent croppings; a critical factor in industrialized glasshouse production. This gini index is visualised in the Lorenz curves wherein deviation from the dashed, black line at 45^o represents (0, perfect equality) higher levels of inequality in pot to pot differences, and thereby a reduction in crop homogeneity.

Waterloss

To establish water loss, pots were weighed and then the substrate was wetted to saturation point, surplus water was then allowed to freely drain for 30minutes. Each pot was then weighed, with this repeated every hour for 12hrs, and once again after 24hrs. The weight loss of the container was then established which correlated directly to the amount of water loss (assuming 1ml=1g).

8.4 Substrate Mixing and Quantities

Substrate mixing was performed with a cement mixer running at 23rpm with a capacity of 134L. Materials were measured volumetrically unless stated in componentry table (see Table 28). Materials for each batch were added in an identical order and allowed to mix for 15minutes. Materials were then allowed to settle for 5minutes and then mixed briefly again before potting up.

Table 28: Component table for quantities of product used to create Peat-Free growing media used for this study .* Fertilizer (NPK); nominal application rate (.375g) ** diluted at 1:3 with DW

Component	Amount (ml) per pot	Small Batch (ml)	Large Batch (ml)
Coir	200	2400	48000
Forest Gold	200	2400	48000
Bark Fine	50	600	12000
Loam	50	600	12000
Lime*	0.5	6	120
Urea*	0.25	3	60
Fertilizer *(NPK)	0.375	4.5	90
Wetter	0.4	4.8	96

8.5 Results

8.5.1 Substrate Characterization and Water loss

A perfect negative $R = -1$ linear regression model demonstrates the relationship of Total Pore Space (TPS) and Bulk density with the substrates (see Figure 61). Where in increased bulk density will reduce TPS, and vice-versa. Peat-free substrates had higher bulk density than Peat, suggesting a stronger ability to provide crop support but lower water retention.

This linear regression model demonstrates the relationship between water porosity and water holding capacity of two substrates (Peat and Peat-Free), $R = 1$. Although Bulk density is higher in Peat-Free substrates, water holding capacities appear to be improved and highly consistent in Peat-Free substrates when observing water loss rates over time (see Figure 62).

This modelling of water retention and loss, as determined by decreasing potweight over time (post-saturation), suggests higher water retention in peat-free substrates. This supports the linear regression models. Peat experienced a total loss of 36.23mls over 24hrs while Peat-Free substrate lost 31.1ml over the same period. The average starting weight post-saturation was 285g for both Peat and Peat-Free pots.

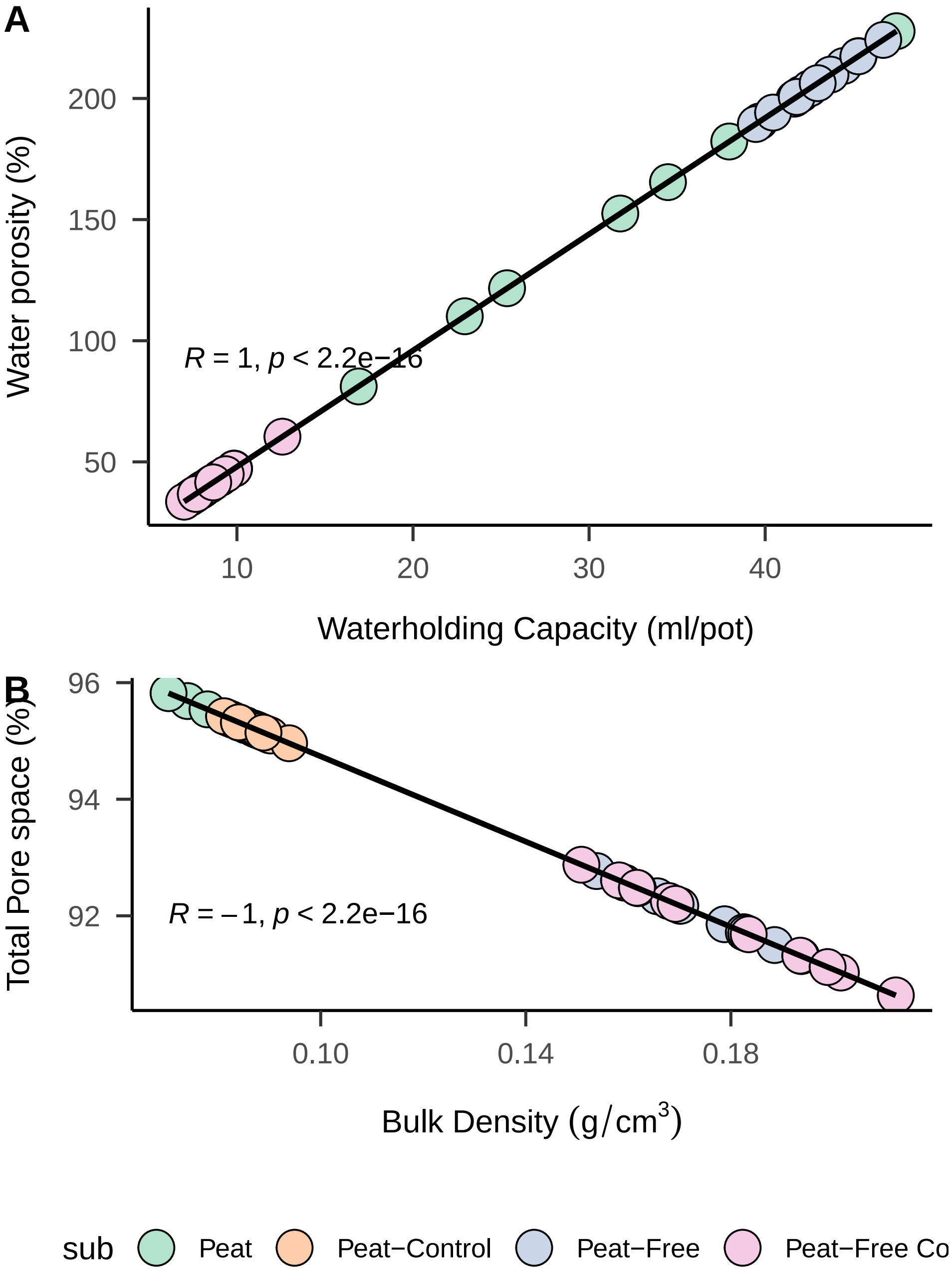

Figure 61: Both substrates demonstrated a perfect correlation between the various physical charectersitics assessed.The regression value of 1/-1 of both Peat and Peat-Free substrates plotted against the same parameters shows the strong potential of Peat-Free substrates to act as a suffcient substrate choice.

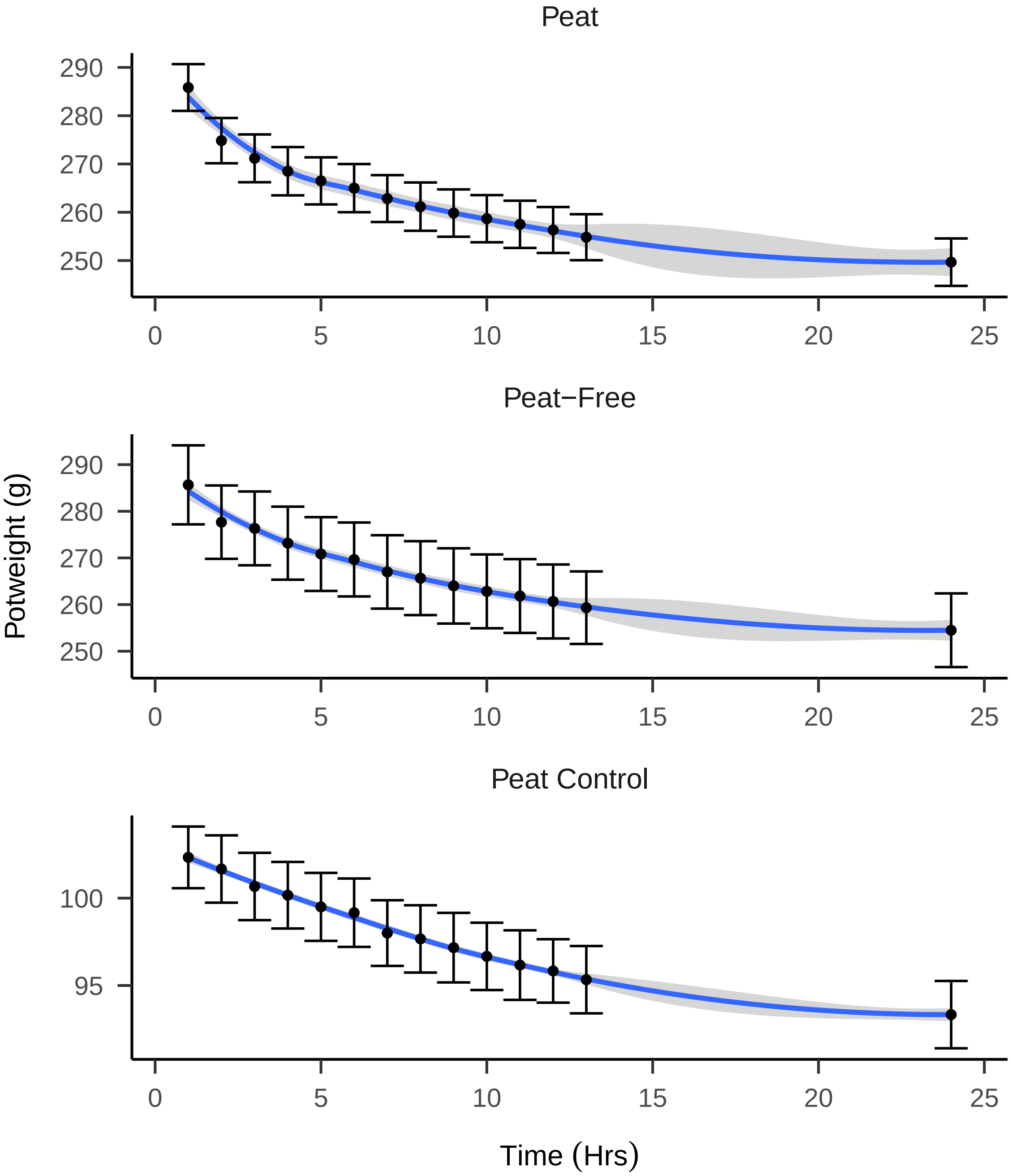

Figure 62: Waterloss over 24hours from saturated (container capacity) substrates. Measurements taken every hour for 12 hours, and a final measurement at 24hours. Peat Control was used as a control (non-saturated) for both substrate types.

Table 29: Summerised water loss over 24hours

Substrate	Water loss (ml)
Peat Control	9
Peat	36.2
Peat-Free	31.2

8.6 Crop Emergence

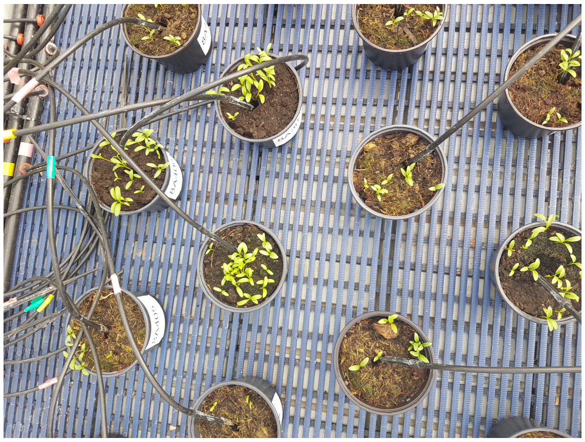

Figure 63: Random sample of emergence differences in Coriander croppings. In this example, a clear difference in emergence rates (crop count) can be seen between Peat and peat-free substrates. This maybe subject to treatment, batch of peat-free material or abiotic factors such as water rates. This issue of crop homogenity was further investigated utlising the Gini index.

Crop emergence was measured as ‘Counts per pot’. A clear reduction in efficacy from Batch C from the small batch trial regarding crop emergence can be seen in Figure 64.

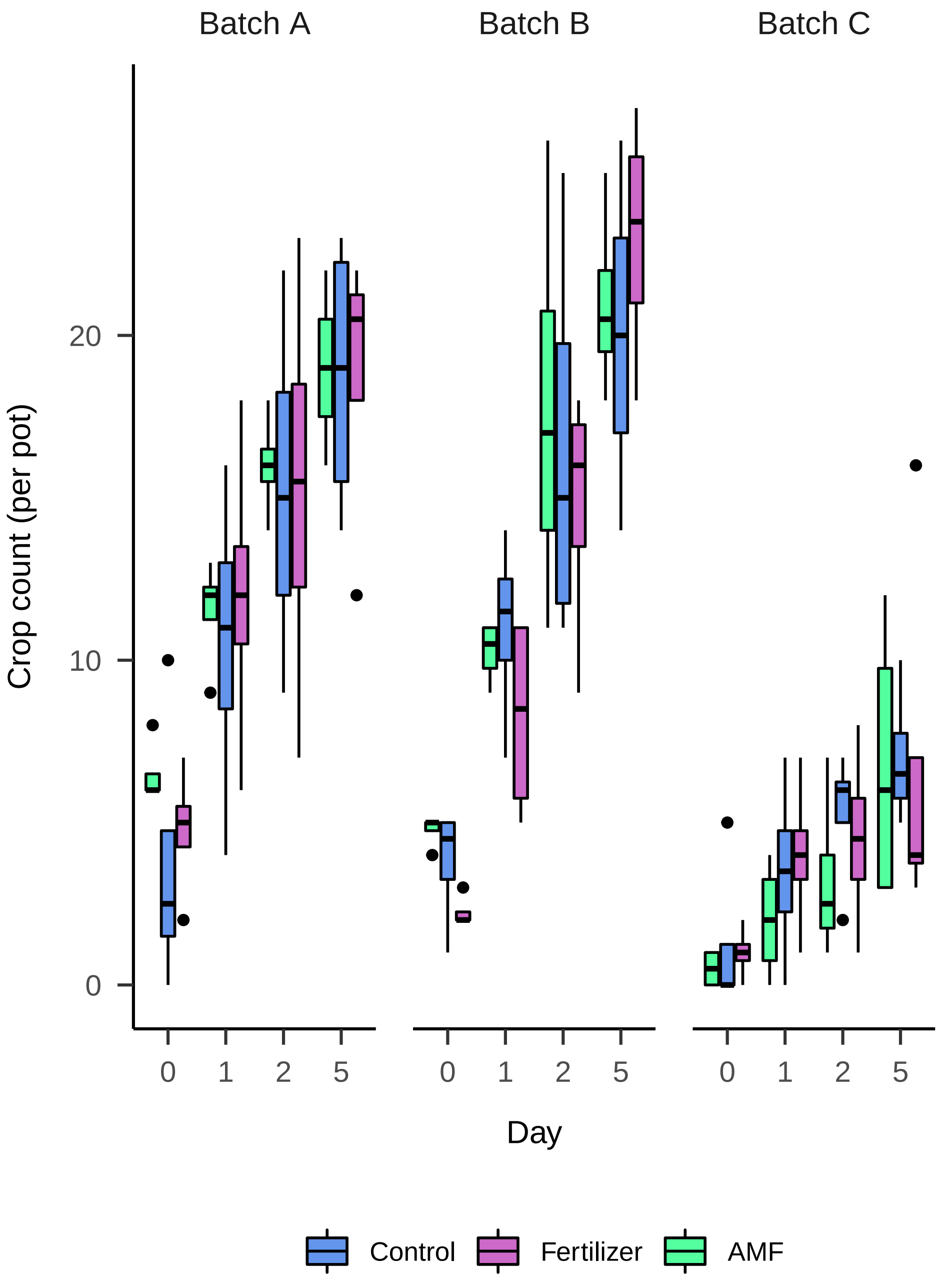

Figure 64: Small batch trial crop emergence over time. This data demonstrates the emergence rates (crop count per pot) of various amendments (AMF, Fertilizer) within 3 different batches of peat-free substrate. Both batch A and B perform well and in a positive upwards trend. However batch C appears to plateau without much upwards moment. This suggests there is a difference between batches which effects crop quality.

At each assessment interval over the emergence period, an analysis of variance demonstrated significant ($p < 0.05$) differences between batches, most notably for batch “C” with a mean crop count per pot of 6.8 at E+5d against batches “B” and “A” of 21.3 and 18.8, respectively .

Table 30: Small Batch Emergence count

Batch	Day	Control	sd	Fertilizer	sd	AMF	sd
A	0	3.75	4.35	4.75	2.06	6.50	1.00
-	1	10.50	5.00	12.00	4.90	11.50	1.73
-	2	15.25	5.56	15.25	6.65	16.00	1.63
-	5	18.75	4.43	18.75	4.57	19.00	2.58
B	0	3.75	1.89	2.25	0.50	4.75	0.50
-	1	11.00	2.94	8.25	3.20	10.25	0.96
-	2	16.50	6.45	14.75	4.03	17.75	6.40
-	5	20.00	5.16	23.00	3.92	21.00	2.94
C	0	1.25	2.50	1.00	0.82	0.50	0.58
-	1	3.50	2.89	4.00	2.45	2.00	1.83
-	2	5.25	2.22	4.50	2.89	3.25	2.63
-	5	7.00	2.16	6.75	6.18	6.75	4.50

This stark contrast between batches is not as severe within batches when observing treatments effects ($p > 0.05$), with only batch “B” at day 0 (emergence) showing a significant difference between treatments (F val. 4.53, p *0.41*) with fertilizer at 2.25, AMF at 4.75 and Control pots at 3.75 mean crop count per pot (see Table 30).

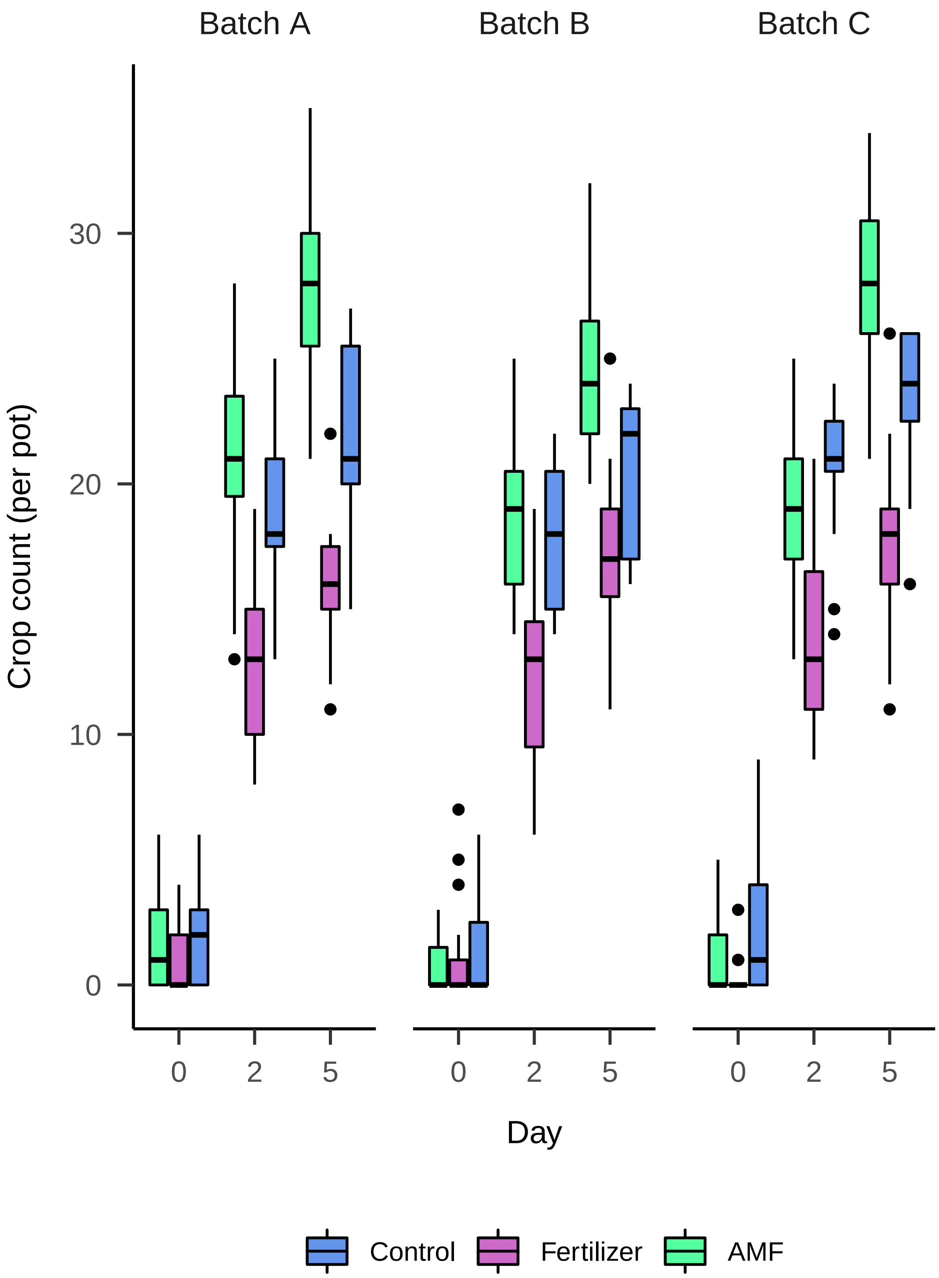

Figure 65: Large batch trial crop emergence over time. Batch differences and treatments demonstrated significant differences, most notably with batch B at a lower mean overall crop count per pot. However, these differences are not as apparent as those shown in Figure 64

Differences for the large batch trial were not statistically significant at batch level ($p\ 0.53$). At a day level the differences between treatment effects were significant ($p < 0.05$), with a demonstrable difference in the mean crop counts of each treatment for every assessment interval. AMF treatments achieved the highest overall crop counts at the end of assessment

Table 31: Large Batch Emergence

	Days	Control	sd	Fertilizer	sd	AMF	sd
A	0	2.00	1.77	0.93	1.33	1.60	1.99
-	2	18.93	3.35	12.73	3.15	20.93	4.10
-	5	21.93	3.75	16.00	2.70	28.00	4.02
B	0	1.33	1.88	1.20	2.27	0.73	1.03
-	2	18.07	2.94	12.53	3.60	18.33	3.22
-	5	20.40	3.07	17.13	3.40	24.67	3.37
C	0	2.40	2.90	0.33	0.82	1.27	1.75
-	2	20.67	2.94	13.67	3.77	18.80	3.86
-	5	23.27	2.99	17.53	3.68	28.00	3.42

period (E+5d, $p < 0.001$), however the control pots performed well, achieving higher mean counts on some assessment dates, most notably at E0d and E+2d (see Table 31). This difference was not significant for these days (ANOVA: emergence ~ day by treatment).

8.7 Crop homogeneity

A gini index and Lorenz curve of each treatment was created from the crop count data taken over a 5 day period from emergence. Each treatment for each batch can be seen as a value on the Lorenz curves. The more divergent a result from the 45 degree dashed line, the higher the inequality of that data and therefore reduced uniformity in substrate/treatment performance.

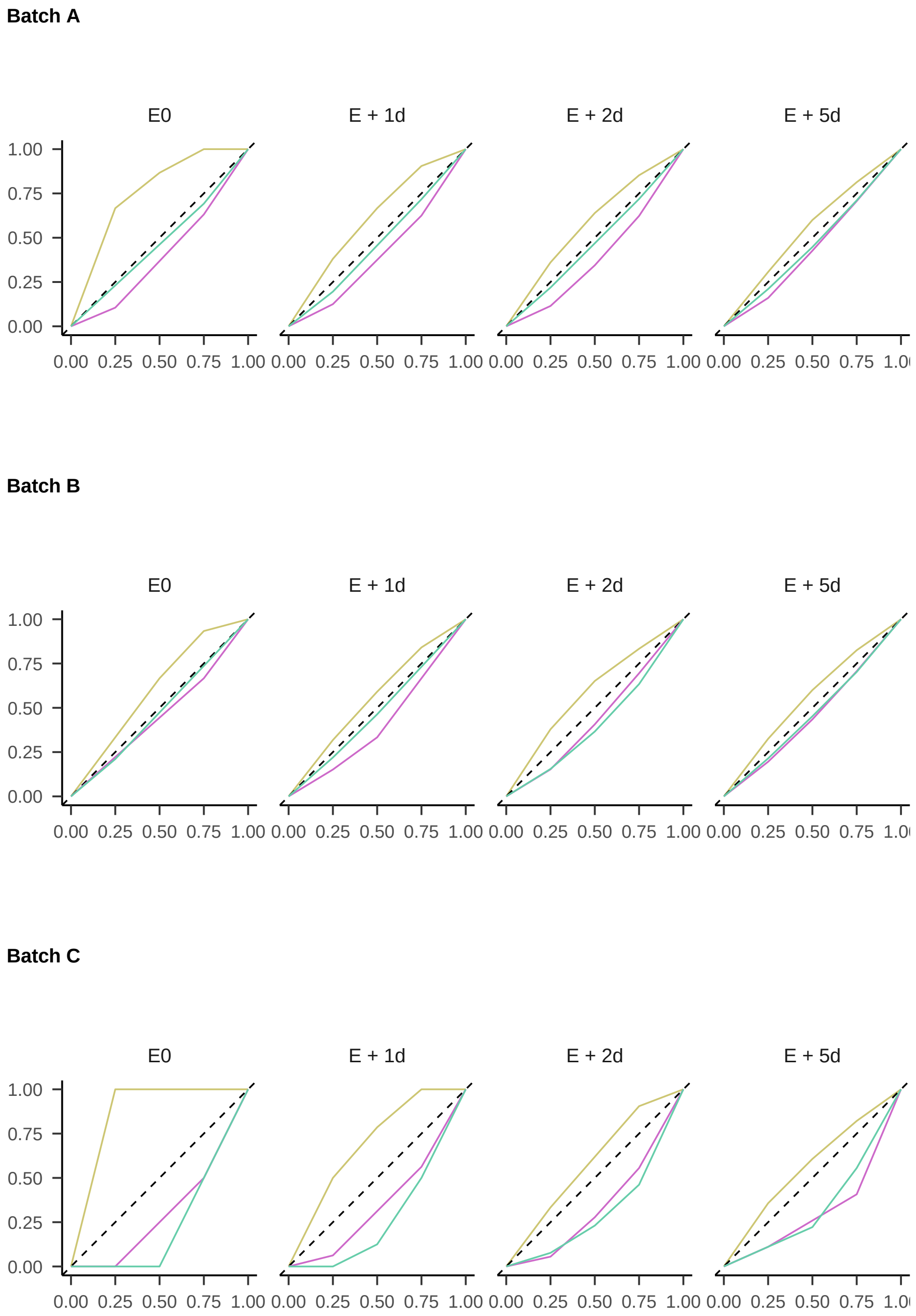

Figure 66: Small Batch trial Lorenz Curves. Control = purple, Fertilizer = yellow, AMF = Green. The initial emergence date (E0) has a low crop count, with some pots measuring 0 counts. This accounts for the broad data range as indicated by the high levels of inequality, clearly demonstrated in Batch C E0 for each treatment type. Following E0, E+1d to E+5d demonstrate increasing levels of equality within the crop count distribution as shown by the treatment curves getting increasingly closer to the 45 degree dashed line (representative of perfect equality in the distribution). However, Batch C remains relatively highly inequal regarding crop counts. This supports the data shown in Figure 64.

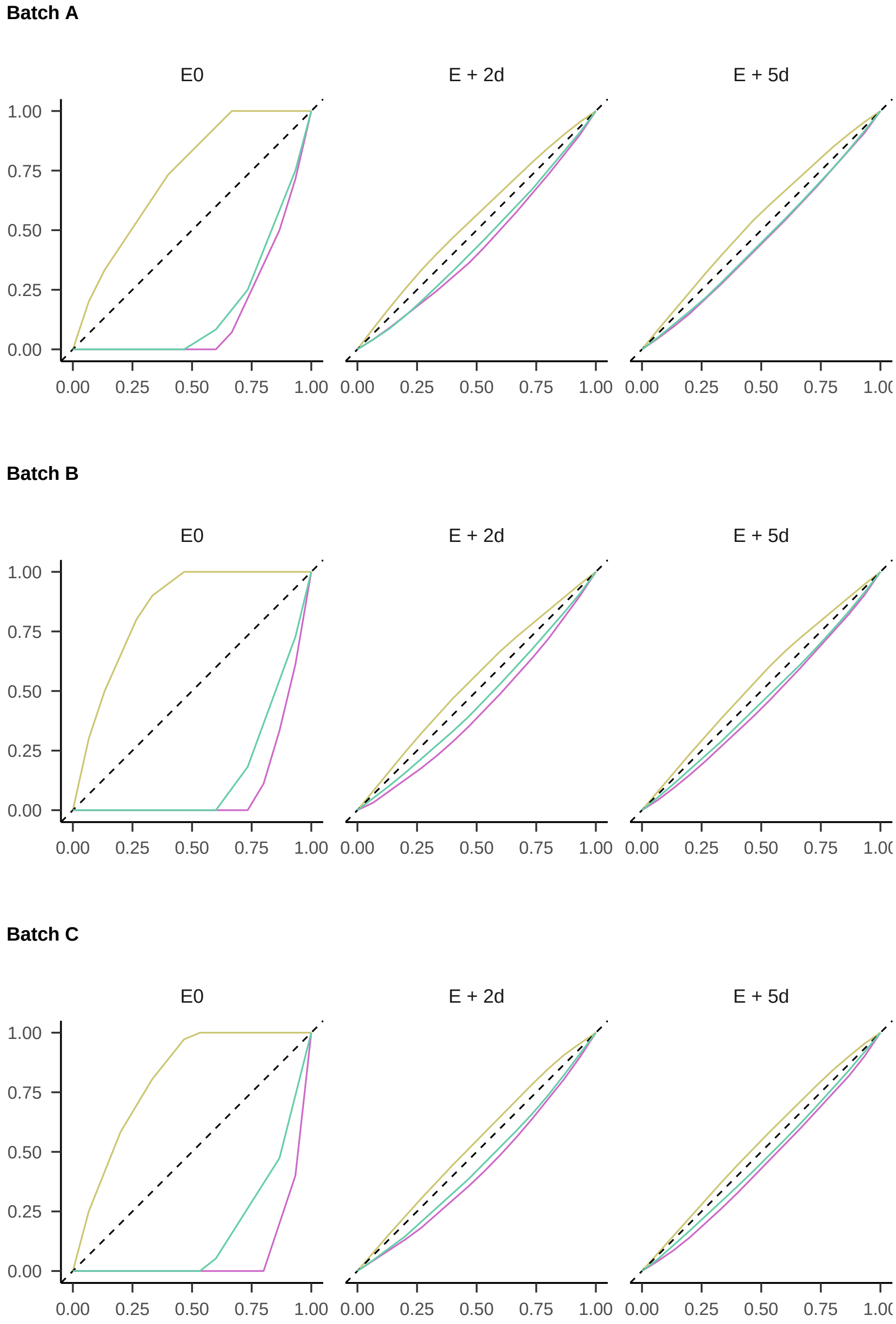

Figure 67: Large Batch trial differences, Control = purple, Fertilizer = yellow, AMF = Green. Similar to Figure 66, E0 (first crop emergence) is shown as unequal in its distrubution for each batch. However, homogenity (read: equality) in the data increases after the following two assessments (E+2d and E+5d) across each of the batches, unlike Batch C in Figure **??**. These results may suggest an error during substrate mixing for the small batch trial, which effected crop emergence negatively.

Table 32: Small batch Gini inequality results

Batch	Days	Control	Fertilizer	AMF
A	0	0.516667	0.197368	0.057692
-	1	0.226191	0.1875	0.065217
-	2	0.17623	0.209016	0.046875
-	5	0.11	0.103333	0.06579
B	0	0.216667	0.083333	0.039474
-	1	0.125	0.174242	0.042683
-	2	0.181818	0.122881	0.172535
-	5	0.125	0.081522	0.065476
C	0	0.75	0.375	0.5
-	1	0.392857	0.28125	0.4375
-	2	0.178571	0.305556	0.365385
-	5	0.142857	0.361111	0.305556

Table 33: Large Batch Gini inequality results

Batch	Days	Control	Fertilizer	AMF
A	0	0.462222	0.685714	0.627778
-	2	0.094366	0.13473	0.104459
-	5	0.092806	0.087778	0.07746
B	0	0.68	0.792593	0.678788
-	2	0.088561	0.157447	0.095515
-	5	0.08061	0.104799	0.072072
C	0	0.614815	0.853333	0.659649
-	2	0.071398	0.150894	0.111111
-	5	0.065712	0.107985	0.066032

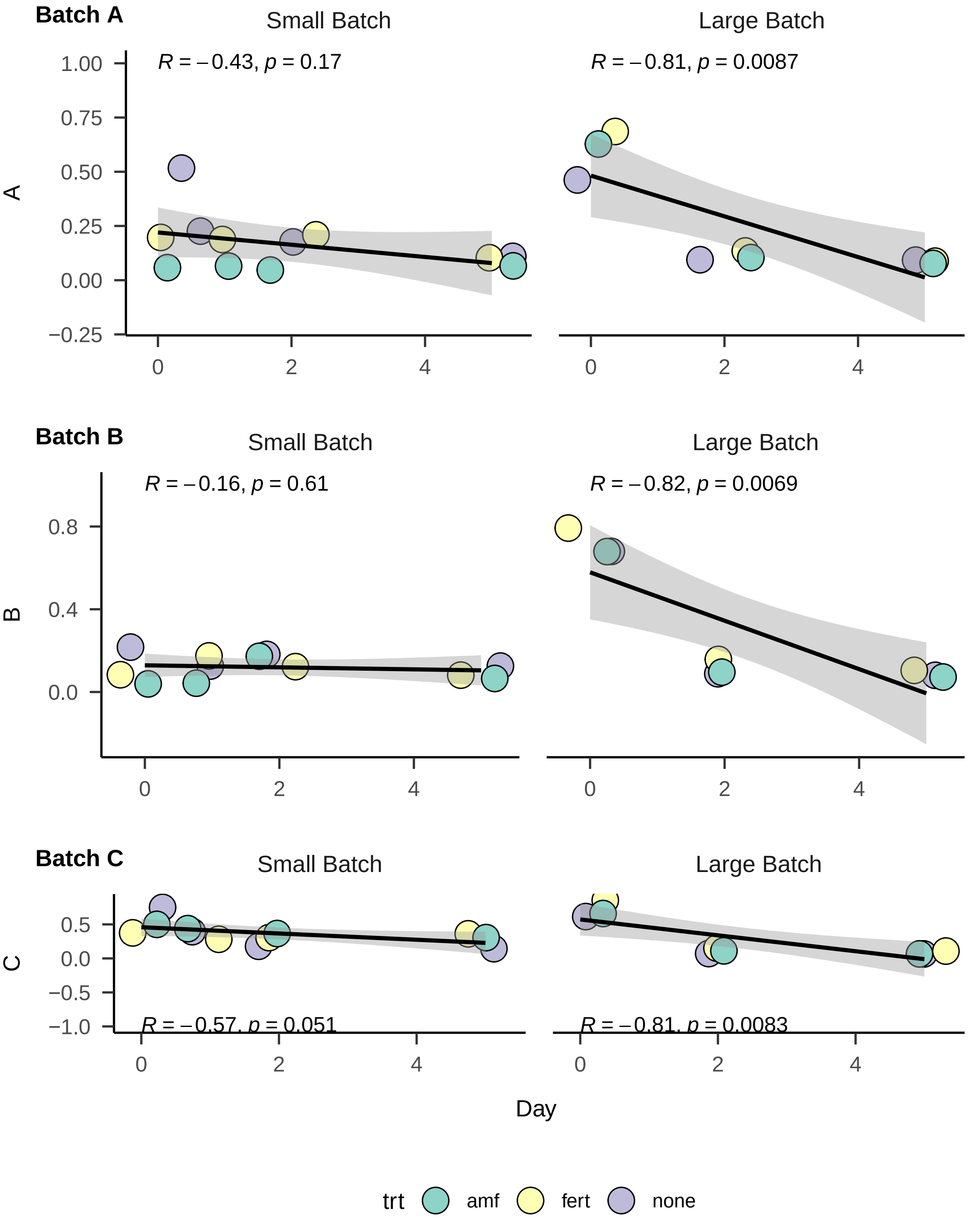

Figure 68: Linear model of Gini results. Diminishing R values can be interpreted as falling inequality (i.e. becoming more homogenous). The small batch and large batch trials demonstrate significant differences. Decreasing inequality in the Large batch trial data suggests increasing crop count homogenitiy between pots, whereas the Small batch trial data demonstrates a significantly lower decrease of inequality over time.

The mean total gini values for each batch and treatment demonstrate a significant difference (*p <0.05*) between overall trial means. In order to aide visualisation, a linear model demonstrating the inverse relationship between diminishing inequality and days of emergence presents an easily digestible format for interpretation of Batch, treatment and trial homogeneity.

For total inequality, Large batch trial data demonstrates a largely uniform pattern of crop emergence when ($R = -0.81, 0.82$) addressing gini means for each treatment (see Table 33). Small batch trial (see Table 32) shows a significant discrepancy between Batch inequality regarding regression assessment (*p <-0.01*).

For the large batch trial, increased inequality can be seen in Fertilizer treatments for each Batch. These values are significantly lower in AMF and Control pots when taken as a mean value across each batch. However, this pattern is not repeated in the Small batch trial due to the inconsistency of Batch results.

Table 34: Combined mean gini values for each batch sorted by Trial and treatment

	Small Trial	Large Trial
Batch	Control	Control
A	0.257272	0.216465
B	0.162121	0.283057
C	0.366071	0.250642
	Fertilizer	Fertilizer
A	0.174304	0.302741
B	0.115495	0.351613
C	0.330729	0.370737
	AMF	AMF
A	0.058894	0.269899
B	0.080042	0.282125
C	0.40211	0.278931

8.8 Discussion

Two trials were assessed for inequality using crop emergence data (gini). This value can be transcribed as a value of crop uniformity. Treatment type and substrate batch were assessed between two trials of differing formats.

The discrepancies demonstrated in crop emergence across each batch and treatment are acutely more visible between batches than treatments for Batch C significant reduction in both mean crop count and high inequality compared to Batches A and B demonstrate serious concern for small batch production. Reasons for this lack of substrate homogeneity occurring may be addressed to significant physical or chemical changes in the materials, such as particle size of each ingredient changing as the resource is used up, residual components being present on potting equipment or user error.

Reduction in crop inequality at 5 days after emergence is most visible in pots inoculated with mycorrhiza in Batches A and B, followed by starter fertilizer. The highest levels of crop inequality for Batches A and B was the control pots. This supports the potential of AMF to increase crop homogeneity.

The descriptiveness between each trial may be a result of batch size effecting crop emergence. Decreased mixing quantities may have resulted in higher error for substrate homogeneity due to decreased resource variability.Differences between Trial results may have also been the result of different growing conditions, with the Large Batch Trial experiencing consistent fertigation, unlike the small batch trial.

Significant efforts must be made in directing and controlling substrate homogeneity when considering industrialized potted herb production whilst also addressing the potential of mychorriza to increase crop homogeneity and seed germination rates in peat-free substrates for potted herb production.