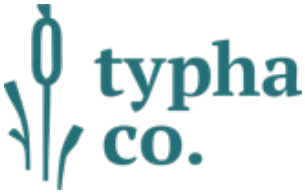
Final Design Report

Typha Growing Media



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Executive Summary

The indoor floricultural industry faces increasing pressure to reduce its reliance on current unsustainable resources, such as peat and coco coir, for use in soilless potting mixes. Typha, commonly known as cattails, may represent a more sustainable alternative for the cultivation of ornamental plants and flowers. Its suitability is further justified by the local availability, quick grow time, and harvesting benefits of these wetland plants in Manitoba.

Three distinct growing media have been designed by subjecting existing shredded Typha plants to specific combinations of three processing methods. These methods have individually been shown to mitigate the challenges with previously tested Typha-based media, as cited in literature, such as a low water holding capacity and high nitrogen immobilization. The benefits of each are as follows:

- Composting, to increase the available nitrogen for plant uptake,
- Milling, to reduce the particle size, and
- Pasteurizing, to eliminate pathogens.

The proposed Typha Media Designs incorporate these processing methods to investigate their unique benefits. The three Media Designs are as follows:

1. Media Design 1 (MD1): [redacted]
2. Media Design 2 (MD2): [redacted]
3. Media Design 3 (MD3): [redacted]

Verification of the success of each Media Design was assessed by 11 passing criteria, or technical specifications, selected based on the properties of peat and other commonly used growing media. None of the three Media Designs passed all criteria; however, [redacted] showed the greatest overall improvement when compared to unprocessed, shredded Typha. Alongside the verification testing, germination and grow trials were performed to further validate the results, utilizing a peat-perlite mix as the control. In the germination trials, media containing [redacted] performed best with higher numbers of germinated plants. Varying trends were observed in the grow trials. The trial conducted in a vertical hydroponic wall, which accommodated the media in net cups with a diameter of two inches, exhibited the best results in [redacted], while the other, conducted in a greenhouse, displayed better outcomes in [redacted].

Moving forward, further research into composted Typha-based media is recommended, including testing growth in larger commercial plant pots, [redacted] an assessment of a flower's full growth cycle solely in Typha-based media, and a full project cost-benefit analysis to ensure economic viability. The results from technical specification testing, germination trials, and grow trials show that, while this Typha-based media does not entirely replicate peat, it may be a viable option for use as a soilless growing media. Testing based on the proposed recommendations will further the success of this media as it nears entry into the market as a local and sustainable growing media for floriculture growers.

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Air Filled Porosity:	The portion of total porosity that is filled with air. Units: %
Bulk Density:	The dry mass per unit volume. Units: g/cm^3
Carbon-to-Nitrogen Ratio (C:N):	The amount of carbon relative to the amount of nitrogen. Given as a ratio.
Cation Exchange Capacity (CEC):	The ability to capture and retain positively charged ions (i.e. cations) that are available to be exchanged with the plant as nutrients. Units: meq/100g
Electrical Conductivity (EC):	The ability to carry an electrical charge. Units: mS/cm
Nitrogen Immobilization:	The depletion of inorganic nitrogen (e.g., nitrate, NO_3^-, or ammonium, NH_4^+), essential for plant growth, due to the increased conversion into organic nitrogen (N_2) by microorganisms present in the media.
Particle Size Distribution:	The discrete ranges of particle diameter. Units: mm
pH:	The acidity or alkalinity of solution on a logarithmic scale.
Phytotoxicity:	The potential of the present substances to negatively impact plant growth (Gorsuch et al. 1990).
Stability:	The tendency for a media to undergo decomposition. Units: mg CO_2 /g VS/ day
Total Porosity:	The amount of open space or voids within a media. Units: %
Water Holding Capacity (WHC):	The maximum amount of water that can be held by the media against the force of gravity (Smith 2013). Can also be referred to as water filled porosity and container capacity. Units: %

1 Introduction

Modern greenhouses are increasingly replacing soils with soil alternatives, also known as soilless media, which primarily include peat and other substances such as coco coir, perlite, vermiculite, pumice, expanded clay, and composted plant waste (Raviv et al. 2019). Soilless media is often selected for use in conjunction with hydroponic systems over traditional soil agriculture to prevent pathogens, increase yield, reduce costs, produce earlier harvests, and increase nutrient and water use efficiency (Savvas and Gruda 2018; Barrett et al. 2016). There has been a recent push to reduce reliance on peat as a growing media as its extraction releases stable and previously hidden carbon into the active carbon cycle, which contributes to the greenhouse gas effect (Barrett et al. 2016; Hartung and Meinken 2021). Currently, sustainable alternatives are in use such as coco coir; however, this media requires energy-intensive processing and lengthy transportation (Barrett et al. 2016).

1.1 Purpose

To displace dependence on these unsustainable sources, Typha Co. is seeking to design a soilless growing media sourced from cattails (scientific name: Typha spp.), shown in Figure 1, which improves upon the current challenges identified in the literature, such as low water holding capacity and high nitrogen immobilization (Leiber-Sauheitl et al. 2021; Hartung and Meinken 2021).

Figure 1. Cattails (Typha spp.) (Sliwoski 2018)

The harvesting and up-cycling of these wetland plants also represent an efficient solution for capturing excess nutrients that have resulted in reduced water quality in Lake Winnipeg. Typha Co.'s objective is to introduce their product for use in the floriculture industry as there are fewer quality parameters of the product compared to fruit and vegetable cultivation, making floriculture growers more likely to consider utilizing novel growing media.

1.2 Problem Statement

Given the adverse ecological consequences associated with the current widespread use of non-renewable soilless growing media, Typha Co. seeks to develop a locally sourced and sustainable

alternative composed of primarily cattails (Typha spp.) that will support the growth of flowers from seed to sale-ready maturity in an indoor commercial setting.

1.3 Background

A detailed overview of the key aspects related to the development of a Typha-based media is delineated below. Existing knowledge of soilless media and its use in hydroponic systems for floriculture provides the framework for this project initiated by Typha Co.

Based in Winnipeg, Manitoba, Typha Co. develops horticultural products derived from Typha. The up-cycling of this locally harvested, biodegradable, and nutrient-rich biomass may resolve the current widespread use of unsustainable soilless growing media, such as peat and coco coir. Furthermore, Typha plants are known to efficiently capture phosphorus and nitrogen for assimilation into their own biomass, acting as a natural filter to capture these nutrients before they enter and disrupt water bodies (Dohan et al. 2012), such as Lake Winnipeg.

1.3.1 Protection of Lake Winnipeg

In 2013, Lake Winnipeg was named the most threatened lake of the year by the Global Nature Fund. It is the tenth largest freshwater lake in the world and receives all uncontrolled urban, industrial, and agricultural runoff from four provinces and four U.S. states. This runoff contains excess phosphorus and nitrogen which trigger algal blooms. These blooms threaten public health and disrupt recreational and commercial activities. They also contribute to the formation of dead zones that suffocate fish and other aquatic species, decreasing the overall biodiversity of the aquatic ecosystem.

1.3.2 Harvesting and Nutrient Uptake by Typha (spp.)

To mitigate algal blooms, Typha can be strategically harvested at key influent locations upstream of Lake Winnipeg. Such a location is Grant's Lake, an engineered wetland located in the Rural Municipality of Rosser, Manitoba, where the Typha plants used for this project were harvested as part of a pilot study in October 2021. Approximately 0.9 hectares of the total 250-hectare area was harvested; the potential for an increased harvesting area would require prior scouting for the accessibility of harvesting and baling equipment (Venema and Murray 2022).

Tests on these samples revealed that 0.03% to 0.06% of the biomass (by dry weight) represented the amount of phosphorus captured, while 0.26% to 0.55% represented the nitrogen content captured. Similar studies in Manitoba have shown phosphorus and nitrogen captures as high as 0.13% and 0.99% (Grosshans and Grieger 2013), where it was noted that maximum nutrient removal from the ecosystem is achieved if harvesting occurs in the late summer. Entering the fall season, the nutrients are translocated from the above ground components back down to their underground rhizomes and will not be removed with the harvesting of the biomass.

1.3.3 Existing Studies on the Viability of Typha as a Substitute for Peat

Due to the benefits provided from the proper harvesting of the nutrient rich Typha biomass, many studies have utilized Typha in soilless growing media. These design experiments have included Typha as a shredded material after a given period of curing, subsequent to harvesting. The partial replacement of peat with Typha in the greenhouse cultivation of lettuce revealed that the potting mixtures with the highest proportions of Typha were comparable to the control treatment (a peat and perlite mix) in terms of height, spread, and number of leaves per plant (Singh 2022). These Typha-peat blends were also noted to hold water more efficiently and required relatively less irrigation cycles than the control. However, these same potting mixtures established the least root densification, which is consistent with the higher electrical conductivity values obtained from the 30% and 40% Typha blends that revealed low nutrient uptake in these plants.

Other challenges with the shredded material were revealed to be a low water holding capacity and a high nitrogen immobilization in a study that evaluated alder, cattail, reed, and composted heather as potential peat substitutes (Leiber-Sauheitl et al. 2021). These challenges must be addressed in the design of a 100% Typha-based media as results showed that seedling germination rates were decreased, which would be deemed unsatisfactory in the for-profit floriculture market. The study attributed the low water holding capacity to its limited particle size distribution when compared to that of peat, where the Typha samples possessed larger pore spaces that allowed water to easily drain.

To address the high nitrogen immobilization, the composting process was demonstrated to be suitable in stabilizing nitrogen dynamics in three fen plant materials, including Typha (Hartung and Meinken 2021). Nitrogen content was found to stabilize after 22 days of composting. Composting also removed phytotoxic substances that would inhibit plant growth.

These studies provide valuable information on feasibility and current issues. Addressing these issues, and considering their mitigation strategies, form the main objective of the project in designing a peat replacement in soilless media growing systems.

1.3.4 Hydroponics

The production of a local and sustainable soilless media, which also meets all the necessary functional requirements, is one of the current major challenges of modern hydroponic cultivation (Atzori et al. 2021). Hydroponics refers to the method of plant cultivation, without the use of traditional soils, in which nutrients are supplied directly to the plant via a nutrient solution (Raviv et al. 2019). The specific growing method of interest is a hydroponic system in which a soilless growing media or substrate is used in place of soil. The process of soil formation, in which organic matter from plants and animals is introduced to a weathered rock base material, can take up to hundreds of years (Daily 1997) to produce a nutrient-rich topsoil which makes this media, essentially, a non-renewable resource.

Hydroponic systems with soilless media provide better root aeration than deep water systems, where roots are submerged in aerated water, and provide a reserve of water and nutrients for the plant in the case of equipment failure (Fussy and Papenbrock 2022). This method of cultivation has been shown to increase productivity, improve product quality, prevent pollution, increase water use efficiency, reduce pesticide use, decrease grow time, allow for cultivation in non-arable land (Fussy and Papenbrock 2022; Raviv et al. 2019; Atzori et al. 2021), and allow for production planning, which is of great importance in the floriculture industry (Di Lorenzo et al. 2013).

1.3.5 Floriculture

The floriculture market, which is the intended target of the soilless media designs, refers to the cultivation of flowering and non-flowering live potted plants, as well as greenhouse and field-cut flowers (Crops and Horticulture Division Agriculture and Agri-Food Canada 2021), for consumer use. A new media may be more accepted by floriculture growers as fewer quality parameters must be met compared to fruit and vegetable production, allowing growers to fine-tune their practices while still producing a marketable product. Fruits and vegetables must meet many specific parameters concerning appearance, texture, flavour, and nutritive value to be sold (Kader 2002). In contrast, flowers are generally only required to meet visual appearance requirements, such as the number of open flowers, flower size, leaf colouring, and plant height (Gallegos-Cedillo et al. 2021). Additionally, the ornamental and floriculture industry are expected to experience a total market growth of 490% between 2020 and 2050 (Blok et al. 2021). This market increase will encourage the introduction of novel growing media into the floriculture industry as demand increases. For these reasons, flowers are grown for the validation of these media designs which allow results to be directly applicable to floriculture growers.

1.4 Target Specifications

A list of technical specifications associated with successful soilless growing media were identified to verify the performance of the media designs, and is as follows: water holding capacity (WHC), nitrogen immobilization, electrical conductivity (EC), pH, stability, bulk density, total porosity, air-filled porosity, carbon-to-nitrogen ratio (C:N), cation exchange capacity (CEC), phytotoxicity, and particle size distribution (Raviv et al. 2019; Caron and Zheng 2021; Noguera et al. 2003). The testing procedures for each technical specification are detailed in Section 3 and Appendix A of this report. The following subsections define each of the technical specifications in their appropriate context.

1.4.1 Water Holding Capacity (WHC)

The water holding capacity (S1.1) is the maximum amount of water held in the growing media against the force of gravity (Smith 2013). It is the percentage of the total porosity that is filled with water after saturation and drainage. WHC is an overall indicator of the growing media's capacity to retain moisture and provide water to the plant. Plants have varying water uptake rates; therefore, the ideal range for WHC varies depending on the target plants to be grown (Zhang et al. 2021).

Note: water holding capacity can also be referred to as water-filled porosity and container capacity. This report exclusively uses water holding capacity and its acronym, WHC, to refer to this parameter.

1.4.2 Nitrogen Immobilization

Nitrogen immobilization (S1.2) occurs when plant-available forms of nitrogen needed for growth are instead taken up by the microbial community present in the growing media. This occurs when the C:N ratio of the media is high (Biswas and Micallef 2019). High nitrogen immobilization is indicated by a nitrogen drawdown index (NDI) close to 0 (Handreck 1992). Conversely, an NDI close to or equal to 1 is most ideal as it represents little to no loss of nitrogen accessible for growth.

1.4.3 Electrical Conductivity (EC)

The electrical conductivity (S2.1) of growing media indicates the salinity of the media, as the EC and salinity are linearly proportional (Raviv et al. 2019; Both et al. 2021). The EC also indicates the amount of nutrients available to the plant for absorption as the salinity affects the delivery of nutrients to the plant (Both et al. 2021). An EC which is above the threshold range will result in reduced crop yield; however, since each plant has a unique tolerance, there is no one ideal range (Santamaría et al. 2022).

1.4.4 pH

The pH (S2.2) of growing media affects the availability of nutrients by changing the form of the nutrient in the media (Cornell University 2023). This could result in specific nutrient deficiencies in the plant even when nutrient levels in the growing media are deemed sufficient based on the overall EC value (Raviv et al. 2019; Landis et al. 2014).

1.4.5 Stability

A stable (S2.3) media is one that undergoes minimal decomposition and is characterized by a low respiration rate due to low microbial activity (Raviv et al. 2019). Conversely, highly unstable media undergoes rapid decomposition, resulting in the consumption of nutrients required for the plant, the intake of oxygen (O_2), the release of carbon dioxide (CO_2) and heat (Gómez et al. 2006), and an anaerobic root environment (García et al. 1992, as cited in Paradelo et al. 2010).

1.4.6 Bulk Density

The importance of bulk density (S2.4) is better understood through its effects on root stability, root penetration and the ease of water, nutrient, and oxygen movement in the media (Raviv et al. 2019). For softer, loose materials, the bulk density can be estimated to provide a general understanding of the suitability which can vary from crop to crop.

1.4.7 Total Porosity

Total porosity (S2.5) is the total pore space of the growing media. Total porosity influences the distribution of bacterial and fungal communities, respiration, water holding capacity and is the best indicator of media structure quality (Yang et al. 2019).

1.4.8 Air-Filled Porosity

Air-filled porosity (S2.7) is the percentage of total porosity that is filled with air after the growing media has been saturated with water and just after the media has stopped draining due to gravitational forces. Air-filled porosity and watering holding capacity make up total porosity, and as a result, they are highly dependent on each other (Dobbie and Smith 2003).

1.4.9 Carbon-to-Nitrogen Ratio (C:N)

A high C:N ratio (S2.7) can indicate the risk of nitrogen immobilization in the growing media. An ideal range of 20-35:1 (Biswas and Micallef 2019) provides a desired equilibrium state. A C:N ratio well below this range will result in rapid mineralization, in which a surplus of inorganic nitrogen may easily be leached out with watering before uptake by the plant. A ratio above this range results in nitrogen immobilization as the microbial community utilizes the high carbon content for decomposition, a process that requires the conversion of the already limited inorganic nitrogen into the plant-inaccessible organic form.

1.4.10 Cation Exchange Capacity (CEC)

A high CEC (S2.8) value indicates that the media has a high capacity for cationic storage. These cations, or positively charged ions, are nutrients essential for plant growth, such as calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), and potassium (K^{+}). If the media possesses a low CEC, a nutrient solution must be applied in conjunction with watering cycles to meet sufficient plant requirements (Raviv et al. 2019).

1.4.11 Phytotoxicity

Phytotoxicity (S2.9) of a media refers to the presence of any soluble compounds, or phytotoxins, which inhibit plant growth (Raviv et al. 2019). Phytotoxicity can be assessed, via a seed germination test (Barral and Paradelo 2011), by the Germination Index (GI) which uses relative seed germination and relative root growth as metrics. Using this index, values above 50% indicate moderate phytotoxicity and above 80% indicate low phytotoxicity (Emino and Warman 2004; Zucconi et al. 1981).

1.4.12 Passing Criteria for Technical Specifications

Upon reviewing the influence of all 11 technical specifications, WHC (S1.1) and nitrogen immobilization (S1.2) have been identified as explicit issues associated with the utilization of Typha as a growing media and is the focus of the design solutions. These have been termed "primary technical specifications" and are provided in Table 1 with the required criteria for the

verification of success. Passing criteria is based on benchmarks sourced in literature for commonly used growing media.

Table 1. Passing criteria for primary technical specifications based on benchmarks found in literature

Spec	Description	Passing Criteria	Benchmark 1	Benchmark 2	Benchmark 3
S1.1	**Water Holding Capacity**	62-90%	50-65% (Evans 2011)	70-90% (Raviv et al. 2019)	65-80% (Sun Gro 2024)
S1.2	**Nitrogen Immobilization**	NDI > 0.79	Peat: 0.89 (Dombrowsky 2012)	Coco coir: 0.79 (Arenas et al. 2002)	-

The remaining nine technical specifications have been isolated as less critical to meet but should still ideally fall within the identified range. Due to the interrelationships between these soil properties, the expectation would be that, in targeting the success of the water holding capacity and nitrogen immobilization, the media designs would also accomplish many of the other specifications. These technical specifications are termed "secondary" and are listed in Table 2 along with the required criteria, also based on benchmarks for successful soilless growing media sourced from literature.

Table 2. Passing criteria for secondary technical specifications based on benchmarks found in literature

Spec	Description	Passing Criteria	Benchmark 1	Benchmark 2	Benchmark 3
S2.1	**Electrical Conductivity**	0.7-3.5 mS/cm	0.7-3.5 mS/cm (A&L Canada Laboratories Inc. 2013)	1.50-3.00 mS/cm (Landis and Dumroese 2006)	-
S2.2	**pH**	5.5-6.5	Peat: 5.5-6.5 (Raviv et al. 2019; Landis et al. 2014)	5.0-6.8 (A&L Canada Laboratories Inc. 2013)	5.5-6.5 (Goh and Haynes 1977)
S2.3	**Stability**	< 4 mg CO_2 /g VS/ day	Stable compost: 2-5 mg C-CO_2 /g VS/ day (Brinton et al. 1995)	Stable compost: < 4 mg CO_2 /g VS/ day (CCME 2005)	Peat: 1.1mg CO_2/g OM/day (Vandecasteele 2023)

Spec	Description	Passing Criteria	Benchmark 1	Benchmark 2	Benchmark 3
S2.4	**Bulk Density**	0.10-0.20 g/cm^3	Peat: 0.113 g/cm^3 (Kipp et al. 2001)	Peat: 0.05 to 0.2 g/cm^3 (Chambers et al. 2011)	Peat: 0.107 g/cm^3 (Cannavo and Michel 2013)
S2.5	**Total Porosity**	71-95%	Perlite: 61.8% (Evans 2011)	Peat: 85-95% (Raviv et al. 2019)	Peat: 71-95.1% (Rezanezhad et al. 2016)
S2.6	**Air-Filled Porosity**	10-31%	10-30% (Sun Gro 2024)	Peat: 10-30% (Raviv et al. 2019)	Peat: 10.3-31.4% (Rezanezhad et al. 2016)
S2.7	**Carbon-to-Nitrogen Ratio**	20-35:1	30:1 (Cannavo et al. 2022)	20-30:1 (Biswas and Micallef 2019)	25-35:1 (Raviv et al. 2019)
S2.8	**Cation Exchange Capacity**	90-140 meq/100g	Peat: 90-140 meq/100g (Raviv et al. 2019)	Peat: 118.51 meq/100g (Corti et al. 1998)	Peat: 124 meq/100g (Basirat 2011)
S2.9	**Phytotoxicity**	GI: > 80% GI	GI: > 80% (Zucconi et al. 1981)	-	-

Each of the 11 total technical specifications were verified by following their respective testing procedures outlined in Section 3 and Appendix A of this report. Results were compared against the passing criteria listed in Tables 1 and 2 to verify the success of the media designs.

1.5 Project Constraints and Limitations

The project constraints and limitations are identified in Table 3. The timeline of the BIOE 4900/BIOE 4950 course resulted in the time constraint (C1), while constraints C2 to C4 were provided by the client.

Table 3. Project constraints and mitigation strategies

Constraint	Description	Mitigation Strategy
C1	Project was to be completed within 8 months.	Project tasks were split up among team members. A detailed work plan was created and followed.

Constraint	Description	Mitigation Strategy
C2	$1200 budget	Project cost was minimized by using already available resources at the university.
C3	Grow space was limited. It would have required a lot of room to grow horizontally.	A vertical wall from Harvest Today was sourced to save room by not growing horizontally.
C4	Must have used a commercially popular flower variety to validate the media design solutions. These typically possess a long growing cycle from seed to flowering stage.	The following two-stage growing plan was implemented to reduce total grow time and observe flower growth at a variety of growth stages: • Flowers were grown from seed in a peat-based mix and transplanted to the media designs. • Rooted plugs were purchased and transplanted to the media designs. • Germination trials from seed were performed in the media designs.

To address C1, a detailed work plan was established which facilitated the timely completion of the project and is provided in Appendix B. A $1200 budget constraint (C2) was allocated for third-party testing and resources that could not be provided by the university. Due to the high cost of most testing apparatuses, the priority was to source equipment that was already available at the university. Growing on a horizontal plane would have required a large amount of space that the project team did not have access to. Thus, the constraint of space (C3) was mitigated by the grow wall provided by the client which grows plants in a vertical plane. Finally, Typha Co. aimed to design a growing media for use in commercial floriculture (C4). Therefore, flowers were grown in a two-stage growing plan to validate the media design's suitability for this purpose.

Considering these project constraints and limitations, only methods which were considered feasible with the current resources and timeline were pursued. The selected processing methods chosen to create the design solutions are described in detail in the following section.

2 Media Design Solutions

Three Media Designs were first conceptualized to address the two primary issues associated with Raw Typha material when utilized as soilless growing media as identified in literature: low WHC and high nitrogen immobilization. A low WHC indicates that the media has a reduced ability to retain water, restricting the plant's ability to absorb sufficient water for photosynthesis. A high nitrogen immobilization depletes inorganic nitrogen, a vital nutrient for plant growth, in the decomposition of the Typha biomass. The three distinct Media Designs utilize different combinations of processing methods that have individually been shown to improve upon these challenges or are recommended when using soilless media in greenhouse settings.

The proposed solutions were:

- Media Design 1 (MD1): [redacted]
- Media Design 2 (MD2): [redacted]
- Media Design 3 (MD3): [redacted]

The production order of these three Media Designs is shown in Figure 2.

Figure 2. The production of the three Media Designs

The three individual processing methods used in the production of the Media Designs are further explained in the next section of the report.

2.1 Processing Methods

The processing methods performed in this project were selected based on their ability to address specific concerns when using Typha as a growing media. The composting process has been shown to decrease the high nitrogen immobilization of the media by providing it with the proper

conditions to decompose before use as a growing media, allowing the plant to freely take up the nutrients that it requires from an applied nutrient solution. Composting also slightly decreases the particle sizes in the media and inhibits pathogenic or phytotoxic substances, increasing the WHC and removing any growth inhibitors, respectively, to enable successful plant growth. Milling further decreases the particle size and improves the WHC by increasing the overall surface area and thus resulting in greater adhesion to the water molecules. Pasteurization is used to kill any disease-causing organisms and render unwanted seeds in the media unviable. This ensures that the media can be stored and used in a greenhouse setting without the growth of unwanted organisms.

The equipment used for each processing method was selected based on availability to both the team and Typha Co. to reduce the associated production costs. [redacted] due to the issues with sourcing a viable compost and the order in which equipment was procured. It should be noted that these processing methods were performed on shredded Typha plants, referred to as Raw Typha in this report. The entirety of the above ground portions of the Typha plants harvested in Rosser were included to avoid waste resulting from fibre extraction methods. In the remaining subsections, the three processing methods performed in this project are delineated below, accompanied by a detailed explanation of the specific methodology undertaken.

2.1.1 Composting

The composting process addresses the issue of high nitrogen immobilization, while also providing additional benefits by increasing WHC and removing pathogenic and phytotoxic substances that may inhibit plant growth.

The composted Typha utilized in this project was produced in [redacted] where the addition of the latter two constituents encouraged optimal conditions for microbial degradation. [redacted] is rich in nitrogen, which decreased the initial C:N ratio of the Raw Typha from [redacted] to approximately [redacted]. By reducing the overall C:N ratio, the risk of nitrogen immobilization should be decreased to allow for successful plant growth (Hartung and Meinken 2021). As the organic material is degraded for energy and nutrients through microbial respiration, carbon compounds are lost into the atmosphere as CO_2. This decreases the volume, and therefore particle sizes, of the material to encourage water retention properties. Furthermore, pathogenic and phytotoxic organisms may be addressed if the operating temperature of the compost pile reaches a value between 55°C to 65°C (Chen et al. 2011). Figure 3 displays the graph monitoring temperature over the 24-hour long composting process, showing that this temperature was achieved for the batch of compost [redacted].

Figure 3. Temperature graph from [redacted] indicating removal of growth-inhibitors during composting

These benefits toward the identified technical specifications are more likely to be secured if the final compost is mature. Compost maturity can be defined as the readiness for use as a growing media for plants; that is, it possesses a high stability and is free of phytotoxic substances (ADAS Consulting Limited 2005). For compost to be characterized as mature, the Canadian Council of Ministers of the Environment (CCME) requires a minimum curing period of 21 days and for it to have a CO_2 evolution rate, or stability, that is less than or equal to 4 milligrams of carbon (as CO_2) per gram of organic matter per day.

Issues with sourcing a mature compost for use in [redacted] occurred during project planning. Initially, compost was to be completed in November 2023 within an in-vessel composter, called a BIOvater, at the University of Manitoba's Sustainability-in-Action Facility (SiAF). However, its immaturity was indicated by factors such as low operating temperatures, an insufficient curing time, and the emission of an odour associated with ammonia (NH_3) that indicated anaerobic conditions. Subsequently, Typha Co. provided two alternate batches of compost [redacted]. One consisted of [redacted], and the second [redacted], as described at the beginning of this subsection.

To test for maturity and suitability in the applicable Media Designs, Solvita® Basic Compost Maturity Tests were conducted in January 2024 on both [redacted] batches, as well as Raw Typha, allowing the compost created in the BIOvater to cure indoors for a total of three months. This test involves placing two gel-coated probes into a sealed incubation jar containing the sample of compost. Over a four-hour period, the gel coatings undergo a colour change according to the detected levels of CO_2 respiration and NH_3 volatility in the headspace of the jar. The results showed that the [redacted] compost was in the "Ideal Curing" phase. Though not yet fully mature, it indicated the most advanced compost maturity status and was therefore most suitable for inclusion [redacted]. More information on how the

Solvita® tests were conducted and interpreted to select the [redacted] compost are provided in Appendix C.

Only one Solvita® test was conducted on the successful compost due to sourcing issues and the high purchasing cost. As stability was initially assessed as a technical specification, the results from these tests were retroactively used to provide additional data on maturity and to increase confidence in the initial result, now in the context of the three Media Designs. The stability test procedure and results are outlined in the Verification section of this report under Section 3.1.5.

2.1.2 Milling

The process of milling Typha in a hammermill for particle size reduction addresses the issue of low WHC. This method was carried out by [redacted]

Figure 4. Biomass machines used for milling

[redacted]

The necessity of milling for particle size reduction is better understood by observing the difference in particle size distribution, shown in Figure 5, between Typha-based media and peat.

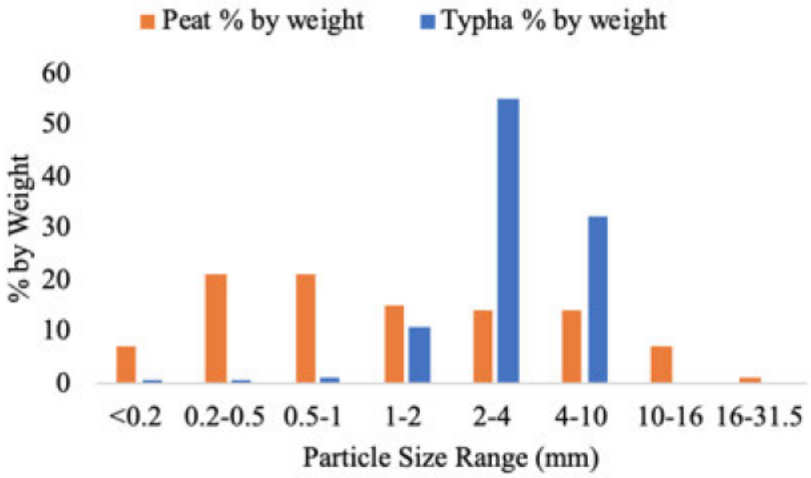


Figure 5. Particle size distribution of peat and Typha (Leiber-Sauheitl et al. 2021)

The Typha particles in this sample, shredded and sieved to 3-6 mm, occupied a narrow range of larger particles, inhibiting their ability to hold water due to decreased surface area and larger pores (Leiber-Sauheitl et al. 2021). [redacted] material degradation from composting was expected to aid in particle size reduction.

Coarser media, such as pumice (Gizas and Savvas 2007) and Miscanthus (Pancerz et al. 2023) media, have been found to drastically reduce flower number, plant size and root and shoot weight in Gypsophila (baby's breath), Rosa (rose), Hylotelephium spectabile (showy stonecrop) and Hydrangea arborescens (smooth hydrangea) due to lower water holding capacity (Gizas and Savvas 2007) and nutrient leaching (Pancerz et al. 2023). A high percentage of particle sizes in the range between 0.25-0.5mm results in the most even relationship between the percentage of available water and air (Noguera et al. 2003).

The particle size distribution for each Media Design, as well as Raw Typha, was determined following the procedure from ASTM D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis (2017). Additional details on how this procedure was carried out can be found in Appendix C. This test provided the particle size distribution as a gradation curve plotting the approximate particle diameter (mm) versus the percentage of material passing (%), as shown in Figure 6. These gradation curves are plotted along with a sample of peat determined by Choi et al. (2019).

Figure 6. Particle size distribution of each Media Design, Raw Typha and peat (Choi et al. 2019)

Well–graded media, as seen in the red curve for peat (Choi et al. 2019; Leiber-Sauheitl et al. 2021), in which particles exist over a wide range of sizes, provides a compromise between sufficient water-holding capacity and aeration. A more detailed discussion of these differences is found in Section 3.

One concern with particle size reduction, however, is regarding its ability to increase pH, potentially moving it outside the ideal range for plant growth, as seen in Miscanthus media shredded in a hammermill screened at 3 mm particle size (Nguyen et al. 2022). This concern restricts the decrease in particle size and identifies the possible need to manually decrease pH when using the media.

2.1.3 Pasteurizing

Pasteurization improves plant appearance, quality and vigor, and crop yields by controlling soil-borne pests (Pandey and Saravaiva 2021). It is important to pasteurize soilless growing media as bagged soilless growing media from wholesale distributors can introduce fungus gnats. In particular, Typha soilless growing media has been shown to introduce aphids into commercial

greenhouse facilities (Cloyd and Zaborski 2004). In Table 4, common temperatures and duration treatments for pasteurization are available along with the outcomes.

Table 4. Pasteurization treatments and outcomes

Temperature (°C)	Duration	Outcomes	Reference
60-71	30 minutes	Kills fungi.	(Greenhouse soil pasteurization 2023)
82-93	30 minutes	Kills any unwanted seeds.	(Greenhouse soil pasteurization 2023)
85	-	Phytotoxicity problems.	(Greenhouse soil pasteurization 2023)
85-100	-	Kills many beneficial soil organisms, such as mycorrhizal fungi, nitrogen fixing bacteria and pathogens. Also leads to the production of phytotoxic compounds harmful to crop plants.	(Pandey and Saravaiva 2021)

[redacted]

A temperature [redacted] which can lead to issues of phytotoxicity and possibly kill the beneficial organisms in the media.

To prepare a sample of media for pasteurization, it is first loosened, to support the movement of heat through the pore spaces, and moistened, to speed up the rate of pasteurization. The sample was prepared [redacted] allowing it to dry to the proper moisture level over that day, as excess moisture can slow down the pasteurization process. This moistening process was assessed by visual appearance and touch. The media was thoroughly mixed by hand to ensure there were no large clumps and sufficient large pores to facilitating the movement of heat. Therefore, cutting down the length of time required to pasteurize the media (Pandey and Saravaiva 2021). [redacted]

2.2 Growing Media Designs

The three Media Designs, presented in the introduction of Section 2, are reiterated after having described the methods of processing and are as follows:

1. MD1: [redacted]
2. MD2: [redacted]
3. MD3: [redacted]

[redacted]

2.3 Features of Media Designs

The design features of these three soilless Media Designs include the texture and appearance, water-holding properties, nutrient transfer properties, and physical stabilization.

Each Media Design varies in terms of texture and appearance. As shown in Figure 7, the designs that have been composted, [redacted], possess a darker brown colour and noticeably finer texture in comparison to Raw Typha, similar to that of traditional soil. This is mainly due to the decomposition of the compost feedstock. The texture influences technical specifications such as WHC, porosity, and bulk density. The non-composted Raw Typha has a lighter tan colour, shown in Figure 7, similar to that of dried Typha stalks and leaves.

Figure 7. Non-composted Typha (left) is coarser in texture, meaning it contains larger particles, and lighter in colour compared to composted Typha (right)

Milling of the media also caused a change in texture [redacted] were milled and have smaller and less varied particle sizes than [redacted] The reduced particle size of [redacted] from processing in the hammermill [redacted] The particles that have not been milled, in Raw Typha, are noticeably more variable in shape as some pieces

have a length that is much larger than their width. This variability can result in a misleading particle size distribution determination which is based on the minimum diameter of an assumed spherical particle. The process of milling decreases this variability, increasing WHC and bulk density. Pasteurization does not affect the texture or appearance of the media. Testing of all Media Designs and Raw Typha will reveal the preferred processing combination.

Figure 8. Non-composted, milled Typha is lighter in colour than composted Typha and finer in texture than Raw Typha (shown in Figure 7)

The water-holding ability of the Media Designs is another important feature. Each Media Design must hold the supplied water-nutrient solution which allows the plant roots to take up the amount they require for growth and survival. The media gradually allows the water to drain, providing the opportunity for the plant roots to take in oxygen. Proper drainage also prevents the growth of mould and fungi that thrive in constantly moist environments. This process of retaining and then releasing moisture is an important dynamic of soilless media. The presence of this feature is confirmed by the testing of technical specifications such as WHC, porosity, bulk density and particle size distribution.

Along with the water holding properties of these designs, the media allows the transfer of nutrients from the water-nutrient solution to the roots of the plant. This corresponds to the success of technical specifications such as EC, pH, nitrogen immobilization, stability, C:N, and CEC. If the results of these technical specifications are in the target range, the media should allow the movement of nutrients toward the roots and encourage the uptake of these molecules by the plant, allowing for healthy plant growth. As a result of the composting and pasteurization of the Media Designs, the soilless media should be free from unwanted seeds, fungi, and disease-causing organisms leading to a, hopefully, low phytotoxicity rating.

The Media Designs provide physical stabilization of the roots and stem of the plant as it continues to grow. An optimal bulk density, which matches that of currently used media, limits the excessive movement of roots due to watering and the force of gravity.

2.4 Operation of Media Designs

The soilless Media Designs are intended to be used in a hydroponic system, similar to one sourced from Harvest Today (described further in Section 4.7 for its use in the validation stage). The media is placed into mesh bags and net cups to contain the loose media and prevent it from being washed away during watering cycles. Approximately 125 cm^3 of media surrounds the roots of the plants to provide an ideal root growth environment. The sequence of steps involved in utilizing a soilless media in a net cup of a hydroponic system is displayed in Figure 9.

Figure 9. A small amount of media is placed in the net cup (left), a plant is held in the cup while additional media is placed around the roots (middle), and the cup is then placed in an open port of the hydroponic system (right)

A nutrient-rich solution must be provided to the media in the root zone as the media does not contain sufficient nutrients to support plant growth. The media in the root zone is watered to saturation (Raviv et al. 2019) and evapotranspiration, from the plant and the media, gradually decreases the amount of stored water. The next irrigation event begins well before the point at which the plant would begin to experience water stress due to insufficient moisture levels. When the plant is fully grown and ready to be sold, the media is often sold with the plant, acting as a soil amendment if the plant is transplanted in the ground (Dombrowsky 2012). The reuse of growing media requires a re-assessment of the media's properties (Gruda 2019) as these can change during use. Nutrient and salt residues have the potential to either benefit or hinder growth depending on their concentration and porosity may decrease due to gradual media breakdown. Post-consumer uses, of this Typha media and other composted plant wastes, include use as soil amendments as well as conversion into pellets for animal bedding or bioenergy fuel (Grosshans et al. 2011).

The success of the proposed processing methods in improving the operation of the Typha soilless growing media was evaluated by the technical specification verification procedures.

3 Verification of the Media Designs

The verification of the technical specifications will ensure that the processed Typha meets the physical, biological, and chemical standards observed in commonly used growing media, as identified in literature. The passing criteria for each of the 11 technical specifications, previously presented in Tables 1 and 2 in Section 1.4.12, are provided again in Table 5. The table serves as a directory toward the applicable subsection which lists the verification approach and procedure undertaken for each technical specification. More extensive details, such as the full list of required equipment, raw data, and calculations are provided, as directed, in Appendix A.

Table 5. Summary of verification methods

Spec	Description	Passing Criteria	Verification Approach	Verification Procedure
S1.1	Water Holding Capacity	62-90%	Measure	Section: 3.1.1 Appendix A (A1)
S1.2	Nitrogen Immobilization	NDI > 0.79	Test	Section: 3.1.2 Appendix A (A2)
S2.1	Electrical Conductivity	0.7-3.5 mS/cm	Measure	Section: 3.1.3
S2.2	pH	5.5-6.5	Measure	Section: 3.1.4 Appendix A (A3)
S2.3	Stability	< 4 mg CO_2 /g VS/ day	Test	Section: 3.1.5
S2.4	Bulk Density	0.10-0.20 g/cm^3	Measure	Section: 3.1.6 Appendix A (A4)
S2.5	Total Porosity	71-95%	Measure	Section: 3.1.1 Appendix A (A1)
S2.6	Air-Filled Porosity	10-31%	Measure	Section: 3.1.1 Appendix A (A1)

Spec	Description	Passing Criteria	Verification Approach	Verification Procedure
S2.7	Carbon-to-Nitrogen Ratio	20-35:1	Measure	Section: 3.1.7
S2.8	Cation Exchange Capacity	90-140 meq/100g	Measure	Section: 3.1.8
S2.9	Phytotoxicity	GI > 80%	Test	Section: 3.1.9 Appendix A (A5)

Each verification procedure was performed on all three Media Designs as well as Raw Typha. Raw Typha was included in the study to identify any possible improvements that the three processing methods provided.

3.1 Verification Procedures

A brief description of each verification procedure, source of adapted procedure and the pass/fail criteria are outlined for each technical specification. The test lead, list of required equipment, detailed procedure, calculations, and raw data, for all internally conducted tests, are found in Appendix A and all results are displayed Table 6.

3.1.1 Total Porosity (S2.5), Water Holding Capacity (S1.1) & Air-Filled Porosity (S2.6) Verification

This test obtains the total porosity, WHC, and air-filled porosity as percentages indicating the percent of water and air held in the sample of soilless media, following saturation and drainage.

Procedure: Adapted from British Columbia Nursery factsheet (Government of British Columbia 2015).

Pass/fail criteria:

- A total porosity within the range of 71-95% is a pass.
- A WHC within the range of 62-90% is a pass.
- An air-filled porosity within the range of 10-31% is a pass.

3.1.2 Nitrogen Immobilization (S1.2) Verification

This test obtains the nitrogen drawdown index (NDI), which indicates the potential of nitrogen immobilization in the sample of soilless media.
Procedure: Presented by Dombrowsky (2012), as adapted from Handreck (1992).

Pass/fail criteria: An NDI greater than or equal to 0.79 is a pass.

3.1.3 Electrical Conductivity (S2.1) Verification (Outsourced)

This test obtains a soluble salt value in mS/cm that is a direct indication of the EC within the sample of soilless media.

Equipment required: One large freezer bag to send samples to A&L.

Procedure: Send to A&L Canada Laboratories. Note: The team did not have control over their procedures and practices.

Pass/fail criteria: An EC within the range of 0.70-3.50 mS/cm is a pass.

3.1.4 pH (S2.2) Verification (Outsourced and Internal)

This test obtains a pH value on the logarithmic pH scale that indicates the acidity or alkalinity within the sample of soilless media.

Equipment required: One large freezer bag to send samples to A&L.

Procedure: Performed by A&L Canada Laboratories. Note: The team did not have control over their procedures and practices.

pH was also tested internally by the team to obtain faster results. The procedure for internal pH testing was adapted from ASTM D2976-22a Standard Test Method for pH of Peat Materials (2022).

Pass/fail criteria: A pH within the range of 5.5-6.5 is a pass.

3.1.5 Stability (S2.3) Verification (Outsourced)

This test obtains a stability value based on CO_2 evolution which is the average CO_2 produced in milligrams of CO_2 per gram of volatile solids (VS) per day of the sample of soilless media.

Equipment required: One large freezer bag to send samples to A&L.

Procedure: Send to A&L Canada Laboratories. Note: The team did not have control over their procedures and practices.

Pass/fail criteria: A CO_2 production rate of less than 4 mg CO_2 /g VS/ day is a pass.

3.1.6 Bulk Density (S2.4) Verification

This test obtains a bulk density value, defined as dry mass over volume, in grams per cubic meter (g/cm^3) of the soilless media sample.

Procedure: Adapted from ASTM D4531 Standard Test Method for Bulk and Dry Density of Peat and Peat Products (2015).

Pass/fail criteria: A bulk density within the range of 0.10-0.20 g/cm^3 is a pass.

3.1.7 Carbon-to-Nitrogen Ratio (S2.7) Verification (Outsourced)

This test obtains the total amount of organic carbon relative to the total amount of organic nitrogen present in the sample of soilless media.

Equipment required: One large freezer bag to send samples to A&L.

Procedure: Performed by A&L Canada Laboratories. Note: The team did not have control over their procedures and practices.

Pass/fail criteria: A C:N ratio within the range of 20-35:1 is a pass.

3.1.8 Cation Exchange Capacity (S2.8) Verification (Outsourced)

This test obtains the total amount of exchangeable cations, mainly calcium, magnesium, and potassium, as milliequivalents per 100 grams of media (meq/100g), that the soilless media can hold for use as nutrients.

Equipment required: One large freezer bag to send samples to A&L.

Procedure: Performed by A&L Canada Laboratories. Note: The team did not have control over their procedures and practices.

Pass/fail criteria: A CEC within the range of 90 – 140 meq/100g is a pass.

3.1.9 Phytotoxicity (S2.9) Verification

This test obtains a Germination Index (GI) value, which considers relative germination and relative root growth, as an indication of potential soluble phytotoxic substances present in the soilless media sample.

Procedure: Adapted from Emino and Warman (2004) and Warman (1998).

Pass/fail criteria: A GI greater than 80% is a pass.

3.2 Verification Results

The results of each technical specification testing procedure for the three Media Designs, as well as Raw Typha, are displayed in Table 6. A technical specification meeting the provided passing

criteria is highlighted in green, one that failed to meet the criteria is highlighted in red, while one that failed but improved upon Raw Typha is highlighted in orange. The results for tests that were performed in triplicate are displayed as the average and the standard deviation of the three repetitions. Any variation in this format is clarified within the notes below Table 6. The pH results obtained internally are not included in Table 6 due to inconsistencies in data between the internal and A&L results. These inconsistencies are believed to be due to measurement errors arising from solid particulates contacting the pH probe during internal testing. This type of error results in a more acidic result which is consistent with the discrepancies encountered in the internal pH results.

Table 6. Technical specification test results. Red indicates a fail, green indicates a pass, and orange indicates a fail, but an improvement from Raw Typha.

Spec	Description	Passing Criteria	Raw Typha	MD1	MD2	MD3
S1.1	Water Holding Capacity	62-90%	5.030% ± 3.770%	25.59% ± 1.990%	22.17% ± 2.280%	20.69% ± 3.470%
S1.2	Nitrogen Immobilization[a]	NDI > 0.79	0.55	0.40	0.70	0.37
S2.1	Electrical Conductivity[b, c]	0.7-3.5 mS/cm	0.6	1.8	1.8	0.6
S2.2	pH[b,c]	5.5-6.5	7.2	8.1	8.2	7.9
S2.3	Stability[b]	< 4 mg CO_2 /g VS/ day	*	3.50 ± 0.01	3.10 ± 0.01	0.50 ± 0.01
S2.4	Bulk Density	0.10-0.20 g/cm^3	0.028 ± 0.0054	0.20 ± 0.026	0.21 ± 0.023	0.061 ± 0.0015
S2.5	Total Porosity	71-95%	72.81% ± 1.220%	50.37% ± 1.860%	49.56% ± 2.790%	53.06% ± 2.220%
S2.6	Air-Filled Porosity	10-31%	67.78% ± 2.800%	24.78% ± 2.270%	27.39% ± 4.490%	32.37% ± 3.470%
S2.7	Carbon-to-Nitrogen Ratio[b, c]	20-35:1	42:1	14:1	14:1	30:1
S2.8	Cation Exchange Capacity[b, c]	90-140 meq/100g	10.4	50.0	40.9	8.7
S2.9	Phytotoxicity[a]	GI: > 80%	49.6	58.8	78.7	58.0

*Due to associated costs, the stability of Raw Typha was not assessed.
[a] Due to the nature of this test, standard deviation could not be calculated.
[b] Test completed by A&L Laboratories.
[c] Standard deviation values (accuracy) were not provided by A&L for these tests.

The technical specifications of Raw Typha serve as a baseline to assess the effects of the processing methods. By comparing these verification test results, the combination of the processing methods which best improve upon the challenges of Raw Typha may be identified, even if a pass was not achieved.

3.3 Verification Results Analysis: Raw Typha

A summary of the results for the technical specifications of Raw Typha are as follows:

- 1 pass
- 9 fails
- 1 unassessed

3.3.1 Physical Properties of Raw Typha

Raw Typha has a low WHC, a high air-filled porosity, and a total porosity which is in the passing range. All further discussion of WHC, air-filled porosity and total porosity refers to the media following saturation and drainage due to gravity. The results of these technical specifications indicate that Raw Typha has an acceptable amount of void space; however, too much of this space is taken up by air and not enough is taken up by water. During early observation of this media, water appeared to immediately drain from plant pots containing the Raw Typha media, whereas those mixed with compost had a 5-10 second delay before water began to drip out from the bottom. These technical specifications also relate to the low bulk density, since the media contains too much air space and a lesser amount of solid mass.

3.3.2 Chemical Properties of Raw Typha

Raw Typha failed with respect to its low EC, low CEC, and high pH, meaning that the media itself is low in nutrients and its ability to retain and deliver nutrients is compromised. Although the passing criteria of EC and CEC would be preferred, as higher values mean greater nutrient potential, they are not vital for successful growth in hydroponic systems where a continuous supply of nutrients can be carefully managed. A low EC is much preferred over a high EC, which could present phytotoxic effects (Silva et al. 2023). The high pH, although lowest in comparison to the Media Designs, is not ideal as this can lessen the availability of the soluble nutrients which may result in nutrient deficiencies in the plant regardless of adequate nutrients being supplementally applied (Raviv et al. 2019). In this case, additional pH adjustments of the nutrient solution, or with media amendments, would also be required to create a more suitable growing environment.

3.3.3 Biological Properties of Raw Typha

Raw Typha has a high C:N ratio and low Nitrogen Drawdown Index (NDI) correlating to high nitrogen immobilization. The high C:N means it possesses a high amount of carbon in its biomass compared to nitrogen. This means that any additional nitrogen, supplied in a nutrient solution for example, may be used up by the present microorganisms to degrade the plant material (Hartung and Meinken 2021). Curiously, Raw Typha has a higher NDI than Media

Designs 1 and 3, indicating that it does not immobilize as much nitrogen. One hypothesis for this finding is that the other two media have a more robust microbial community, due to favourable conditions provided during processing, that readily immobilize the nitrogen. Nitrogen immobilization is also closely related to the stability since a stable media is one in which the present microbes do not readily degrade the material. Due to the high cost of obtaining the stability result, it was not carried out for Raw Typha as these values were only for comparison and not required to provide pass or fail indicators.

The failure of phytotoxicity, at a less than 50% germination index, indicates a high degree of phytotoxic substances (Zucconi et al. 1981) which reduced seed germination and root length in the Raw Typha extract compared to those grown in distilled water. This provides further evidence, along with the other eight failed technical specifications, that Raw Typha is broadly unsuitable as a soilless growing media and processing is required to increase its viability.

3.4 Verification Results Analysis: Media Design 1

A summary of the results for the technical specifications of MD1 are as follows:

- 4 passes
- 3 fails
- 4 improvements

3.4.1 Physical Properties of Media Design 1

MD1 has a low WHC, an ideal air-filled porosity and a low total porosity. This means that, although the media lacks sufficient total void space, the existing void space allows for an acceptable amount of air but not enough water. Comparing these values to Raw Typha, composting and milling increased the WHC from 5.03% to 25.59% and decreased the air-filled porosity from 67.78% to 24.78%, which are both improvements. These processing methods also resulted in a passing bulk density, increasing it from 0.028 g/cm^3 to 0.20 g/cm^3. The ideal combination of high WHC and high air-filled porosity in peat (Raviv et al. 2019) may be difficult to replicate in Typha with the processing methods employed, as any additional decrease in particle size would likely decrease air-filled porosity to below acceptable levels, and without sufficiently increasing WHC.

3.4.2 Chemical Properties of Media Design 1

MD1 has a passing EC, low CEC, and high pH, indicating that processing helped to increase its nutrient content (from dissolved salt content) but its ability to retain and deliver nutrients is still compromised. The increase in EC from 0.6 mS/cm in Raw Typha to 1.8 mS/cm in both Media Designs 1 and 2, indicate that composting is likely responsible. The CEC, although still low, increased from 10.4 meq/100g in Raw Typha to 50.0 meq/100g which is an improvement and the highest CEC of all tested media. The composting process is known to increase CEC (Saharinen 1998) by the formation of humic acids, composed of phenolic and carboxylic functional groups, which attract these positive ions (Harrison 2008), or nutrients. The higher CEC in MD1 compared to MD2, which was also composted, could be a result of smaller particles since greater

surface area increases cationic bonding sites (Altland et al. 2014). The pH increased from 7.2 to 8.1, failing to decrease to within the passing range of 5.5-6.5. This was expected as composted plant waste growing media is known to have an elevated pH (Raviv et al. 2019).

3.4.3 Biological Properties of Media Design 1

MD1 has a low C:N ratio, a low NDI (correlating to a high nitrogen immobilization) and a passing stability. [redacted] Soil has a C:N ratio of 10:1 to 12:1 (Magdoff and Van Es 2021) indicating that the 14:1 ratio of MD1 (and MD2) may be acceptable. Due to procedural differences in the determination of nitrogen immobilization and stability, the results appear contradictory. The NDI decreased from 0.55 in Raw Typha to 0.40 in MD1, indicating an even higher degree of nitrogen immobilization and media degradation, which represents a worsening in the criteria. Conversely, the low CO_2 production suggests high stability with low levels of degradation. In the determination of NDI, samples were supplied with excess nitrogen (in the form of a potassium nitrate solution) to assess the nitrogen losses from degradation supported by the nitrogen increase, whereas the stability procedure assessed only the current rates of CO_2 production in the sample. This may have led to a false stability result if the addition of nutrients, via a nutrient solution, causes the microbes involved in degradation to re-establish.

The phytotoxicity rating of MD1 decreased from Raw Typha which is an improvement likely due, in part, to the utilization of pasteurization. This is observed by an increase in germination index, going from 49.6% to 58.8%, indicating only moderate phytotoxicity (Zucconi et al. 1981).

3.5 Verification Results Analysis: Media Design 2

A summary of the results for the technical specifications of MD2 are as follows:

- 3 passes
- 2 fails
- 6 improvements

3.5.1 Physical Properties of Media Design 2

MD2 has a low WHC, an ideal air-filled porosity, and the lowest total porosity of all media. This means that MD2 contains an acceptable amount of air and not enough water in its void space. WHC improved from Raw Typha, increasing from 5.030% to 22.17%; however, there was less of an improvement compared to MD1. This greater improvement in MD1 could be the result of milling, which further reduced the particle sizes in MD1, allowing it to retain more water. The bulk density of MD2 is higher than MD1, at 0.21 g/cm^3, which contradicts the previous hypothesis of larger particles responsible for lower WHC. It is likely that MD1 and MD2 have very similar bulk densities and that both are around the upper limit of the passing range (0.20 g/cm^3). While pasteurizing MD1 and MD2, the texture of the media was observed to vary

following air drying. Some samples formed small clumps during the drying process, decreasing their overall bulk density. These clumps were not stable and could easily be broken up by hand, leading to variability with breakdown from normal use.

3.5.2 Chemical Properties of Media Design 2

MD2 has a passing EC, a low CEC, and a high pH meaning that MD2 also increased in nutrient content and has a restricted ability to retain and deliver nutrients. The EC and pH of MD1 and MD2 are comparable and likely a result of the composting process (Raviv et al. 2019). The CEC of MD2 improved from Raw Typha, going from 10.4 meq/100g to 40.9 meq/100g, but saw less of an improvement than MD1 (50.0 meq/100g) potentially due to the larger particles present (Altland et al. 2014). MD2 has the highest pH of all the media, which is a deterioration in the criteria compared to Raw Typha.

3.5.3 Biological Properties of Media Design 2

MD2 has a low C:N ratio, a low NDI (correlating to a high nitrogen immobilization and a passing stability. The media has a low C:N ratio (the same as MD1) likely due to the composting process. MD2 has a high degree of nitrogen immobilization but the lowest compared to all other media, increasing from an NDI of 0.55 in Raw Typha to 0.70. It also has a high stability represented by low rates of CO_2 production. Both technical specifications indicate lower levels of degradation than both MD1 and Raw Typha, which are improvements. MD2 may immobilize less nitrogen and produce less CO_2 due to a lower surface area as a result of not being milled. High surface area increases particle contact with microbes leading to faster rates of degradation (Magdoff and Van Es 2021).

The phytotoxicity rating follows the same trend as nitrogen immobilization, with the highest improvement seen in MD2, compared to Raw Typha. MD2 has the highest germination index at 78.7%, which indicates moderate phytotoxicity but approaches the low phytotoxicity rating, above 80% (Zucconi et al. 1981), which is most ideal.

3.6 Verification Results Analysis: Media Design 3

A summary of the results for the technical specifications of MD3 are as follows:

- 2 passes
- 5 fails
- 4 improvements

3.6.1 Physical Properties of Media Design 3

MD3 has a low WHC, a high air-filled porosity and a low total porosity. This means MD3 does not have enough total void space, and within that void space, there is too much air and not enough water. WHC and air-filled porosity both improved from Raw Typha, likely due to milling, but displayed the least improvement compared to MD1 and MD2. Bulk density also improved, from 0.028g/cm^3 in Raw Typha to 0.061g/cm^3, but is still below the passing range.

Even this small increase in bulk density enhanced the media texture, improving the team's experience of working with the media. All three Media Designs, including MD3, were easier to scoop, mix, fill into net cups, and mix into a slurry than Raw Typha.

3.6.2 Chemical Properties of Media Design 3

MD3 has a low EC, a low CEC, and a high pH. Its EC is equal to that of Raw Typha, indicating no change from milling or pasteurizing. CEC decreased which contradicts the previous assumption made for MD1, in which a higher particle surface area increases cationic bonding sites. It is not understood why this occurred. The pH of MD3 increased from Raw Typha, but to a lesser extent than MD1 and MD2. Some hypotheses for this finding are that increased microbial activity, as seen in Miscanthus media (Nguyen et al. 2022), or decreased particle size, as seen in Switchgrass media (Altland and Krause 2009), led to an increase in pH. Addition research should be done before any conclusions are drawn.

3.6.3 Biological Properties of Media Design 3

MD3 has an ideal C:N ratio, a low NDI (correlating to a high nitrogen immobilization), and a passing stability. MD3 has the highest nitrogen immobilization, represented by the lowest NDI of 0.37. Since minimal degradation had taken place, nitrogen was more readily consumed by the microbes to degrade the media. Its C:N ratio is in the passing range, which is an improvement from Raw Typha. The increase in immobilized nitrogen and decrease in C:N between Raw Typha and MD3 is likely due to the increase in surface area from the particle size reduction of milling (Haynes et al. 2015). MD3 showed the highest stability, although this result is likely incorrect based on the test procedure. The stability test performed is designed specifically for compost, which assumes that the sample of media has been provided with the ideal amount of carbon, nitrogen, oxygen, and water and allowed to begin decomposing. By analyzing the CO_2 production of a compost sample, the rate of decomposition currently taking place can provide an indicator of how mature, or complete, the compost is. If performed on a fresh media that has not been previously provided with the necessary composting constituents, the media may be in a pseudo-stable state (Grigatti et al. 2007). Although the media would appear to be currently stable, as soon as conditions become more favourable for degradation with the addition of nitrogen and water, its stability will likely decrease.

The phytotoxicity rating decreased, which is observed by an increase in the germination index from 49.6%, in Raw Typha, to 58.0%. This indicates only moderate phytotoxicity (Zucconi et al. 1981), but was the lowest of the three Media Designs.

3.7 Summary of Verification Results Analysis

Utilizing the three processing methods as designed generally resulted in an overall improvement from Raw Typha across the three Media Designs. The major takeaways from the analysis of each Media Design are as follows:

- MD1 and MD3 improved in one primary technical specification: WHC.

- Only MD2 improved in both primary technical specifications: WHC and nitrogen immobilization.
- MD3 has the least amount of passing criteria with results that are not fully understood or not entirely indicative of improvements. Its criteria improved to a lesser extent than the other Media Designs.

Media Designs 1 and 2 have more comparable results, with MD1 having more passes but MD2 having more improvements. With the assistance of the discussion above on the relationship between the technical specification results within each Media Design, MD2 appears to outperform MD1.

Alongside this verification stage of the project, the technical specification results of each of the Media Designs were supplemented by validation grow trials. These trials provided further information on whether the combination of technical specifications, unique to each media, supported the goal of successful flower growth.

4 Validation of the Media Designs

The validation of the three Media Designs further evaluated the feasibility of Typha as a soilless growing media. This was carried out by floriculture grow trials in a vertical hydroponic system and in a greenhouse. Results from this stage of testing can be used to inform greenhouse floriculture growers of the Typha-media's characteristics in practice and provides recommendations on the required nutrient solution, pH adjustments, and irrigation cycles. An outline of the type of plant grown and the soilless media mixes compared are further explained. The details of each growing location, including preparation, operation, and growing conditions, are provided for each growing process: the vertical wall and the greenhouse. All plants began in the greenhouse and were then transferred to a vertical hydroponic system until all working ports were filled. The remaining plants were left to grow in the greenhouse.

4.1 Growing From Rooted Plugs and Seeds

A petunia plant was selected as they are a commonly grown greenhouse floriculture crop with a relatively quick grow time of 8-10 weeks from seed (Russ 2007). Given that the validation stage was scheduled to begin in January 2024 concurrently with the verification stage, it was imperative to mitigate the risks associated with completing a full growth cycle within the confined time frame of two months. To address this challenge, two options were considered: using rooted plugs and unrooted cuttings.

Unrooted cuttings are clippings from existing plants and are commonly used in Manitoban greenhouses due to the short growing season. Rooted plugs are collected in a similar manner but are then replanted in a small plug of commercial, peat-based media to establish new roots and develop into a seedling. Either solution is more time-efficient than growing from seed, both for this project and for greenhouse growers, by eliminating the additional weeks required for germination from seed. Grow time is especially shortened using rooted plugs, as it allows the plant to develop roots prior to delivery and transplantation into the Typha media.

Issues with sourcing unrooted cuttings and plugs arose as many local greenhouses start growing in March. To address this uncertainty, Orchid Mist Petunia seeds, sourced from T&T Seeds in Headingley, Manitoba, were planted in a peat-based commercial growing mix (Pro-Mix® Premium Potting Mix) on December 22, 2023, and were allowed to grow to seedling stage. This was conducted in the grow room within the Faculty of Agriculture's Greenhouse at the University of Manitoba. By January 2024, rooted plugs of two Supertunia® cultivars, Vista Bubblegum® and Royal Velvet®, were successfully sourced from van der Meer Garden Centre. Plants from both plugs and the Orchard Mist seeds were used in the grow trials to analyze the performance of different petunia varieties in the Media Designs. The seedlings were transplanted from their existing peat-based mixes into 13 test media mixes (described in the next subsection, 4.2) within mesh bags and net cups to assess how well the mixes sustained the growth of an existing plant.

To align with project constraint C4 (presented in Section 1.5) which specifies the evaluation of a growing cycle from seed to flowering stage within the test media mixes, germination trials using

the test media mixes were also conducted within the Agriculture Greenhouse using Supercascade Burgundy Petunia seeds, also sourced from T&T Seeds. This evaluated how effectively the Media Designs facilitated germination and supported the earlier growth stages of this popular flower variety.

4.2 Test Media Mixes

Each Media Design, along with Raw Typha, was included in the grow trials and was mixed with peat and perlite at varying percentages. The legend, displayed in Table 7, outlines a colour scheme indicating which Typha media each test media mix contains (MD1, MD2, MD3 or Raw Typha). This colour scheme is applicable for the subsequent tables of Section 4.

Table 7. Colour scheme indicating the type of media each test media mix contains

Media	Colour
MD1	Blue
MD2	Orange
MD3	Green
Raw Typha	Grey
Control – No Typha Media	Yellow

Each mix is identified by a single mix number, for ease of labelling, and Typha mix proportion (T35, T70 or T100), shown in Table 8, which indicates the percentage of Typha media, by mass, included in the mix.

Table 8. Composition (%) of each test media mix

Media Design	Mix Number	Typha Mix Proportion	MD1	MD2	MD3	Raw Typha	Peat	Perlite
MD1	1	T35	35	-	-	-	35	30
	2	T70	70	-	-	-	-	30
	3	T100	100	-	-	-	-	-
MD2	4	T35	-	35	-	-	35	30
	5	T70	-	70	-	-	-	30
	6	T100	-	100	-	-	-	-
MD3	7	T35	-	-	35	-	35	30
	8	T70	-	-	70	-	-	30
	9	T100	-	-	100	-	-	-
Raw Typha	10	T35	-	-	-	35	35	30
	11	T70	-	-	-	70	-	30
	12	T100	-	-	-	100	-	-
CTRL	13	-	-	-	-	-	70	30

Gradually increasing the proportion of Typha-based media may reveal if the processing methods improved upon Raw Typha's ability to support plant growth. For example, if a T35 mix (composed of a Typha media, peat, and perlite) provides better plant growth compared to a T100 mix (100% Typha media), this would indicate that the processing methods were not adequate in creating a fully Typha-based media, and the inclusion of peat and/or perlite was necessary to promote growth.

The ability of the four Typha samples, in the three different mixes, to support the growth of flowers was directly compared to a 70:30 peat-to-perlite mix (CTRL). Peat, with the addition of perlite to improve aeration and drainage (Bowler 2009), is a standard growing media for indoor commercial floricultural greenhouses (Arenas et al. 2002; Tsakaldimi 2006). Proving that the plants grown in any of the Media Designs are either comparable to, or better than, plants grown in this control mixture would further validate the project's overall goal of displacing the widespread use of peat moss.

Six flowers were planted in each of the 13 test media mixes in order to provide sufficient data for plant quality indicators. This resulted in a single trial requiring a total of 78 flowers.

4.3 Plant Quality Indicators

Upon conclusion of the grow trials, the success of growth for each plant was assessed based on the plant quality indicators identified in Table 9.

Table 9. Plant quality indicators

Plant Quality Indicator	Evaluation Type
Number of Flowers	Visual Assessment
Plant height	Measurement
Stem diameter	Measurement
Fresh weight	Measurement

These indicators were chosen to obtain data on plant health and the marketable features of the plants (Gallegos-Cedillo et al. 2021). The results of the three mixes containing varying amounts of a single Media Design were compared to each other, as well as to mixes containing other Media Designs. The number of flowers was counted by visually inspecting the plants. This count included those at three different states: those that were already blooming (see Figure 10 for an example within Trial 3 and 4), those that had recently died, and any noticeable budding formations.

Figure 10. Example of a flower bloom from Trial 3 (left) and Trial 4 (right)

All three flowering states were included to assess the overall flower production of the plant, and not only the number of open flowers on the day of assessment. The plant height and stem diameter were measured using a pair of electronic calipers. The plant height was measured from the surface of the growing media to the top of the plant when stretched and held straight. The stem diameter was measured from the largest stem at the base of the plant, closest to the growing media. Finally, fresh weight was collected by removing the plant from its net cup, shaking the excess media off its root system, and weighing it on an electronic scale. From the combined results of these plant quality indicators, comparisons between the success of the different mixes and any potential problems were identified.

4.4 Grow Trial Phases

Four phases of grow trials (two trials of rooted plugs and two trials from seed) were initially conducted at staggered time intervals to prevent the loss of all flower data due to any operating errors in the beginning stages of growing. This resulted in a total of 312 flowers that were transplanted into net cups for use in grow trials. Both rooted plugs and flowers from seed began in a standard peat-based media and were transferred to the test mixes at varying points in the seedling stage. The stage of a plant at transfer is shown in Figure 11.

Figure 11. Plant stage at time of transfer to test media mixes for rooted plugs (left) and petunias from seed (right)

The important characteristics of each grow trial are highlighted in Table 10, with the plant variety, growth stage at procurement, and significant timelines.

Table 10. Details of each grow trial phase

	Trial 1	Trial 2	Trial 3	Trial 4
Flower variety	Supertunia® Vista Bubblegum®	Orchid Mist	Orchid Mist	Supertunia® Royal Velvet®
Grown from	Rooted Plug	Seed	Seed	Rooted Plug
Weeks in peat-based mix	Unknown*	5	5.43	Unknown*
Location of grow trial	Hydroponic Wall	Hydroponic Wall	Hydroponic Wall	Greenhouse
Weeks in test media mix at time of flower number, stem diameter and plant height measurement	-	-	4.57	3
Weeks in test media mix at time of fresh weight measurement	-	-	5.29	3.29

*Rooted plugs were received in a peat-based mix. The number of weeks that the petunias spent in this mix, prior to delivery, is unknown.

The plant quality indicators (flower number, stem diameter, plant height and fresh weight measurement) were not collected for Trials 1 and 2. Trial 1 was utilized for initial practice in applying watering and lighting cycles through the hydroponic wall, potentially leading to excessive variation and stress. Trial 2 experienced significant plant mortality after a pump failure early in the grow trials.

4.5 Germination Trial

A germination trial was conducted in the 13 test media mixes to assess the influence of the Media Designs on early plant growth stages. The trials took place in the Faculty of Agriculture's Greenhouse at the University of Manitoba. Figure 12 displays the thirteen 12-cell seeding trays used, each filled with one of the 13 media mixes, watered, and labeled to indicate where each mix was placed.

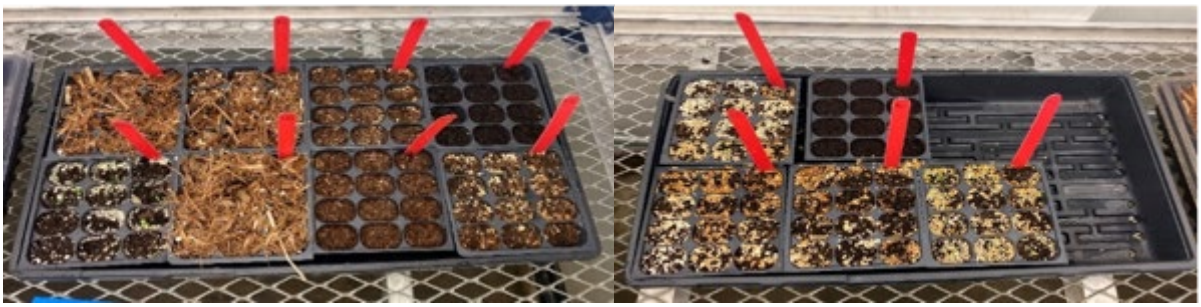


Figure 12. Beginning stage of germination trials

A Supercascade Burgundy Petunia seed was planted in each cell and the trays were placed in the grow room with a "water as needed" sign. The seeds were monitored by the greenhouse staff and watered as required. The temperature maintained in the grow room was 22°C during the day and 18°C overnight.

The germination trials ran for four weeks, from February 2nd to February 29th, 2024. A picture was taken of each test media mix on the day that germination trial data was collected, shown in Appendix C. The data recorded from the germination trials included the number of plants germinated, leaf count, and largest leaf length. These results are provided in Table 13 within Section 4.8 Validation Results: Germination.

4.6 Growth in the Greenhouse

The Agriculture Greenhouse was used to germinate and store the Orchid Mist petunia seedlings for Trials 2 and 3, and store both varieties of rooted plugs for Trials 1 and 4. After transplanting the petunias into the test media mixes within their individual net cups, Trials 1 to 3 were left in the greenhouse for a minimum of one week before transferring to a hydroponic system. This was done to prevent possible losses due to plant stress, incurred from transplanting and a change in

conditions. Trial 4 remained in the greenhouse for the entirety of its grow cycle due to time and space constraints in the hydroponic system.

4.6.1 Preparation of Petunias for the Four Grow Trials

Preparation of growing in the Agriculture Greenhouse involved communicating with the Greenhouse Manager, [redacted] to ensure sufficient space was set aside for the petunias. For the germination of the Orchard Mist petunia seeds, seeding trays were filled with a commercial peat-based mix and saturated with water. The seeds were placed in the trays, one seed per cell, as shown in Figure 13.

Figure 13. Planting Orchid Mist Petunia seeds

The seeds were placed in the grow room of the Agriculture Greenhouse and fertilized once with 10-52-10, a fertilizer that encourages root growth. A clear cover was added on top of the tray to reduce evaporation and a “water as needed” sign was included next to the trays to inform the greenhouse staff of the desired watering regimen. The greenhouse staff checked on the seeding trays every morning, although the plants did not require watering every day while they were in the grow room. After three weeks, seedlings had started to sprout; if more than one had sprouted in a single cell, the additional plants were removed. This minimized any competition for resources and allowed simple removal of the petunias from the peat-based mix.

After five weeks, the Trial 2 and 3 seedlings were removed from the seeding trays and transplanted into net cups, along with Trial 1 of Supertunia® Vista Bubblegum® plugs. The peat-based mix was removed from the roots of the petunia plants by submerging each in a water bath and manually removing any remaining media.

The petunias were then moved to the net cups in one of the 13 media mixes, as shown in Figure 14, and then returned to the greenhouse for a week, to adjust to the new media condition.

Figure 14. Freshly transplanted Orchid Mist petunias in net cups (Trials 2 and 3)

Once the petunias had acclimatized into their new net cup vessel, Trials 1 to 3 were transferred to the hydroponic system, at staggered intervals, to continue growing. Trial 4 was scheduled to be moved to the hydroponic system following Trial 3, when the time arrived the plants in Trial 4 had already blossomed and reached a stage where plant quality indicators could be collected. Due to time and space constraints as well as the maturity level of the plants, Trial 4 Supertunia® Royal Velvet® plugs, shown in Figure 15, remained in the greenhouse to continue growing.

Figure 15. Trial 4 in greenhouse on February 20, 2024

Trial 4 was fertilized twice a week using Miracle Gro and continued to follow the watering regimen, as indicated by the "water as needed" sign for the greenhouse staff. The grow trial for Trial 4 ended on March 1, 2024, following the collection of plant quality indicators. This represented the completion of greenhouse growing.

Due to Trial 4 remaining in the greenhouse and Trials 1 to 3 moving to the hydroponic wall it was decided that the petunias in each trial would be examined separately and the different conditions of each space would be recorded.

4.6.2 Greenhouse Conditions

Using a sling psychrometer, the temperature in the Greenhouse was recorded as 22˚C, with a relative humidity of 67.7% according to an online psychrometric calculator (Relative Humidity Calculator 2024). Some of the petunias showed signs of stress once moved from the grow room into the greenhouse. On sunny days, the temperature control was less consistent compared to the stable conditions of the grow room, which were 22˚C during the day and 18˚C at night. The petunias planted into the test media mixes with Raw Typha (10, 12 and 13) required more watering as the Raw Typha did not hold as much water. They were very dry in the morning and required repeated watering to soak and revive the petunia plants. Some days, the Raw Typha media mixes were watered again in the afternoon. Trial 4 remained in the greenhouse until the end of the grow trials and Trials 1, 2 and 3 were moved into the hydroponic system, a grow wall from Harvest Today as planned to complete the grow trials.

4.7 Growth in the Harvest Today Grow Wall

The Harvest Today grow wall functions as a hydroponic system that uses soilless media in each plant port and delivers a nutrient solution that is pumped along the top of the wall and flows down the back of each port. The wall can hold up to 360 plants, with two-inch diameter plant ports, a 12.5-gallon reservoir and a pump to facilitate the water cycles. Preparation of the wall, prior to use, was required as the wall was received from a previous project.

4.7.1 Grow Wall Preparation

Prior to installation, each component of the grow wall was cleaned with dish soap and water to prevent contamination from previous use of the wall. It was installed on the University of Manitoba campus in 120 GSRL Grain Storage Research Lab, as shown in Figure 16. Before the grow trials commenced, the reservoir and tubes that supply the irrigation water to the wall were disinfected with a diluted bleach solution to prevent the growth of algae.

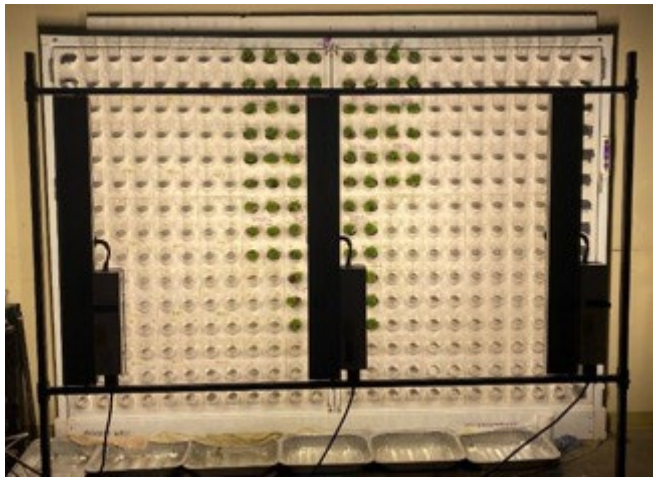


Figure 16. Installed hydroponic wall in 120 GSRL Grain Storage Research Lab

The placement of individual petunias, in their media mixes, was randomized in the grow wall to address the risk of varying conditions concerning the amount of water delivered and the amount of light experienced. A diagram of port locations is displayed in Figure 17 to enhance understanding of this setup.

		8	4	11	12	9	13		1	10	4		2	5	6	9	4	1	5	11	8	9		
		5	1	6	2	7	3		12	11	13		8	2	1	9	13	2	11	2	6	12		
		10	5	4	3	13	1		11	13	7		8	4	12	10	10	13	5	8	10	7		
		9	7	12	11	8	2		5	12	11		2	9	1	4	7	5	12	10	12	3		
		10	6	8	4	9	3		8	3	6		5	10	13	10	1	11	4	9	1	5		
		12	13	11	7	2	6		13	3	7		2	5	12	1	11	13	2	8	6	11		
		1	10	5	2	13	4		4	9	11		7	8	13	9	4	9	1	5	3	10		
		10	9	6	7	11	8		3	8	4		11	13	10	1	10	7	6	13	2	9		
		3	5	12	1	13	5		10	7	5		12	1			3	9	2	9	6	12		
		7	4	1	3	9	8		11	5	2		6	12			8	6	13	7	5	4		
		6	2	11	10	12	5		4	6	3						3	7	2	4	11	12		
		1	2	6	11	7	8		3	7	6						3	12	8	3	1	10		
		13	10	4	3	9	12		8	7	3						13	7	1	6	4	8		
									2	9	6													

Figure 17. Schematic of grow wall ports including empty ports (grey), Trial 1 petunias (blue), Trial 2 petunias (pink), Trial 3 petunias (green) and division in the middle between wall panel doors (grey-purple)

Each coloured box represents a single plant, where the number signifies the test media mix that the plant is grown in.

4.7.2 Grow Wall Operating Conditions

The growing conditions in 120 GSRL were similar to that of a warehouse, with concrete floors, high ceilings and shelving for equipment storage. Using a sling psychrometer, the temperature of the room was recorded as 22˚C, with a relative humidity of 27.4% according to an online psychrometric calculator (Relative Humidity Calculator 2024). This was significantly lower than the 67.7% relative humidity of the greenhouse. The impact of the low humidity in the grow wall environment is unknown.

4.7.3 Grow Wall Watering Cycles and Nutrient Solution

Water and nutrients were supplied at continuous intervals to the media during the grow trials. Initially, irrigation cycles were set up to run hourly, for a one-minute duration, at the recommendation of Dr. [redacted] a soilless media researcher for horticultural crops at Assiniboine Community College. This high-frequency cycle was selected as a starting point due to the small size of the net cup and dry conditions in the room. After visually monitoring the moisture level in the media, irrigation levels were reduced to once every two hours as the media was being watered while still saturated. Ideally, the length of time between successive watering events would have been at the halfway point between the WHC, and the point of wilting (University of Manitoba, Department of Biosystems Engineering 2023); however, time constraints did not allow for the testing of these two parameters prior to the start of grow trials.

The nutrient solution used in the wall was a Miracle Gro water-soluble plant food (20-20-20), with the exact breakdown of nutrients displayed in Table 11.

Table 11. Nutrient breakdown of hydroponic nutrient solution

Nutrient	Miracle Gro Concentration (%)	Miracle Gro Concentration (ppm)	Nutrient Formula Example (ppm) (Morgan 2021)
Total Nitrogen (N)	20	192.5	70-450
Available Phosphorus (P_2O_5)	20	192.5	20-100
Soluble Potash (K_2)	20	192.5	70-650
Boron (B)	0.02	0.185	0.1-0.9
Copper (Cu)	0.05	0.463	0.05-0.1
Iron (Fe)	0.1	0.927	1-6
Manganese (Mn)	0.05	0.436	0.5-3
Molybdenum (Mo)	0.0005	0.00463	0.02-0.07
Zinc (Zn)	0.05	0.463	0.1-0.5
EDTA	0.6	5.56	-
Calcium (Ca)	-	-	70-240
Magnesium (Mg)	-	-	20-95
Sulfur (S)	-	-	20-100

A comparison of the nutrient solution used to the example provided by Morgan (2021) identifies potential deficiencies in iron, manganese, molybdenum, calcium, magnesium and sulfur and a potential excess of phosphorus and copper. Further research would need to be conducted on the specific nutrient requirements of petunias. The solution was created on the basis of supplying the petunias with adequate nitrogen and at a suitable pH, identified as 200 ppm and 5.5-6.2, respectively (Henry et al. 2018).

The nutrient solution was created by mixing 1 tsp of Miracle Gro and ¼ tsp of pH down, to decrease pH, per gallon of water. Every time additional nutrient solution was made, its EC and pH were recorded with a BlueLab Combo Meter probe to ensure consistency in solutions. The recorded values ranged between 1.3-1.5 mS/cm for EC and 6.3-6.7 for pH. This EC was within the ideal range for hydroponic solutions, 0.8-4.5 mS/cm (Morgan 2021); however, the pH may not have been sufficiently decreased.

4.7.4 Grow Wall Lighting Conditions

Raging Kale lights, provided by Harvest Today, were placed 0.5 meters from the hydroponic grow wall. The lights were controlled, via Bluetooth, on the Theia Stratus mobile app allowing for mode selection of the following parameters: light intensity, start time, end time and sunrise/sunset time (the length of time for the light to reach its programmed intensity). A light intensity of 40% was ultimately selected in the app, after observation of discoloured leaves at 60% intensity, a potential indication of light "burns." This discolouration is shown in Figure 18.

Figure 18. Test media mix 7 in Trial 1 with discolouration due to high light intensity

The lighting duration was set to 16 hours to simulate a day cycle, at the recommendation of Dr. [redacted] The grow trial parameters programmed in the Theia Stratus app are shown in Table 12.

Table 12. Lighting parameters programmed in the Theia Stratus application

Control	Value
Master intensity	40%
Start time	8:15 am
End time	12:15 am
Duration	16 hours
Sunrise/sunset time	30 minutes

The lighting conditions, at 60 locations along the wall, were measured with a hand-held light meter, placed at the plant canopy, in photosynthetic photon flux density (PPFD). PPFD refers to "the number of photosynthetically active photons that fall on a given surface each second." (Fluence n.d.) and is a measure of the photosynthetic active radiation (PAR) that arrives at the plant. Figure 19 displays the recorded PPFD values, ranging from 23.640 $\frac{\mu mol}{m^2 s}$ to 258.66 $\frac{\mu mol}{m^2 s}$ at various locations on the grow wall.

93.400	95.930	96.400	127.72	124.75	107.43		103.59	67.470	110.09	109.50	106.86	36.500
129.51	148.04	178.66	192.40	157.63	157.50		194.72	182.61	155.57	164.86	169.72	91.450
190.91	212.54	237.74	229.80	218.53	237.21		236.56	196.41	220.03	258.66	244.49	106.72
124.65	131.27	167.87	182.68	133.05	146.31		196.58	175.13	136.43	161.55	176.11	102.52
61.920	95.300	75.780	75.070	69.610	83.780		59.920	33.860	91.760	75.510	81.530	23.640

Figure 19. Schematic of grow wall lighting measured in photosynthetic photon flux density (PPFD) in $\frac{\mu mol}{m^2 s}$. Areas of the wall containing Trial 1 petunias are blue, Trial 2 petunias are pink, Trial 3 petunias are green, and empty ports are grey.

The higher PPFD values were recorded in the centre of the wall and the lower levels of PPFD were recorded along the outermost border. Centering the petunias and avoiding placement along the outside border increased the amount of light the plants received, ensuring optimal lighting conditions; however, additional research should be done to determine the ideal lighting conditions for petunias.

4.7.5 Issues Encountered During Grow Trials

Throughout grow trial testing, the plant conditions were monitored, and any changes or notes of interest were recorded. [redacted]

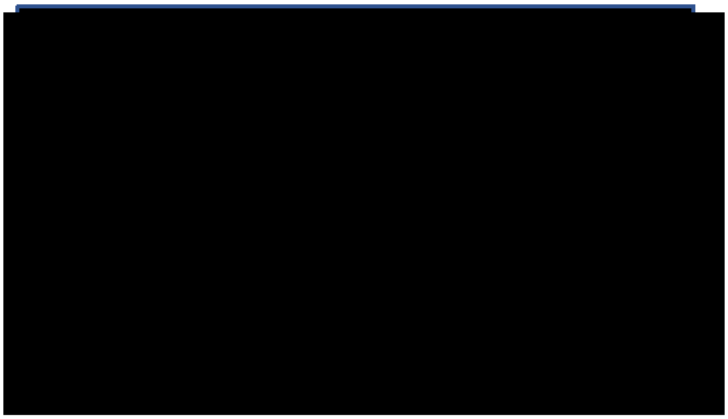


Figure 20. Observations of growing conditions during grow trials. [redacted]

Between February 16th-20th, the wall experienced a pump failure due to low water levels in the reservoir inducing water stress across all trials. This contributed to the failure of Trial 2 and put Trial 1 and 3 at a disadvantage. As shown in Figure 19, the center of the wall received a larger amount of light compared to the outer border. Since Trial 2 was placed in the center of the wall, its location could account for the large number of plants which dried out and ultimately died. Trial 1 and 3 were also negatively affected by this pump failure causing multiple plants to wilt, but minimally die. Almost all plants in Trial 3 were able to recover once the pump was restored, likely attributed to its most recent placement into the wall compared to the other two trials. It was noted that those planted into the Raw Typha test media mixes (mix 10 to 12) generally did not recover.

It was ultimately decided to remove Trials 1 and 2 from plant quality indicator testing. Trial 1 was omitted due to its exposure to fluctuating water and light conditions during initial set-up and Trial 2 due to unrecoverable stress from pump failure. Only Trial 3 was used to collect plant quality indicators among the trials in the grow wall.

4.8 Validation Results: Germination

The results from the germination trials are shown in Table 13. The data collected includes the number of plants germinated, average leaf count, and average largest leaf length. These results supply us with information on whether the test media mixes could facilitate germination, as well as a visual assessment to show the variation in the germinated plants.

Table 13. Germination trial results, including number of plants germinated, average leaf count and average largest leaf length

Media Design	Mix Number	Number of Plants Germinated	Average Leaf Count	Average Largest Leaf Length (mm)
MD1	1	11	4.75	9.36
	2	3	0.500	9.36
	3	10	2.58	2.94
MD2	4	8	2.58	6.25
	5	5	1.17	1.56
	6	8	2.33	4.37
MD3	7	12	2.00	2.51
	8	10	1.25	2.13
	9	10	1.67	1.99
Raw Typha	10	5	0.833	0.953
	11	1	0.167	0.169
	12	5	0.833	1.13
CTRL	13	9	3.75	8.98

Each test media mix was able to germinate the Supercascade Burgundy Petunia seeds. Increasing amounts of Typha media in the mixes did not yield any observable trends in the number of germinated plants. Mixes 1, 3, 4, 6, 7, 8, 9, and 13 germinated the most with 8 to 12 plants, and mixes 2, 5, 10, 11, and 12 germinated the least with 1 to 5 plants. On average, mixes with MD3 (7, 8, and 9) germinated the most plants and mixes with Raw Typha (10, 11, and 12) germinated the least. Mix 1 and mix 2, along with the control, had the highest value for average largest leaf length. Trends were inconsistent with increasing amounts of Typha media for largest leaf length. The average leaf length of plants germinated in the mixes containing MD3 were much smaller than those germinated in mix 1 (35% MD1, 35% peat, 30% perlite), mix 2 (70% MD1, 30% Perlite), and 13 (CTRL). This difference can also be seen in the germination photos provided in Appendix C, taken just before the data was collected. Mix 1 was the only mix to have a larger average leaf count than the control. Among all four Typha media, [redacted] Although mix 7 (35% MD3, 35% peat and 30% perlite) germinated the most seedlings, it can be concluded that mix 1 performed the best in this germination trial as it provided a comparable number of germinated plants and the highest averages for leaf count and leaf length. The next stage of growth was tested through grow trials which monitored petunia plants as they grew from seedlings to mature plants.

4.9 Validation Results: Grow Trials

Plant quality indicators were only assessed for Trials 3 and 4. This is due to Trial 1 acting as the "test" trial where it experienced multiple different irrigation and light cycles. Trial 2 was heavily challenged by a pump failure in which many of the plants did not recover. Therefore, Trial 3,

which was grown in the Harvest Wall, and Trial 4, which was grown in the greenhouse, were the trials assessed for plant quality indicators.

4.9.1 Trial 3 Results

Throughout the grow trials, flowers of various sizes were seen in each test media mix containing 100% Media Design, except for those grown in Raw Typha. Before analyzing the numerical data associated with each mix quality, Figure 21 shows the visual improvements that the different Media Designs made to the growth environment compared to that of Raw Typha. Pictures of plants from all Trial 3 test media mixes can be found in Appendix C.

Figure 21. Visual comparison between flowered plants grown in different mixes. From Left to Right: Mix 3 (100% MD1), 6 (100% MD2), 9 (100% MD3), and 12 (100% Raw Typha). Photos taken on February 25th after four weeks in test media mixes.

The plant quality indicator results for Trial 3 are shown in Table 14.

Table 14. Plant quality indicator average results for Trial 3 of grow trials

Media Design	Mix Number	Number of Flowers	Fresh Weight (g)	Stem Diameter (mm)	Plant Length (mm)
MD1	1	3.17	15.24	4.55	107.48
	2	3.17	17.65	4.55	120.18
	3	1.67	18.34	3.60	86.18
MD2	4	3.17	13.80	4.10	111.50
	5	2.67	14.97	5.08	112.00
	6	2.67	23.55	4.18	90.05
MD3	7	2.83	19.46	4.19	99.51
	8	2.50	17.70	4.53	95.47
	9	2.67	17.44	4.15	96.49
Raw Typha	10	1.33	13.24	3.80	86.89
	11	0.33	4.50	3.31	65.56
	12	0.17	2.93	3.21	57.62
CTRL	13	1.83	10.86	4.12	94.52

4.9.2 Trial 3: Media Design 1 Analysis

Mixes 1, 2, and 3 contained increasing amounts of MD1 and are compared by their plant quality indicator results. Mixes 1 and 2 performed similarly to each other. Their average number of flowers and stem diameters were identical, which indicates the same strength and resilience of the plants. Where these mixes differed was in their fresh weight and plant length, where mix 2 produced higher results in both.

Mix 3, in comparison to mixes 1 and 2, produced plants with smaller stem diameters and plant lengths, but higher fresh weights. This indicates that more of the plant's weight was held in its roots as opposed to its shoot system. This may suggest that mix 3 provided less favourable growing conditions since the plants must focus on obtaining water and nutrients with their roots instead of growing their shoot volume (Harris 1992).

Overall, mixes 1 and 2 performed better than mix 3. Due to the higher fresh weight and plant length of mix 2, it can be concluded that mix 2 (70% MD1, 30% perlite) produced the most suitable growing environment. [redacted] The addition of peat, in mix 1, did not appear to benefit MD1.

4.9.3 Trial 3: Media Design 2 Analysis

Mixes 4, 5, and 6 contained increasing amounts of MD2 and are compared by their plant quality indicator results. When comparing mixes 4 and 5, the latter performed better in fresh weight, stem diameter, and plant length; however, mix 4 produced more flowers on average. The fewer flowers present in mix 5 could be due to the temporary drought all plants in Trial 3 endured during the pump failure or could be attributed to a nutrient imbalance (Doubrava and Polomski 2018). The differences in results between mixes 4 and 5 are not large enough to draw significant conclusions. Further testing would be required to determine the exact cause of reduced flower growth.

Mix 6, with the highest amount of MD2, produced plants with a higher fresh weight but lower stem diameters and plant lengths than the other mixes containing MD2. This trend was also observed in the mixes containing MD1. This indicates that more of the plant's weight was held in its roots rather than its shoot system which provides evidence that mix 6 provided a less favourable growing environment (Harris 1992).

Overall, it is inconclusive whether mix 4 (35% MD2, 35% peat, 30% perlite) or mix 5 (70% MD2, 30% perlite) provided the most suitable growing environment. [redacted]

[redacted] Given the similarities in results between mix 4 and 5, it is unclear whether the addition of peat, in mix 4, benefits the properties of MD2.

4.9.4 Trial 3: Media Design 3 Analysis

Mixes 7, 8 and 9 contained increasing amounts of MD3 and are compared by their plant quality indicator results. [redacted] Mix 7 produced plants with the highest number of flowers, fresh weight, and plant length, showing healthy growth in all areas. Mix 8 produced plants with the largest stem diameter but displayed lower results in number of flowers and plant length. This shows that the media did not provide a suitable environment for the plant to thrive in the areas of shoot growth and flowering. Rather, it had to focus on root and stem diameter growth. [redacted]

4.9.5 Trial 3: Raw Typha Analysis

Mixes 10, 11 and 12 contained increasing amounts of Raw Typha and are compared by their plant quality indicator results. The overall comparison of these three mixes shows a relative decline in the success with increasing amounts of Raw Typha in the media. Of these three media's, mix 10 produced the highest values in all categories. Mix 12 gave the lowest values in all plant quality indicators when compared to mixes from all other Media Designs, showing that 100% Raw Typha was the least successful in creating a suitable growing environment.

It can be concluded that mix 10 (35% Raw Typha, 35% peat, 30% perlite) provided the most suitable growing environment of this category. However, in comparison to mixes containing other Media Designs, this mix produced the lowest values in the number of flowers, stem diameter, and plant length. [redacted]

4.9.6 Summary of Trial 3 Analysis

Overall, mixes containing MD1 and MD2 produced plants that yielded the best results in each plant quality indicator category. Those containing MD3 and Raw Typha produced plants with fewer flowers and shorter stem lengths, indicating that ideal growth conditions were not present. The results of the control, mix 13, are located between the mixes containing MD3 and those

containing Raw Typha. It is inconclusive as to why the control was not as successful as mixes 1 through 6. Potentially, the watering schedule and nutrient supply was more suited to these mixes as opposed to the control. However, the exact cause could not be determined without further testing of the plants as other factors may have been involved. Mix 2, containing 70% MD1 and 30% perlite, produced plants with the most flowers and longest stems overall. While this shows that this mix created the best growing environment in this trial, mixes [redacted] should all be investigated further in the pursuit toward a 100% Typha-based media. Their similar outcomes suggest they could all be viable options for fostering petunia growth in the future.

4.9.7 Trial 4 Results

Trials 3 and 4 were exposed to different conditions during their growth periods in the test media. Since the rooted plugs of Trial 4 were grown only in the greenhouse, watering occurred once or twice a day via a watering can and fertilization occurred about twice a week. This differs from the seedlings of Trial 3 within the grow wall, where watering and fertilization occurred for one minute every two hours. With these different conditions, the results from Trial 4 cannot be directly compared to those of Trial 3. However, the two sets of results provide two perspectives on the success of the Media Designs.

The plant quality indicator results for Trial 4 are shown in Table 15.

Table 15. Plant quality indicator average results for Trial 4 of grow trials

Media Design	Mix Number	Number of Flowers	Fresh Weight (g)	Stem Diameter (mm)	Plant Length (mm)
MD1	1	7.00	6.98	2.18	121.26
	2	7.00	6.45	1.98	112.82
	3	7.17	7.81	2.05	116.33
MD2	4	9.17	7.73	2.29	117.48
	5	8.17	6.00	3.09	121.92
	6	7.33	7.16	2.16	123.09
MD3	7	6.00	6.97	1.65	122.96
	8	5.67	7.71	1.76	116.15
	9	7.33	8.03	2.23	100.39
Raw Typha	10	5.67	4.97	2.13	91.96
	11*	1.50	0.75	1.75	42.66
	12*	1.50	0.85	1.74	41.52
CTRL	13	6.50	4.62	2.18	62.08

*Plants died prior to indicator collection

4.9.8 Trial 4: Media Design 1 Analysis

Mixes 1, 2, and 3 contained increasing amounts of MD1 and are compared by their plant quality indicator results. Mix 1 produced flowers with the largest stem diameter and largest plant length. The number of flowers and fresh weight were less than that of mix 3 but were high compared to other mixes. Mix 2 produced flowers with a lower fresh weight, smaller stem diameter, and smaller plant length when compared to those produced by mixes 1 and 3. Mix 3 produced the most flowers and the highest fresh weight of the MD1 mixes. It is unclear whether the higher fresh weight was due to a higher root volume or due to the higher number of flowers.

Overall, all three mixes were very similar in their growth success. Therefore, it is inconclusive whether mix 1 (35% MD1, 35% peat, 30% perlite), mix 2 (70% MD1, 30% perlite), or mix 3 (100% MD1) provided a more suitable growing environment. Due to the similar results of the three mixes, it is inconclusive whether the amendments of peat and perlite were beneficial to MD1 in this trial.

4.9.9 Trial 4: Media Design 2 Analysis

Mixes 4, 5, and 6 contained increasing amounts of MD2 and are compared by their plant quality indicator results. Mix 4 produced the most flowers and highest fresh weight overall. It is unclear whether the higher fresh weight was due to a higher root volume or due to the higher number of flowers. When comparing mixes 4 and 5, stronger and taller plants were produced in mix 5, whereas shorter plants with more flowers were produced in mix 4. A factor that could have influenced this plant height difference was the placement of each mix within the planting trays. Of these three mixes, mix 4 was the only mix placed in an interior row of the tray. This could have limited growth by reducing the available space, and the access to light, that the plant had to grow. Mix 6 produced the lowest number of flowers and the smallest stem diameter which could indicate reduced strength of the plants. However, this mix also produced the tallest plants. As previously mentioned, this could be attributed to the placement of mix 6 on the edge of a tray where it had plenty of room to grow.

Overall, it is inconclusive whether mix 4 (35% MD2, 35% peat, 30% perlite) or mix 5 (70% MD2, 30% perlite) provided a more suitable growing environment. Due to the similar results of the three mixes, it is inconclusive whether the amendments of peat and perlite were beneficial to MD2 in this trial.

4.9.10 Trial 4: Media Design 3 Analysis

Mixes 7, 8, and 9 contained increasing amounts of MD3 and are compared by their plant quality indicator results. Mix 7 produced plants with the longest plant length, but also with the lowest stem diameter, fresh weight, and number of flowers. The small stem diameter implies weaker plants, and the reduced flower count also follows this theory of a less than ideal growing environment. Mix 8 yielded a reduced number of flowers when compared to mixes containing MD3 and mixes containing other Media Designs. It is likely that some type of nutrient imbalance was the cause of this reduced yield. Mix 9 performed the best in the flower number, fresh weight, and stem diameter categories. However, it produced plants with a reduced plant length. It is

unclear why these plants did not grow as tall, but the other parameters show that strong and healthy plants were produced in this mix.

Overall, mix 9 (100% MD3) created the most suitable growing environment. By observing that mixes 7 and 8 did not perform to the level of mix 9, it can be concluded that MD3 did not benefit from the addition of amendments.

4.9.11 Trial 4: Raw Typha Analysis

Mixes 10, 11, and 12 contained increasing amounts of Raw Typha and are compared by their plant quality indicator results. The overall comparison of these three mixes shows a clear decline in the success with increasing amounts of Raw Typha in the media. Mix 10 produced plants with the highest values for each plant quality indicator. All plants in mix 11 and 12 had died prior to indicator collection which resulted in record low values for each indicator. This shows that Raw Typha was the least successful overall in creating a suitable plant environment.

Overall, mix 10 (35% Raw Typha, 35% peat, 30% perlite) created the most suitable growing environment for this category. [redacted]

4.9.12 Summary of Trial 4 Analysis

Overall, mixes containing MD2 and MD3 yielded the highest performing plants across all plant quality indicator categories. However, mixes containing MD1 also produced results similar to those containing MD2 and MD3. Only mixes containing Raw Typha showed significantly reduced growth, indicating that ideal growth conditions were not present. The control's growth was similar to that of mixes containing MD3; however, it also had a significantly lower plant length than other mixes. The reasons for this reduction were not clear and further testing would be required.

The tray that held mixes 11 to 13 were found to be in an area of the greenhouse that was noticeably colder than spaces around it. At the time of discovery, all plants were still alive, and the tray was moved to a warmer spot immediately. However, the long-term effects of this temperature difference cannot be identified with certainty.

In this trial, the highest record for each plant quality indicator was held by a different mix, and many of the mixes showed similar levels of success. There are fewer noticeable trends in the Trial 4 data compared to Trial 3. It is worth noting that Trial 3 spent a total of 4.57 weeks in the test media mixes, whereas Trial 4 only spent 3 weeks. This means that more prominent trends may have appeared in Trial 4 if the plants were left to grow in the test media for longer. Based on the data collected for Trial 4, all mixes containing MD1, MD2, as well as mix 9 containing

MD3, should be further investigated as they could all be viable options for petunia growth in the future.

Unexpected results emerged from both the verification and validation stages of the project despite efforts to mitigate random errors and enhance accuracy, such as taking the average of triplicate measurements. These results may be explained by the limitations of the project, which are discussed in the next section. The project faced many complexities stemming from the extensive work conducted and the challenges that were encountered across each stage. Addressing these complexities is crucial to achieving true reliability and validity in the endeavour toward displacing peat with a Typha-based soilless growing media.

5 Project Limitations

The results presented in the previous two sections for both verification and validation stages are limited by the constraints of the project, unexpected challenges, and the availability of equipment and resources. These factors may have affected the analyzed results and arose during all three stages of the project: while processing the three Media Designs, conducting verification testing of the 11 technical specifications, and conducting validation testing using the grow trials.

5.1 Limitations with the Design Solutions

Conclusions on the feasibility of any of the three Media Designs in displacing peat within the commercial floricultural market are limited by their production. This includes the prolonged life cycle of the growing media from harvesting of the cattails conducted by a third-party company and the limitations of the chosen processing methods.

5.1.1 Limitations with Harvesting the Typha

[redacted]

5.1.2 Limitations with the Processing Methods

None of the chosen processing methods applied to Raw Typha were completely successful in achieving the properties provided by a commercially popular growing mix. Although plants continued to grow to the blooming stage during grow trials, not one Media Design passed all criteria to be met by technical specification testing. Most significantly, the primary technical specifications of water holding capacity and nitrogen immobilization both failed to pass their criteria. These discrepancies may have also hindered plants from reaching their full growth potential. It is probable that the specific implementation of the three processing methods contributed to these outcomes.

[redacted]

Although composting Raw Typha was successful in decreasing the C:N ratio and facilitating a high stability, the biological tests for nitrogen immobilization and phytotoxicity ultimately did not meet their passing criteria, indicating the remaining presence of growth-inhibitors in the media. [redacted]

[redacted] it is unknown if the full benefits of composting would have been realized had the original recipe been pursued.

The extent of benefits provided by milling, mainly water holding capacity, may have been limited by the single screen size [redacted] within the hammermill. To maintain the project budget, purchasing any alternative sizes was not pursued. Targeting a media with a higher number of larger particles and aggregates (i.e. clumps) may have been advantageous in providing the pore space needed for plant root penetration and aeration. When comparing the results provided by the 100% Typha-based mixes, mixes 6 and 9 (100% MD2 and 100% MD3, respectively) facilitated higher values for the chosen plant quality indicators, likely due to their well-graded particle size distribution with a higher proportion of larger particles. Mix 3 (100% MD1), which possessed significantly more smaller particles sized [redacted] generally resulted in the weakest growth data between the three mixes. This poor growth could also be attributed to the result of milling the composted media to create MD1: any aggregates visibly larger [redacted] were broken up.

After milling, the last stage in creating all Media Designs was pasteurization. Original plans included using an autoclave to achieve steam pasteurization; however, available autoclaves at the University of Manitoba could not be set to a temperature as low as the required [redacted] Instead, Media Designs were moistened with water, enclosed within [redacted], and placed in a [redacted]. It is unknown if the center of the sample within the bag truly reached [redacted] or if any inconsistent moistening of each batch placed in the oven contributed to the possible lowered effectiveness of pasteurization. This may be indicated by the failure of all Media Designs under the phytotoxicity test.

Had these limitations not arisen during the implementation of the three processing methods, the results from both the verification stage and the validation stage of the project may have been more favourable.

5.2 Limitations with the Verification Stage

Due to inexperience, inaccuracies may exist in the results obtained for the verification procedures performed by the design team. The timeline of the project did not allow for the sourcing of all relevant equipment and the subsequent practicing of all test procedures to verify that results would be replicable and reliable. This may explain the large discrepancy between the pH values obtained by the design team and by A&L.

As per communication with Dr. [redacted] a professor within the Department of Soil Sciences at the University of Manitoba, the common practice for these projects would be to outsource testing to a soil sampling laboratory where results are obtained by trained professionals. A&L, and other local Manitoban laboratories considered for this project, offered testing in packages, which included set lists of properties to be tested. Purchasing multiple packages or adding individual technical specifications to these lists was not cost-effective in comparison to the

project team conducting the tests on the University campus using readily available equipment. This is why only the four chemical properties and stability were outsourced. Future soilless media projects with a similarly extensive list of technical specifications should consider the benefits and drawbacks between labour and budget. When choosing to conduct tests internally, work plans should account for inexperience and the need to pursue reliability.

5.3 Limitations with the Validation Stage

Results obtained from the validation stage of the project possess limitations due to methods undertaken to design and prepare the grow trials, as well as the use of the grow wall.

5.3.1 *Limitations with the Preparation of Grow Trials*

Using different growing media and the handling of the seedlings during the beginning of project grow trials may have skewed the obtained plant quality indicator results. The period of transplanting may have also introduced stress to their growth that would not be experienced in a traditional horticultural setting. These instances resulting in possibly inaccurate data are listed and described below.

- Initial growth of the Orchard Mist seeds (used for Trial 3) and the Royal Velvet rooted plugs (Trial 4) occurred in a commercial peat-based growing mix, an ensured avenue toward successful or sustained growth.
- Transplanting both sources of seedlings involved displacing the plant from its established growth environment. The roots of the plugs had formed around a thin mesh material; removing this material resulted in substantial destruction of most root systems. Preserving most of the roots also meant that it was difficult to remove the entirety of the peat-based mix. Small traces and aggregates of the peat mix remained when transplanting the plants into the net cups.
- Media mixes were measured by mass. Significantly more perlite was observed when preparing the mixes. Measuring by mass did not account for the varying densities of the three components included in the media mixes: the Media Designs, peat, and perlite. Later communication with Dr. [redacted], a soilless media researcher for horticultural crops at Assiniboine Community College, revealed that most growers and researchers prepare their potting mixes on a volume basis.
- All plants were allowed to acclimatize in their respective media mixes and net cups within the Agriculture Greenhouse for at least one week before transport into the grow wall.

The initial growth in the peat-based mixes and the period of acclimatization before transport into the grow wall may have provided possible advantages that allowed the plants to sustain themselves in the Media Designs. Disadvantages in growth are represented by the disruption to the root systems and the measurement of each mix by mass. Due to these factors, it is inconclusive that the growth results obtained represent the true capabilities of the Media Designs.

5.3.2 Limitations with the Selected Plant Quality Indicators

The four plant quality indicators for validating the media were selected to ensure the collection of all data at least two weeks before the submission deadline of the final design report. This accommodated the extensive analysis and interpretation of results from both the verification and validation stages. However, subsequent analysis of the chosen parameters revealed to not fully represent plant growth performance, as it was difficult to identify consistent growth patterns within Trial 3 and 4 that could be connected to technical specification results. Re-testing was not possible as plants had already been destroyed after recording their fresh weight. Additional parameters could have been pursued, such as the dry weight, shoot to root ratio (by mass), and a nutrient content analysis (mainly nitrogen, phosphorus, and potassium) of the plant tissue. While measuring fresh weight may be advantageous, when the pricing of the plant is on a fresh weight basis, tracking dry weight would have removed possible fluctuations due to the dynamic nature of water content within fresh weight. The latter method is more relevant to a project such as this in tracking the true yield. Since information on possible nutrient deficiencies was not collected, it was impossible to determine if the nutrient solution recipe used in this project sufficiently supplied the correct proportions to support maximum growth.

5.3.3 Limitation with the Design of Grow Trial 4

Potential inconsistencies in the data collected for Trial 4 may be due to the crowded conditions of the trial. All 13 mixes were placed into three trays to minimize the total space used within the greenhouse, as activities were charged on a square footage basis. Randomization of the net cups within the trays would have been preferred; however, in this small amount of space, it was difficult to properly label each of the 78 net cups for easy identification. Instead, each of the six plants per test media mix were grouped together. This placement of net cups, side-by-side without randomization, may have led to competition for resources among the plants, as seen in the shorter plant height result from mix 4.

5.3.4 Limitations with the Design of Grow Trial 3

Inconsistencies from the validation data for Trial 3 could be attributed to the operational requirements of the hydroponic wall sourced from Harvest Today. Six limitations associated with the use of the wall to test the 13 media mixes have been identified and are described in the paragraphs below.

I. Only one irrigation cycle could be set for the entire wall. This meant that it was impossible to target the estimated watering needs of all 13 test media mixes, where the results of testing the WHC of all three Media Designs and Raw Typha showed a vast range of values. The frequent watering likely would have benefited the media with a lower WHC. Common practice by horticultural growers is to water plants “as needed” when dry media conditions are felt by hand. Due to the immediate dripping of solution that occurred when the media was pressed upon, the three Media Designs were likely over-watered, as they had relatively similar WHC values (MD1 possessed the highest at 25.59% ± 1.990%). The excess of water would have induced stress on the plants as the resulting oxygen deficient environment may have impeded root activity, such as

respiration and nutrient uptake.

II. Over-watering also increased the labour requirements in replenishing the 12.5-gallon reservoir. A significant volume of nutrient solution dripped out of the system with each watering due to the difficulty in sourcing net cups that fit tightly within the two-inch diameter ports. Bins and trays were purchased solely to be placed at the base of the wall and capture this excess. [redacted]

III. The use of the net cups within the wall also represents a limitation toward properly assessing growth results. The roots of the plants slightly penetrated past the thin mesh bag and through the slits of the net cups. As the hydroponic system frequently applied the nutrient solution directly onto these exposed roots, it is difficult to pinpoint the extent to which the media mixes contributed biochemical advantages (or disadvantages) or simply began to only provide physical support for the plant. If seedlings were transplanted into larger pots, the higher volume may have encouraged more robust root growth within the media, and therefore, more plant biomass (Poorter et al. 2012). The common practice by commercial growers is to water their plants once a day, either using a watering can or bottom-watering (to allow the growing media to absorb moisture through capillary action). The less frequent watering and presence of additional media would have allowed for the consideration of factors affecting growth, such as a low CEC failing to capture nutrients supplied to the media.

IV. The depletion of the reservoir due to dripping resulted in the largest stressor encountered to the plants in the wall. The pump in the wall shut off once the available volume of nutrient solution in the reservoir fell below its minimum capacity, which occurred during the first long weekend after grow trials had begun. Access to the building had not yet been granted and the LED lights could not be shut down since the Theia app required a short-range Bluetooth connection. Therefore, the continued operation of the LED lights likely stimulated drought conditions for the plants. Once access to the building was available, all plants were significantly wilted, with those housed in Raw Typha mixes found dead. Before this event, all plants within Trials 1 to 3 were growing. The impact of this stressor on the results for Trial 3 is unknown, potentially leading to decreased growth due to the extra time needed to recover from the substantial wilting.

V. [redacted] Although plants were randomized within their respective trials, each trial was positioned either along the left, middle, or right section of the wall. The PPFD measurements showed that the middle received the highest light intensity, resulting in the death of most Trial 2 plants and some Trial 3 plants that were closer to the centre. [redacted]

[redacted] Relative locations of Media Design mixes and Raw Typha mixes may have also affected growth. If a plant within a Media Design mix was located below a plant within a Raw Typha mix, the Media Design plant would be over-watered due to the low WHC of Raw Typha. If these positions were reversed, the higher WHC of the Media Designs would tend to absorb most of the applied nutrient solution and reduce the amount supplied to the Raw Typha mix.

VI. Finally, the dry environment within the Grain Storage Research Lab was unconventional for a plant growth experiment. While the temperature was similar to that of a traditional greenhouse (22°C), its 27.4% RH was significantly lower than the measured value of 67.7% in the Faculty of Agriculture Greenhouse. This may have affected the results of the validation grow trials, seen when comparing the rather consistent results of the trials in the Greenhouse against that in the wall. All plants in Trial 4 flowered (except Mixes 10-13 due to its tray being kept in a cooler area for a period of time). Flowers in Trial 3 bloomed significantly less, and at a slower rate, at the time of data collection. The dry conditions also contributed to the decision of supplying continuous irrigation, which would not be ideal for market as this would increase operational costs through water and energy use.

Although these limitations may have resulted in the misrepresentation of the true capabilities of Media Designs, their identification sheds light on areas for improvement. A general drawback toward the implementation of these Media Designs in industry would be the vast resources used during the project at little to no cost. Taking these into consideration would substantially increase the cost of production and testing, as most of the machinery and analytical equipment that were used in this project were purchased by faculty members at the University for thousands of dollars (identified in the Bill of Materials in Appendix D). Consequently, mitigating the effects of all the project limitations are crucial in the endeavour toward a 100% Typha media.

6 Recommendations

The breadth of production and testing completed for this project resulted in many limitations. Addressing them in future studies will support the progression toward a 100% Typha-based soilless growing media. To do this, key recommendations for the three stages of the project have been identified.

6.1 Recommendations on Processing Methods for the Design Solutions

Improvements on all three chosen processing methods should be pursued. Although the results of the verification tests generally showed improvements from Raw Typha, the two primary technical specifications, water holding capacity and nitrogen immobilization, did not meet the defined passing criteria. Recommendations on approaching each processing method are provided to target these criteria.

III. **For pasteurizing, pursue a steam method to ensure the media is uniformly heated to a temperature** Insufficient pasteurization within the drying oven may explain the failed phytotoxicity tests in all Media Designs. For small-scale studies, steam pasteurization can be conducted in a small household pressure cooker, which was available to the project team but ultimately not utilized due to the larger volume required to accommodate both verification and validation testing. In that case, future studies will need to source a larger vessel.

Before performing any of the processing methods, it would be recommended to conduct immediate prior testing on the Raw Typha to specifically target the desired results. Any changes due to [redacted] would most critically affect the composting process, in which the amount of [redacted] was selected to lower the original C:N ratio of the Raw Typha to the optimal 20-35:1 range.

6.2 Recommendations on Verification Testing

When verifying the performance of the media designs, **ensure all technical specification tests selected will produce replicable and reliable results**. Outsourcing these tests to an accredited soil sampling laboratory, such as A&L, will accomplish this. However, if the budget does not allow for the cost associated with external testing, projects should ensure that the workplan accommodates time to practice performing test procedures.

6.3 Recommendations on Validation Testing

When validating the performance of the media design, changes may be made at each life stage of the plants to align with industry standards and are as follows:

I. **Grow plants from seed within the Typha media design** to remove any advantages provided by utilizing seedlings that were grown in a peat-based growing mix. This will allow growth performance to be completely attributed to the quality of the Typha-based media design and simulate what is done in industry. Germinated plants can then remain in the mix for grow trial testing to track any sustained growth, instead of the out-of-order trial done in this project due to time and labour constraints.

   Transplanting the seedlings from their initial peat-based mix into the Typha designs was also inefficient in cost and labour. In the case of the rooted plugs, plants were ripped from their established homes, which greatly disrupted their root systems, and were painstakingly transplanted into small net cups. The peat-based media was immediately disposed of as waste.

II. **Grow plants in pots** instead of in a vertical hydroponic wall limited to a single irrigation schedule. This is especially important for grow trials consisting of several mixes with varying water and nutrient needs. Justification for this is as follows:

   i. The higher volume within pots would allow for the proper evaluation of the media design, rather than the nutrient solution, in supporting growth.
   ii. The single setting for irrigation cycles allocated equally over 24 hours on the Harvest Today wall did not target the individual needs of the 13 individual media mixes. In pots, watering can occur on an "as needed" basis and avoid wasting water as irrigation continued through the night when LED lights were shut off and plant stomata were closed.

[redacted]

[redacted]

III. **Ensure mixes are measured volumetrically** if grow trials are to include test media mixes using decreasing proportions of peat and perlite. By demonstrating adherence to standard practices, the likelihood of the adoption of a Typha media in a practical setting is increased.

IV. **Conduct grow trials within a typical controlled plant growth environment**, such as a greenhouse, with an RH similar to the standard of 67.7%. Plant growth performance could more reliably be attributed to the conditions provided by the Typha media, and not the frequent watering used to counteract the dry 27.4% RH environment in the Grain Storage Research Lab.

V. **Collect more informative plant quality indicators**, such as dry weight, the ratio of shoot-to-root mass, and leaf nutrient content. This may help to establish clearer trends that could be related to the verification results and provide more confidence in the feasibility of a Typha growing media.

Aligning with greenhouse standards during grow trials, facilitating replicable tests of technical specifications, and improving upon the three processing methods will optimize the current proof of concept. Once a 100% Typha media is achieved, it would be recommended to conduct a cost-benefit analysis that encompasses the full life cycle of the project (from the beginning, when harvesting the Typha plants, to the end, when flowers have bloomed and have reached sale-ready maturity). The project relied upon several external sources, such as various departments at the University of Manitoba, to lend most of the required materials and equipment at no cost. Based on correspondence with the appropriate contacts and taking into consideration the heavy machinery and analytical equipment, an approximate cost was calculated as $80 429.74 (the full itemized list with purchasing costs is provided in Appendix D). Nevertheless, implementing the recommendations discussed in this section on a smaller scale may work to enhance the likelihood that Typha may be adopted as a sound alternative soilless media in commercial greenhouses.

7 Conclusion

The increasing need for sustainable soilless growing media inspired Typha Co. to initiate this Typha Growing Media Project. Current Typha-based soilless media, exhibiting low water holding capacity and high nitrogen immobilization, have been improved upon in the three Media Designs created. These designs are as follows:

1. Media Design 1 (MD1): Composting + Milling + Pasteurizing
2. Media Design 2 (MD2): Composting + Pasteurizing
3. Media Design 3 (MD3): Milling + Pasteurizing

The success of each Media Design was assessed by 11 technical specifications, selected based on the physical, chemical, and biological properties of peat and other commonly used growing media. None of the Media Designs passed all criteria; however, [redacted] showed the greatest overall improvement when compared to unprocessed, shredded Typha, increasing its water holding capacity and decreasing its nitrogen immobilization. The results of [redacted] are followed by [redacted] and then [redacted] which both only improved in water holding capacity. Alongside the verification testing, germination and later stage grow trials were performed to further validate the results. In the germination trials, the test media mix containing [redacted] performed the best overall, with high numbers of germinated plants that had the largest leaves. Of the four grow trials conducted, data was collected for Trials 3 and 4. In Trial 3, [redacted] performed better when compared to [redacted] and unprocessed Typha, with the mix containing [redacted] producing the most flowers and longest stems. In Trial 4, [redacted] performed best, although Trial 4 displayed less noticeable trends overall.

Moving forward, further research into composted Typha-based media is recommended. Future testing involving larger pots, than the 2-inch net cups used, with more media surrounding the root system, would provide additional information on the success of the Media Designs. Larger pots would prevent the roots from directly contacting the nutrient solution supplied by a hydroponic system and therefore, would better test the ability of water and nutrients to travel through the media. [redacted] The assessment of a flower's full growth cycle, from seed to flowering, solely in the Typha-based media is recommended to mitigate positive or negative effects from the two-stage growing method used. Finally, a full cost-benefit analysis is recommended for the Typha-based media prior to scaling of the product to ensure economic viability.

The proof of concept presented justifies the further study and eventual use of Typha-based media within the indoor floricultural market, providing commercial growers with compelling insights on its viability. This market shift toward a locally sourced product, that is further leveraged by the environmental benefits of harvesting Typha, aligns with the main objective of displacing non-local, unsustainable peat-based media.

8 References

A&L Canada Laboratories, Inc. 2013. Evaluation of potting media analysis. Fact Sheet No. 544. London, Ontario: A&L Canada Laboratories, Inc. (2023/12/4)

ADAS Consulting Limited. 2005. Assessment of options and requirements for stability and maturity testing of composts. Banbury, England. Waste and Resources Action Programme. https://solvita.com/wp-content/uploads/2013/05/Stability-Maturity-Testing-WRAP.pdf (2023/10/28)

Altland, J.E., J.C. Locke and C.R. Krause. 2014. Influence of Pine Bark Particle Size and pH on Cation Exchange Capacity. *HortTechnology* 24(5): 554–559. https://doi.org/10.21273/HORTTECH.24.5.554

Altland, J.E. and C. Krause. 2009. Use of Switchgrass as a Nursery Container Substrate. *HortScience* 44(7): 1861–1865. https://doi.org/10.21273/HORTSCI.44.7.1861

Arenas, M., C.S. Vavrina, J.A. Cornell, E.A. Hanlon and G.J. Hochmuth. 2002. Coir as an alternative to peat in media for tomato transplant production. *HortScience* 37(2): 309–312. https://doi.org/10.21273/HORTSCI.37.2.309

ASTM International. 2015. Standard test methods for bulk and dry density of peat and peat products, D4531 − 15. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D4531-23.

ASTM International. 2017. Standard test methods for particle-size distribution (gradation) of soils using sieve analysis, D6913/D6913M-17. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D6913_D6913M-17.

ASTM International. 2022. Standard test method for pH of peat materials, D2976 – 22a. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D2976-22A

Atzori, G., C. Pane, M. Zaccardelli, S. Cacini and D. Massa. 2021. The role of peat-free organic substrates in the sustainable management of soilless cultivations. *Agronomy* 11(6): 1236. https://doi.org/10.3390/agronomy11061236

Awad, Y.M., S.-E. Lee, M.B.M. Ahmed, N.T. Vu, M. Farooq, I.S. Kim, H.S. Kim, M. Vithanage, A.R.A. Usman, M. Al-Wabel, E. Meers, E.E. Kwon and Y.S. Ok. 2017. Biochar, a potential hydroponic growth substrate, enhances the nutritional status and growth of leafy vegetables. Journal of Cleaner Production 156: 581–588. https://doi.org/10.1016/j.jclepro.2017.04.070.

Barral, M.T. and R. Paradelo. 2011. A review on the use of phytotoxicity as a compost quality indicator. *Dynamic Soil, Dynamic Plant*. (2023/10/17)

Barrett, G.E., P.D. Alexander, J.S. Robinson and N.C. Bragg. 2016. Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review. *Scientia Horticulturae* 212: 220–234. https://doi.org/10.1016/j.scienta.2016.09.030

Basirat M. 2011. Use of palm waste cellulose as a substitute for common growing media in aglaonema growing. *Journal of Ornamental and Horicultural Plants*: 1(1): 1-11. https://jornamental.rasht.iau.ir/article_513685_c2297104d8ec123fb9832a8262fc9632.pdf (2023/10/09)

Biswas, D. and S.A. Micallef. 2019. *Safety and Practice for Organic Food*. San Diego, UNITED STATES: Elsevier Science & Technology. https://doi-org.uml.idm.oclc.org/10.1016/C2016-0-02314-8

Blok, C., B. Eveleens and A. Van Winkel. 2021. Growing media for food and quality of life in the period 2020-2050. *Acta Horticulturae* (1305): 341–356. https://doi.org/10.17660/ActaHortic.2021.1305.46

Both, A.K., M.A. Helle, G. Madireddy and C.L. Cheung. 2021. Green chemical approach to fabricate hemp fiber composites for making sustainable hydroponic growth media. *ACS Agricultural Science & Technology* 1(5): 499–506. https://doi.org/10.1021/acsagscitech.1c00118

Bowler, P. 2009. Nursery manual for native plants: A guide for tribal nurseries. R. Kasten Dumroese, Tara Luna, Thomas D. Landis, editors. 2009. Washington DC: USDA Forest service. 302 pages. *Ecological Restoration* 27(4): 498–499. https://doi.org/10.3368/er.27.4.498-a

Brinton, W.F., E. Evans, M.L. Droffner and R.B. Brinton. 1995. Standardized test for evaluation of compost self- heating. *BioCycle*, 36:64-69. (2023/12/03)

Canadian Council of Ministers of the Environment (CCME). 2005. Guidelines for Compost Quality. PN-1340. Winnipeg, MB: Canadian Council of Ministers of the Environment. https://ccme.ca/en/res/compostgdlns_1340_e.pdf (2023/11/03)

Cannavo, P. and J.-C. Michel. 2013. Peat particle size effects on spatial root distribution, and changes on hydraulic and aeration properties. *Scientia Horticulturae* 151: 11–21. https://doi.org/10.1016/j.scienta.2012.12.021

Cannavo, P., S. Recous, M. Valé, S. Bresch, L. Paillat, M. Benbrahim and R. Guénon. 2022. Organic fertilization of growing media: Response of N mineralization to temperature and moisture. *Horticulturae* 8(2): 152. https://doi.org/10.3390/horticulturae8020152.

Caron, J. and Y. Zheng. 2021. Glossary of terms and basic characteristics to be reported in scientific publications on growing media. *Acta Horticulturae* (1317): 55–64. https://doi.org/10.17660/ActaHortic.2021.1317.7

Chambers, F.M., D.W. Beilman, and Z. Yu. 2011. Methods for determining peat humification and for quantifying peat bulk density, organic matter and carbon content for palaeostudies of climate and peatland carbon dynamics. *Mires and Peat* 7(7): 1-10 (2023/10/08)

Chen, L., M. de Haro Marti, A. Moore, C. Falen. 2011. Dairy compost production and use in Idaho: the composting process. https://www.vineyardteam.org/files/resources/Commercial%20compost%20production%20process.pdf (2023/11/03)

Choi, S., L. Xu and H.-J. Kim. 2019. Influence of physical properties of peat-based potting mixes substituted with parboiled rice hulls on plant growth under two irrigation regimes. *Horticulture, Environment, and Biotechnology* 60(6): 895–911. https://doi.org/10.1007/s13580-019-00179-9

Cloyd, R. A. and E. R. Zaborski. 2004. Fungus gnats, Bradysia spp. (Diptera: Sciaridae), and other Arthropods in commercial bagged soilless growing media and rooted plant plugs. *Journal of Economic Entomology* 97(2): 503–510. https://doi.org/10.1603/0022-0493-97.2.503

Corti, C. L. Crippa, P.L. Genevini and M. Centemero. 1998. Compost use in plant nurseries: hydrological and physicochemical characteristics. *Compost Science & Utilization* (6)1: 35-45.

https://www.tandfonline.com/doi/epdf/10.1080/1065657X.1998.10701907?needAccess=true (2023/10/09)
Crops and Horticulture Division Agriculture and Agri-Food Canada. 2021. Statistical Overview of the Canadian Ornamental Industry 2020. Government of Canada. http://agriculture.canada.ca/en/sector/horticulture/statistical-overview-canadian-ornamental-industry-2020 (2023/12/03)
Daily, G.C., P.A. Matson and P.M. Vitousek. 1997. Ecosystem services supplies by the soil. In *Nature's Services : Societal Dependence On Natural Ecosystems*, 113–115. Washington, D.C.: Island Press. (2023/12/04)
Depth of one irrigation. Sept. 18, 2023. Class notes for BIOE 4600, Department of Biosystems Engineering, University of Manitoba. (2023/12/06)
Di Lorenzo, R., A. Pisciotta, P. Santamaria and V. Scariot. 2013. From soil to soil-less in horticulture: quality and typicity. *Italian Journal of Agronomy* 8(4): 30. https://doi.org/10.4081/ija.2013.e30
Dobbie, K.E. and K.A. Smith. 2003. Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling variables: N_2O EMISSION FACTORS FOR AGRICULTURAL SOILS. *Global Change Biology* 9(2): 204–218. https://doi.org/10.1046/j.1365-2486.2003.00563.x
Dohan, R., D. Roy, R. Grosshans, P. Gass, M. McCandless and H.D. Venema. 2012. Cattail (Typha spp.) harvesting in Manitoba: a legislative and market analysis for operationalization and carbon emission offsets. International Institute for Sustainable Development. Winnipeg, Manitoba. https://www.iisd.org/system/files/publications/nr_cattail_harvesting_mb.pdf (2023/10/12)
Dombrowsky, M. 2012. Growing substrates comprised of composted materials and reduced peat moss for production of greenhouse potted *Gerbera*, M.S. thesis, Department of Environmental Biology, University of Guelph, Guelph, ON. https://atrium.lib.uoguelph.ca/server/api/core/bitstreams/aa8aed0a-c5ad-4fd6-8c1c-f63364bb6904/content (2023/12/06)
Doubrava, N. and R.F. Polomski. 2018. Why plants fail to flower or fruit. Home & Garden Information Center. https://hgic.clemson.edu/factsheet/why-plants-fail-to-flower-or-fruit/#:~:text=Nutrient%20Imbalance%3A%20Too%20much%20nitrogen,flower%20production%20or%20poor%20pollination (2024/03/12)
Emino, E.R. and P.R. Warman. 2004. Biological assay for compost quality. *Compost Science & Utilization* 12(4): 342–348. https://doi.org/10.1080/1065657X.2004.10702203
Evans, M.R. 2011. Physical properties of and plant growth in peat-based root substrates containing glass-based aggregate, perlite, and parboiled fresh rice hulls. *HortTechnology* 21(1): 30–34. https://doi.org/10.21273/HORTTECH.21.1.30
Evanylo, G. 2020. Confined Animal Manure Managers Workshop. https://www.clemson.edu/extension/camm/manuals/proceedings/camm_2020/07_compost_quality_and_standards_camm_jan_2020.pdf (2024/03/13)
Fluence. n.d. About PAR, PPF, And PPFD. https://fluence-led.com/science-articles/horticulture-lighting-metrics/ (2024/3/18)
Fussy, A. and J. Papenbrock. 2022. An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. *Plants* 11(9): 1153. https://doi.org/10.3390/plants11091153

Gallegos-Cedillo, V.M., F. Diánez, C. Nájera and M. Santos. 2021. Plant agronomic features can predict quality and field performance: a bibliometric analysis. *Agronomy* 11(11): 2305. https://doi.org/10.3390/agronomy11112305

Gizas, G. and D. Savvas. 2007. Particle size and hydraulic properties of pumice affect growth and yield of greenhouse crops in soilless culture. *HortScience* 42(5): 1274–1280. https://doi.org/10.21273/HORTSCI.42.5.1274

Global Nature Fund. 2013. Lake Winnipeg named world's most threatened lake this year. https://www.globalnature.org/37072/HOME/Press/Press-Archives/resindex.aspx?newsid=1573 (2023/10/09)

Goh, K.M. and R.J. Haynes. 1977. Evaluation of potting media for commercial nursery production of container-grown plants: 1. Physical and chemical characteristics of soil and soilless media and their constituents. *New Zealand Journal of Agricultural Research* 20(3): 363–370. https://doi.org/10.1080/00288233.1977.10427348

Gómez, R.B., F.V. Lima and A.S. Ferrer. 2006. The use of respiration indices in the composting process: a review. *Waste Management & Research: The Journal for a Sustainable Circular Economy* 24(1): 37–47. https://doi.org/10.1177/0734242X06062385

Gorsuch, J.W., R.O. Kringle and K.A. Robillard. 1990. Chemical effects on the germination and early growth of terrestrial plants. *Plants for Toxicity Assessment, ASTM STP 1091:* 49-58 (2023/10/08)

Government of British Columbia. 2015. Nursery factsheet: Importance of aeration in container media. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/crop-production/importance_of_aeration_in_container_media_2015.pdf (2023/12/07)

Greenhouse Soil Pasteurization. 2023. https://www.greenhouse-management.com/greenhouse_management/soil_pasteurization_fumigation_solarization/greenhouse_soil_pasteurization.htm (2023/10/28)

Grigatti, M., M.D. Pérez, W.J. Blok, C. Ciavatta and A. Veeken. 2007. A standardized method for the determination of the intrinsic carbon and nitrogen mineralization capacity of natural organic matter sources. *Soil Biology and Biochemistry* 39(7): 1493–1503. https://doi.org/10.1016/j.soilbio.2006.12.035

Grosshans, R.E., H.D. Venema, N. Cicek and G. Goldsborough. 2011. Cattail farming for water quality: Harvesting cattails for nutrient removal and phosphorous recovery in the watershed. *Proceedings of the Water Environment Federation* 2011(1): 1107–1132. https://doi.org/10.2175/193864711802867478

Grosshans, R.E and L. Grieger. 2013. Cattail biomass to energy: commercial-scale harvesting of cattail biomass for biocarbon and solid fuel. International Institute for Sustainable Development. Winnipeg, MB. https://www.iisd.org/system/files/publications/cattail-biomass-to-energy-commercial-scale-harvesting-solid-fuel.pdf (2024/03/21)

Gruda, N. 2019. Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. *Agronomy* 9(6): 298. https://doi.org/10.3390/agronomy9060298

Handreck, K.A. 1992. Rapid assessment of the rate of nitrogen immobilisation in organic components of potting media: I. method development. *Communication in Soil Science and Plant Analysis*. 23(3&4): 201-215. (2023/11/04).

Harris, R. 1992. Root-Shoot Ratios. *Arboriculture & Urban Forestry* 18(1): 39–42. https://doi.org/10.48044/jauf.1992.009.

Harrison, R.B. 2008. Composting and Formation of Humic Substances. In *Encyclopedia of Ecology*, 713–719. Elsevier. https://doi.org/10.1016/B978-008045405-4.00262-7

Hartung, C. and E. Meinken. 2021. Fen plant biomass as growing media constituent – cultivation of Pelargonium zonale and Begonia × hiemalis in peat reduced mixtures with composted fen plant biomass. *Acta Hortic* 1317: 17–22. https://doi.org/10.17660/ActaHortic.2021.1317.3.

Haynes, R.J., O.N. Belyaeva and Y.-F. Zhou. 2015. Particle size fractionation as a method for characterizing the nutrient content of municipal green waste used for composting. *Waste Management* 35: 48–54. https://doi.org/10.1016/j.wasman.2014.10.002

Henry, J., B.E. Whipker and G.W. Owen. 2018. Nutritional Monitoring Series: Petunias (Petunia ×atkinsiana). (2024/03/23)

Kader, A. 2002. Quality parameters of fresh-cut fruit and vegetable products. *Fresh-Cut Fruits and Vegetables.* https://doi.org/10.1201/9781420031874.ch2.

Khan, A., N. Savidov, J. Zhang, J. Yang, T. Anderson, D. Harfield and A.O. Anyia. 2015. Biochar substrate for hydroponic vegetable production. In *Biochar: Production, Characterization and Applications*, eds. Y. Sik Ok, S.M. Uchimiya, S.X. Chang and N. Bolan, 274-292. Boca Raton: CRC Press. https://doi-org.uml.idm.oclc.org/10.1201/b18920

Kipp, J.A., G. Wever and C. De Kreij. 2001. International Substrate Manual. *Elsevier*. (2023/10/07)

Landis, T.D. and K.R. Dumroese. 2006. Monitoring electrical conductivity in soils and growing media, Report Number R6-CP-TP-04–2006. Portland, OR: USDA Forest Service, Pacific Northwest Region, State and Private Forestry, Cooperative Programs. https://www.researchgate.net/publication/272817935_Monitoring_electrical_conductivity_in_soils_and_growing_media (2023/12/04)

Landis, T.D., D.F. Jacobs, K.M. Wilkinson and T. Luna. 2014. Growing Media. In *Tropical Nursery Manual: A Guide to Starting and Operating a Nursery for Native and Traditional Plants*, 101–122. U.S. Department of Agriculture, Forest Service. https://www.fs.usda.gov/rm/pubs_series/wo/wo_ah732.pdf (2023/12/04)

Leiber-Sauheitl, K., H. Bohne and J. Böttcher. 2021. First steps toward a test procedure to identify peat substitutes for growing media by means of chemical, physical, and biological material characteristics. *Horticulturae* 7(7): 164. https://doi.org/10.3390/horticulturae7070164

Lin, L., F. Xu, X. Ge and Y. Li. 2019. Biological treatment of organic materials for energy and nutrients production—Anaerobic digestion and composting. In *Advances in Bioenergy*, 121–181. Elsevier. https://doi.org/10.1016/bs.aibe.2019.04.002

Magdoff, F. and H. Van Es. 2021. *Building Soils for Better Crops: Ecological Management for Healthy Soils*. Fourth edition. Handbook series bk. 10. College Park: Sustainable Agriculture Research & Education. (2024/03/16)

Morgan, L. 2021. *Hydroponics and Protected Cultivation: A Practical Guide*. Boston, MA: CAB International. (2024/03/23)

Nguyen, V.T.H., T. Kraska, W. Winkler, S. Aydinlik, B.E. Jackson and R. Pude. 2022. Primary mechanical modification to improve performance of miscanthus as stand-alone growing substrates. *Agronomy* 12(2): 420. https://doi.org/10.3390/agronomy12020420

Noguera, P., M. Abad, R. Puchades, A. Maquieira and V. Noguera. 2003. Influence of particle size on physical and chemical properties of coconut coir dust as container medium. *Communications in Soil Science and Plant Analysis* 34(3–4): 593–605. https://doi.org/10.1081/CSS-120017842

Northeast Region Certified Crop Advisor (NRCCA) Study Resources. 2023. Cornell University. https://nrcca.cals.cornell.edu/nutrient/CA5/CA0539.php (2023/12/01)

Pancerz, M., M. Czaplicka and P. Bąbelewski. 2023. Assessment of fresh miscanthus straw as growing media amendment in nursery production of Sedum spectabile 'stardust' and Hydrangea arborescens 'annabelle.' *Plants* 12(8): 1639. https://doi.org/10.3390/plants12081639

Pandey, S.K., S.N. Saravaiya, A.K. 2021. Soil Pasteurization. In Precision Farming and Protected Cultivation, CRC Press. (2023/12/6)

Paradelo, R., A.B. Moldes, B. Prieto, R.-G. Sandu and M.T. Barral. 2010. Can stability and maturity be evaluated in finished composts from different sources? *Compost Science & Utilization* 18(1): 22–31. https://doi.org/10.1080/1065657X.2010.10736930

Poorter, H., J. Bühler, D. Van Dusschoten, J. Climent and J.A. Postma. 2012. Pot size matters: a meta-analysis of the effects of rooting volume on plant growth. Functional Plant Biology 39(11): 839. https://doi.org/10.1071/FP12049

Raviv, M., J. Heinrich Lieth and A. Bar-Tal. 2019. *Soilless Culture: Theory and Practice*. 2nd edition. London: Academic Press. https://doi.org/10.1016/C2015-0-01470-8

Relative Humidity Calculator. 2024. https://www.1728.org/relhum.htm#google_vignette (2024 /3/18)

Rezanezhad, F., J.S. Price, W.L. Quinton, B. Lennartz, T. Milojevic and P. Van Cappellen. 2016. Structure of peat soils and implications for water storage, flow and solute transport: A review update for geochemists. *Chemical Geology* 429: 75–84. https://doi.org/10.1016/j.chemgeo.2016.03.010

Russ, K. 2007. Petunia. *Home & Garden Information Center | Clemson University, South Carolina*. https://hgic.clemson.edu/factsheet/petunia/ (2023/12/6)

Saharinen, M.H. 1998. Evaluation of Changes in CEC During Composting. *Compost Science & Utilization* 6(4): 29–37. https://doi.org/10.1080/1065657X.1998.10701938

Santamaría, A.R., J.E. Candelo-Becerra and F.E. Hoyos Velasco. 2022. Modelling of phosphorus accumulation in an aeroponic coriander crop. *International Journal of Agricultural & Biological Engineering* 15(6): 73–79. https://doi.org/10.25165/j.ijabe.20221506.6760

Savvas, D. and N. Gruda. 2018. Application of soilless culture technologies in the modern greenhouse industry – A review. *European Journal of Horticultural Science* 83(5): 280–293. https://doi.org/10.17660/eJHS.2018/83.5.2

Silva, P.F.D., B.D.B.D. Santos, J. Dantas Neto, A.S.D. Melo, R.M.D. Matos, S.I. Bonou, T.J.A.D. Silva, E.M. Bonfim-Silva, A.P.C.G. Berilli and T.F. Duarte. 2023. Effect of Electrical Conductivity Levels and Hydrogen Peroxide Priming on Nutrient Solution Uptake by Chives in a Hydroponic System. *Agriculture* 13(7): 1346. https://doi.org/10.3390/agriculture13071346

Singh, P. 2022. Preliminary experiments exploring potential of Typha spp. for partial peat replacement in the soilless growing media. Russ Edwards School of Agriculture and Environment Assiniboine Community College. Brandon, MB. (2023/10/09)

Sliwoski, K. 2018. Are Cattails Good or Bad? How Can They Be Successfully Managed? *SOLitude Lake Management: Full-Service Lake And Pond Management*. https://www.solitudelakemanagement.com/cattails-good-bad-successfully-managed/ (2023/10/12)

Smith, T. 2013. Know Your Water Holding Capacity. *Crop Quest.* https://www.cropquest.com/know-your-water-holding-capacity/ (2024/2/19)

Solvita Compost Test Reveals Wide Range CO_2 Detection Using IRGA. 2021. https://solvita.com/solvita-compost-test-reveals-wide-range-co2-detection-using-irga/ (2024/3/13).

Sun Gro. 2024. Air Porosity and Water-Holding Ability of Media Components. Sun Gro. https://www.sungro.com/en-ca/air-porosity-and-water-holding-ability-of-media-components/ (2024/2/19)

Tsakaldimi, M. 2006. Kenaf (Hibiscus cannabinus L.) core and rice hulls as components of container media for growing Pinus halepensis M. seedlings. *Bioresource Technology* 97(14): 1631–1639. https://doi.org/10.1016/j.biortech.2005.07.027

Vandecasteele, B. 2023. Oxygen uptake rate versus CO2 based respiration rate for assessment of the biological stability of peat, plant fibers and woody materials with high C:N ratio versus composts. *Waste Management* 167: 74–80. https://doi.org/10.1016/j.wasman.2023.05.019

Venema, H. and A. Murray. 2022. Rosser biomass harvest fall 2021 draft report. Manitoba: Strategic Systems Engineering Inc. (2023/11/06)

Yadav, K. and S. Jagadevan, 2020. Influence of process parameters on synthesis of biochar by pyrolysis of biomass: an alternative source of energy. In *Recent Advances in Pyrolysis*, ed. H.A. Ibrahim. IntechOpen. https://doi.org/10.5772/intechopen.88204

Yang, C., N. Liu and Y. Zhang. 2019. Soil aggregates regulate the impact of soil bacterial and fungal communities on soil respiration. *Geoderma* 337: 444–452. https://doi.org/10.1016/j.geoderma.2018.10.002

Zhang, Y., K. Wang, J. Wang, C. Liu and Z. Shangguan. 2021. Changes in soil water holding capacity and water availability following vegetation restoration on the Chinese Loess Plateau. *Scientific Reports* 11(1): 9692. https://doi.org/10.1038/s41598-021-88914-0

Zucconi, F., M. de Bertoldi, M. Forte and A. Pera. 1981. Evaluating toxicity of immature compost. *BioCycle* 2(2): 54–57. (2023/10/08)

Appendix A: Detailed Technical Specification Procedures and Data

A detailed description of each verification procedure is provided for one Media Design conducted in triplicate. Each test is repeated three more times for a total of four tests (MD1, MD2, MD3, Raw Typha).

A1 Total Porosity, WHC & Air-Filled Porosity Testing (S2.5, S2.6, S2.7)

Test Lead: Jayda Cockwell

Equipment required:

- Three containers with a drainage hole at the bottom.
- Plug or waterproof tape for sealing the drainage holes.
- Graduated cylinder for measuring liquid volume.
- Three watertight pan that is wider than the bottom of the container.
- 750mL of water.
- 300mL of media.

Procedure:
Adapted from British Columbia Nursery factsheet (Government of British Columbia 2015):

1. Seal the drainage hole on all three of the containers.
2. Fill each container with 250ml of water.
3. Measure the volume of water in each container.
4. Record as container volume for trial 1, trial 2 and trial 3.
5. Empty and dry the containers.
6. Fill the containers with 100ml of the growing media each.
7. Slowly saturate the growing medium in each container by gradually pouring water onto the surface.
8. Continue adding water over a period of an hour and a half until the growing media is completely saturated in each container.
9. Record the total volume of water added to each container as total pore volume for the respective trial (1, 2 or 3).
10. Place each container over a watertight pan and remove the seal from the container's drainage holes.
11. Allow all the free water to drain out of each container, can take up to several hours.
12. Measure the amount of drainage water for each container and record as aeration pore volume for the respective trial (1, 2 or 3).
13. Repeat procedure again for each Media Design and Raw Typha.

Calculations:
Use Equations 1, 2, and 3 to compute total porosity, air filled porosity and water filled porosity, respectively:

$$Total\ porosity\ (\%) = \frac{(total\ pore\ volume)}{(container\ volume)} \times 100 \qquad \text{Equation 1}$$

$$Air\ filled\ porosity\ (\%) = \frac{(aeration\ pore\ volume)}{(container\ volume)} \times 100 \qquad \text{Equation 2}$$

$$Water\ holding\ capacity\ (\%) = total\ porosity - air\ filled\ porosity \qquad \text{Equation 3}$$

Data:

The results of the total porosity, water holding capacity, and air-filled porosity procedure are displayed in Tables A1 to A4 for each of the media tested.

Table A1. Porosity data for Media Design 1

[redacted]

Table A2. Porosity data for Media Design 2

[redacted]

Table A3. Porosity data for Media Design 3

[redacted]

Table A4. Porosity data for Raw Typha

[redacted]

A2 Nitrogen Immobilization Testing (S1.2)

Test Lead: Hannah Lubi

Equipment required:

- One 6-cell seedling trays of at least 125 mL, with drainage holes
- 600 mL of the soilless growing media sample, moistened
- Rack
- One bin
- 1.2L deionized water
- 1.2L potassium nitrate (KNO_3) solution at a concentration of 75 mg/L
- Six beakers
- Stirring rod
- Three funnels
- Six filter papers (No. 1 Qualitative Paper, Whatman)
- Six 0.45-micron syringe filters (25 mm diameter)
- Four syringes
- Six 10 mL glass collection vials
- Parafilm
- Flow Injection Analyzer for NO_3-N concentration (ASX-410 XYZ AutoSampler, Lachat Instruments)
- Incubator (KB115 Kb Series Refrigerated Incubator, Binder)

Procedure:
Presented by Dombrowsky (2012), as adapted from Handreck (1992):

1. Fill each cell of a seedling tray with 100 mL of the moist media sample, tapping the bottom against a counter as it is filled to avoid large air spaces within the sample.
2. Place the tray on a rack over a bins to collect the excess liquid that will be poured through the media.
3. Slowly pour 100 mL deionized water into each cell. Allow to drain for 30 minutes.
4. Slowly pour 100 mL KNO_3 solution into each cell. Allow to drain for 30 minutes. Pour another 100 mL of KNO_3 solution into each cell and allow to drain for 15 minutes.

5. Give each tray a sharp vertical shake to ensure any excess water at the bottom of the cells is removed. Allow to sit for 5 minutes.
6. Transfer the contents of three of the six cells in one tray into three separate beakers, each filled with 100 mL deionized water. Mix using a stirring rod to create a slurry. Allow to sit for 5 minutes.
    a. To remove large particles, pour each slurry into individual funnels with a filter paper placed inside and allow each to drain into another beaker.
    b. To prepare the samples for flow injection analysis, use a syringe to collect a minimum of 5 mL of the drained solution. Connect a 0.45-micron syringe filter to the tip of the syringe and dispense the filtered solution into one of the glass collection vials. Cover with Parafilm.
    c. Measure the NO_3-N concentration of the double-filtered solution using the Flow Injection Analyzer to obtain values for Day 0.
7. Place the remaining three samples into an incubator set at 21°C for four days.
    a. After the incubation period is complete, repeat Step 6 to obtain the concentration of NO_3-N for Day 4.
8. Calculate the nitrogen drawdown index (NDI) by dividing the concentration of NO_3-N at Day 4 by the concentration of NO_{3-}-N at Day 1.

Calculations:
The NDI is calculated with Equation 4:

$$NDI = \frac{[NO_3 - N]_{Day\ 4}}{[NO_3 - N]_{Day\ 0}} \qquad \text{Equation 4}$$

Where $[NO_3\text{-}N]_{Day\ 4}$ is the concentration of nitrogen contained in nitrate present in the solution on Day 4, and $[NO_3\text{-}N]_{Day\ 1}$ is the concentration of nitrogen contained in nitrate present in the solution on Day 0.

Data:
The results of the nitrogen immobilization test procedure are presented in Tables A5 to A8, where Equation 4 was used to calculate the NDI for each of the four samples.

Table A5. Nitrogen immobilization data for NDI of MD1

Table A6. Nitrogen immobilization data for NDI of MD2

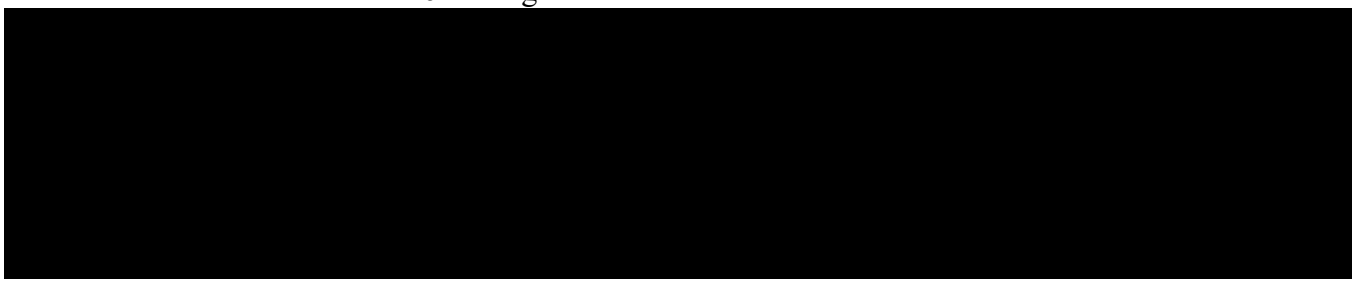


Table A7. Nitrogen immobilization data for NDI of MD3

Table A8. Nitrogen immobilization data for NDI of Raw Typha

A3 pH Testing (S2.2)

Test Lead: Kristen Semenko

Equipment required:

- Bluelab combo meter (pH Meter)
- Six 100 mL glass beakers
- Six glass funnels
- Thermometric Device readable to 0.5ºC or better and having an accuracy of at least ± 0.5 ºC.
- 150 mL Distilled water
- Buffer solutions of pH 4.0 and 7.0
- Latex or rubber gloves
- Safety glasses
- Wash/rinse bottle
- Stirring rod

- 150 mL Calcium Chloride Hydrate Solution ($CaCl2 \cdot 2H2O$) having a molarity of 0.01 M and a pH between 5 and 7

Procedure:
Adapted from ASTM D2976-22a Standard Test Method for pH of Peat Materials (2022):

1. Standardize the pH meter using the manufacturer's instructions of the meter. Buffers of 4.0 and 7.0 are used for this standardization.
2. Record the date, time, and name or initials of person completing the standardization.
3. Redo this standardization after 10 specimens or at the end of testing, whichever occurs first.
4. Obtain two similar specimens of the material, each 50 ± 5 mL.
5. Measure and record the volume of each specimen to the nearest 1 mL.
6. Place one of the test specimens in a glass beaker.
7. Add the same amount of test water in mL as the specimen volume in mL to make a 1 to 1 slurry.
8. Place the other test specimen into a glass beaker and add the same amount of 0.01 M calcium chloride solution in mL as the specimen volume to make a 1 to 1 slurry.
9. Initially mix each specimen thoroughly for approximately 10 s and allow them each to stand/soak for 30 min at room temperature (15 to 25°C).
10. After 30 min, take and record the temperature of each specimen to the nearest 1°C to verify they are at room temperature.
11. Then, mix the specimen for approximately 10 s just prior to taking the pH measurement.
12. If there is a clear aqueous part of the specimen, fully submerge the pH electrode into this aqueous section. Be careful not to insert the electrode into the solids. If there is no clear aqueous part of the specimen, pour the specimen carefully through a glass funnel so that the solids stay in the funnel and the liquid portion drains into a beaker beneath. Then, fully submerge the pH electrode into the beaker of liquid.
13. Read and record the pH of this specimen to the nearest 0.1 pH unit and indicate which pH is measured: in test water or calcium chloride solution.
14. If the pH meter does not automatically compensate for temperature, determine and record it to the nearest 0.5°C or better and follow the manufacturer's instructions to compensate for the temperature.
15. Rinse off the pH electrode using a wash/rinse bottle filled with test water making sure to remove any sample.
16. Repeat steps 10) to 14) for the other specimen and other trials.

Data:
The results of the pH procedure are displayed in Tables A9 to A12 for each of the media tested. The final results are consolidated in Table A13. They do not appear in the main body of the report due to issues with the accuracy of the results, as stated in Section 3.2 of the report.

Table A9. pH data for Media Design 1

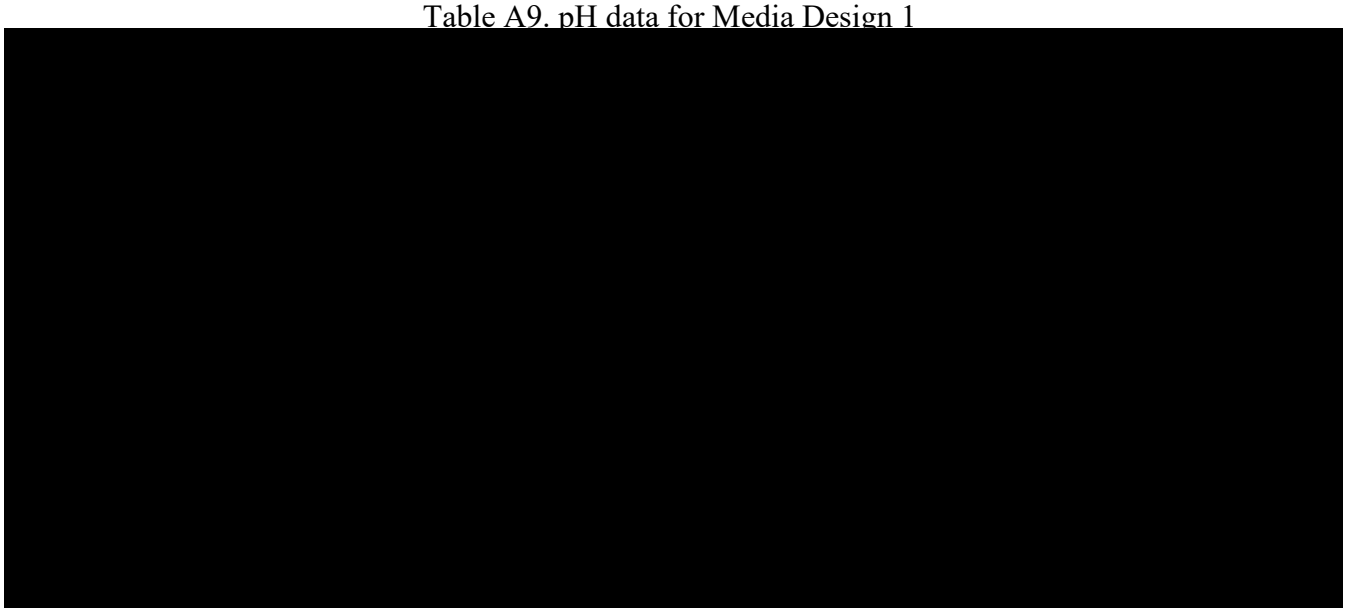


Table A10. pH data for Media Design 2

Table A11. pH data for Media Design 3

Table A12. pH data for Raw Typha

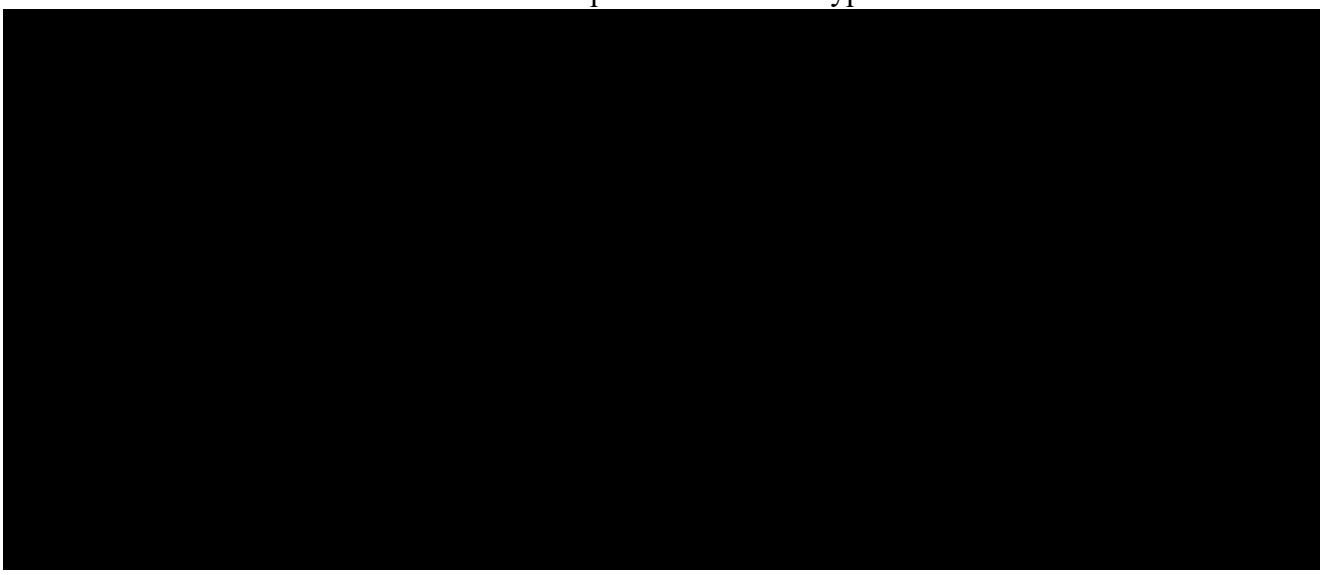


Table A13. Final pH results from internal testing

A4 Bulk Density Testing (S2.4)

Test Lead: Kiara Calista

Equipment required:

- Drying oven (VWR® Signature™ High-Performance Horizontal Air Flow Oven)
- Balance – sensitive to 0.1 g
- 0.5L known volume measure
- 1.5L of sample

- Three aluminum foil trays
- Desiccator
- Silica gel desiccant

Procedure:
Adapted from ASTM D4531 Standard Test Method for Bulk and Dry Density of Peat and Peat Products:

1. Collect media sample with known volume measure.
2. Record the mass of the aluminum foil tray.
3. Transfer the sample to the tray. Record the moist mass of the sample.
4. Dry the sample in a drying oven at 105°C for 24 hours.
5. Place sample in desiccator to cool for 2-3 minutes.
6. Record the dry mass of the sample.
7. Repeat for a total of three samples.

Calculations:
To calculate the dry bulk density (p_d), Equation 5 is used:

$$\rho_d = \frac{M_s}{V} \qquad \text{Equation 5}$$

Where:
M_s = mass of dry specimen, g
V = volume of specimen, mL or cm^3

Data:
The results of the bulk density procedure are shown in Tables A14 to A17 for each media tested.

Table A14. Bulk density data for Media Design 1

Table A15. Bulk density data for Media Design 2

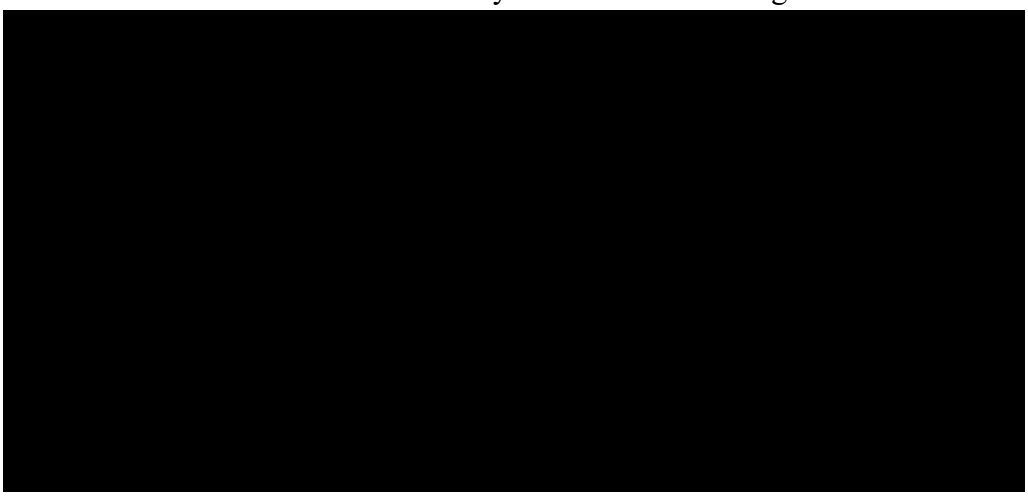
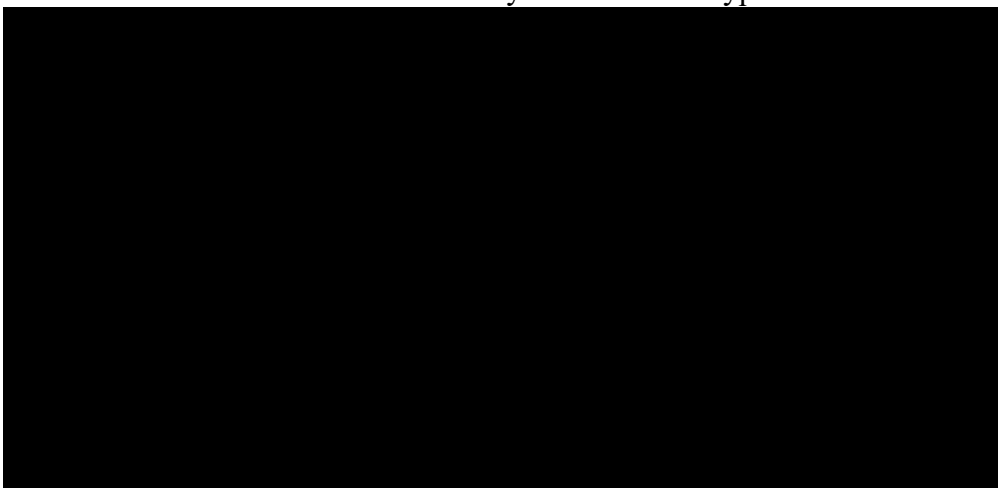


Table A16. Bulk density data for Media Design 3

Table A17. Bulk density data for Raw Typha



A5 Phytotoxicity Testing (S2.10)

Test Lead: Kiara Calista

Equipment required:

- 120mL distilled water
- 9g sample
- Four 250mL beakers
- Magnetic stirrer
- Centrifuge (ThermoFisher Scientific Centrifuge Model Sorvall Legend RT+)
- Four centrifuge tubes
- Refrigerator
- Four filter papers (Sigma-Aldrich Whatman WHA1001090)
- Four 90mm petri dishes with lids
- Forty Chinese cabbage seeds
- Incubator (KB115 Kb Series Refrigerated Incubator, Binder)
- Calipers

Procedure:
Adapted from Emino and Warman (2004) and Warman (1998):

1. Dilute the sample to a 1:10 (w/v) ratio with 3g of sample and 30mL of distilled water.
2. Place the solution in a beaker and stir for 1 hour with a magnetic stirrer.
3. Transfer sample from beaker to labeled centrifuge tube.
4. Samples are stored in fridge for one day.
5. Centrifuge sample for 1 hour at 2000 rpm and filter.
6. Samples are stored in fridge for three days.
7. Place a filter paper at the bottom of a petri dish.
8. Place 10 seeds on filter paper.
9. Moisten filter paper with 5 mL of extract.
10. Cover the petri dish with a lid.
11. Repeat steps 7-10 for a total of 3 petri dish extract samples.
12. Repeat steps 7-10 moistening the filter paper with distilled water instead of extract for the control.
13. Allow seeds to germinate in a dark incubator at 20°C.
14. Record the number of germinated seeds and the root elongation at 72 hours.

Calculations:
The equations for calculating the Germination Index (GI), from relative seed germination and relative root growth, are from Zucconi et al. (1981).

$$RSG = \frac{SG_{extract}}{SG_{control}} \cdot 100\% \qquad \text{Equation 6}$$

Where:
RSG = relative seed germination
$SG_{extract}$ = number of seeds germinated in extract
$SG_{control}$ = number of seeds germinated in control

$$RRG = \frac{RL_{extract}}{RL_{control}} \cdot 100\% \quad \text{Equation 7}$$

Where:
RRG = relative root growth
$RL_{extract}$ = mean root length in extract
$RL_{control}$ = mean root length in control

$$GI = \frac{RSG \cdot RRG}{100\%} \quad \text{Equation 8}$$

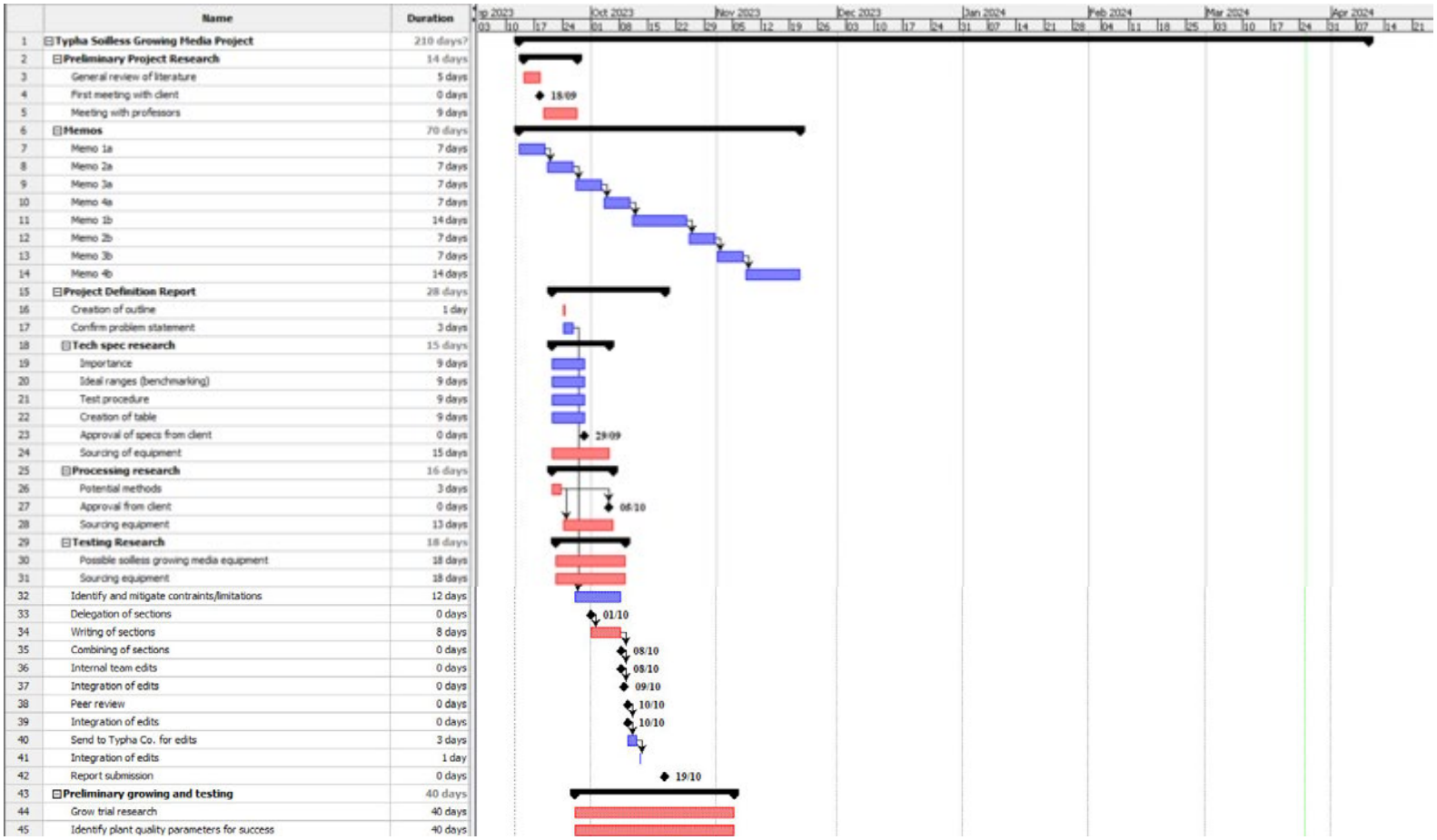
Where:
GI = germination index

Data:
The results of the phytotoxicity procedure are displayed in Table A18 for each of the media tested.

Table A18. Germination index data for phytotoxicity criteria

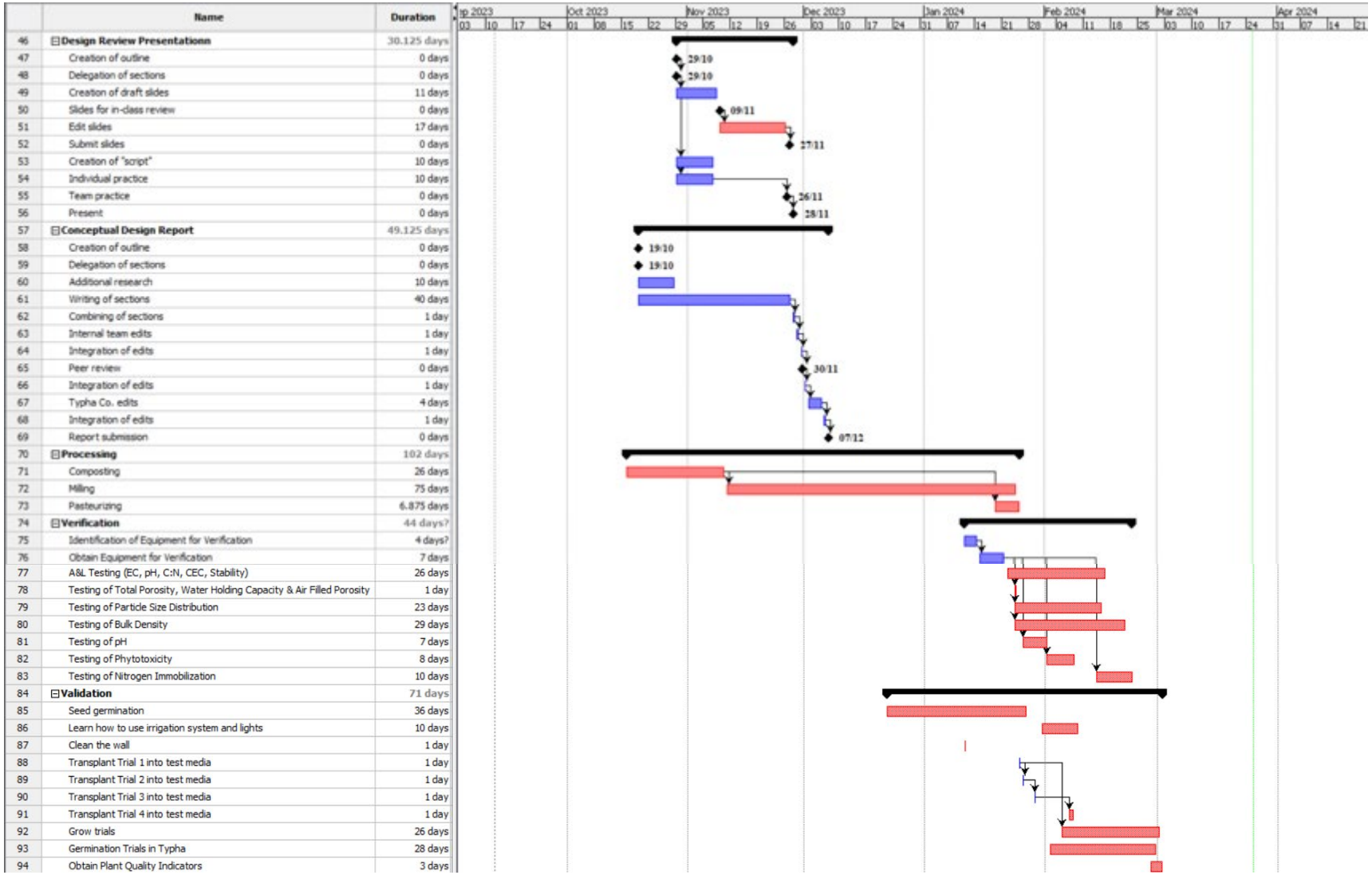
Appendix B: Workplan

The project Gantt chart schedule from, September 2023 to April 2024, is shown in Figures B1 to B3. This schedule shows all deadlines throughout the course of this project.



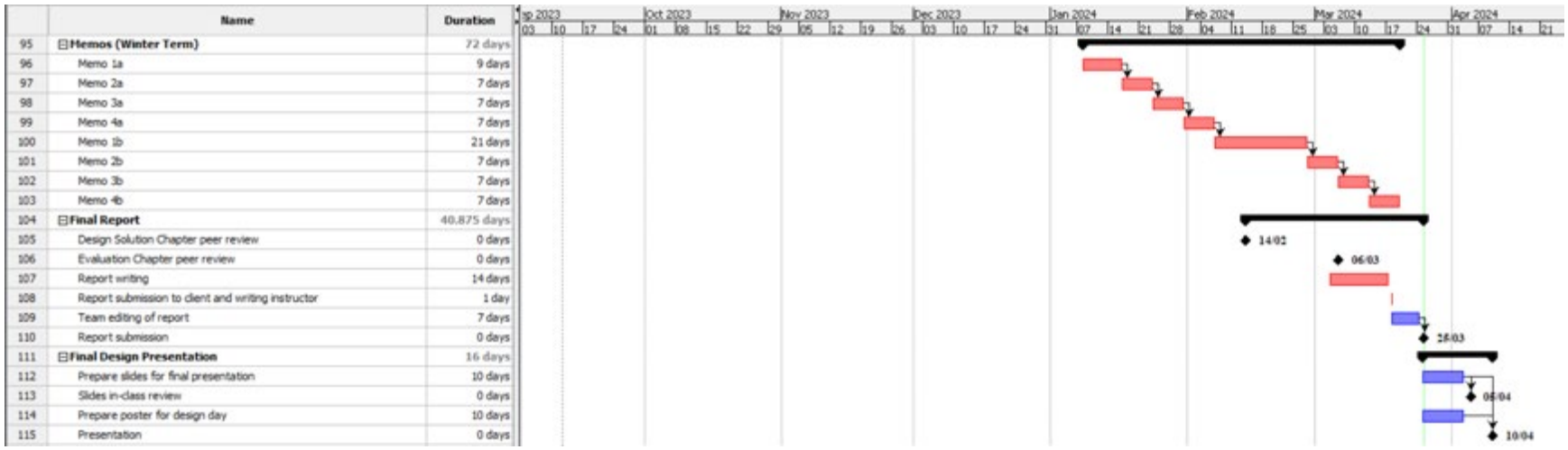
	Name	Duration
1	**Typha Soilless Growing Media Project**	210 days?
2	**Preliminary Project Research**	14 days
3	General review of literature	5 days
4	First meeting with client	0 days
5	Meeting with professors	9 days
6	**Memos**	70 days
7	Memo 1a	7 days
8	Memo 2a	7 days
9	Memo 3a	7 days
10	Memo 4a	7 days
11	Memo 1b	14 days
12	Memo 2b	7 days
13	Memo 3b	7 days
14	Memo 4b	14 days
15	**Project Definition Report**	28 days
16	Creation of outline	1 day
17	Confirm problem statement	3 days
18	**Tech spec research**	15 days
19	Importance	9 days
20	Ideal ranges (benchmarking)	9 days
21	Test procedure	9 days
22	Creation of table	9 days
23	Approval of specs from client	0 days
24	Sourcing of equipment	15 days
25	**Processing research**	16 days
26	Potential methods	3 days
27	Approval from client	0 days
28	Sourcing equipment	13 days
29	**Testing Research**	18 days
30	Possible soilless growing media equipment	18 days
31	Sourcing equipment	18 days
32	Identify and mitigate contraints/limitations	12 days
33	Delegation of sections	0 days
34	Writing of sections	8 days
35	Combining of sections	0 days
36	Internal team edits	0 days
37	Integration of edits	0 days
38	Peer review	0 days
39	Integration of edits	0 days
40	Send to Typha Co. for edits	3 days
41	Integration of edits	1 day
42	Report submission	0 days
43	**Preliminary growing and testing**	40 days
44	Grow trial research	40 days
45	Identify plant quality parameters for success	40 days

Figure B1. Project Gantt chart from September 2023 to April 2024, showing tasks from Preliminary Project Research to Preliminary Growing and Testing



	Name	Duration
46	**Design Review Presentationn**	30.125 days
47	Creation of outline	0 days
48	Delegation of sections	0 days
49	Creation of draft slides	11 days
50	Slides for in-class review	0 days
51	Edit slides	17 days
52	Submit slides	0 days
53	Creation of "script"	10 days
54	Individual practice	10 days
55	Team practice	0 days
56	Present	0 days
57	**Conceptual Design Report**	49.125 days
58	Creation of outline	0 days
59	Delegation of sections	0 days
60	Additional research	10 days
61	Writing of sections	40 days
62	Combining of sections	1 day
63	Internal team edits	1 day
64	Integration of edits	1 day
65	Peer review	0 days
66	Integration of edits	1 day
67	Typha Co. edits	4 days
68	Integration of edits	1 day
69	Report submission	0 days
70	**Processing**	102 days
71	Composting	26 days
72	Milling	75 days
73	Pasteurizing	6.875 days
74	**Verification**	44 days?
75	Identification of Equipment for Verification	4 days?
76	Obtain Equipment for Verification	7 days
77	A&L Testing (EC, pH, C:N, CEC, Stability)	26 days
78	Testing of Total Porosity, Water Holding Capacity & Air Filled Porosity	1 day
79	Testing of Particle Size Distribution	23 days
80	Testing of Bulk Density	29 days
81	Testing of pH	7 days
82	Testing of Phytotoxicity	8 days
83	Testing of Nitrogen Immobilization	10 days
84	**Validation**	71 days
85	Seed germination	36 days
86	Learn how to use irrigation system and lights	10 days
87	Clean the wall	1 day
88	Transplant Trial 1 into test media	1 day
89	Transplant Trial 2 into test media	1 day
90	Transplant Trial 3 into test media	1 day
91	Transplant Trial 4 into test media	1 day
92	Grow trials	26 days
93	Germination Trials in Typha	28 days
94	Obtain Plant Quality Indicators	3 days

Figure B2. Project Gantt chart from September 2023 to April 2024, showing tasks from Design Review Presentation to Validation



	Name	Duration
95	**Memos (Winter Term)**	72 days
96	Memo 1a	9 days
97	Memo 2a	7 days
98	Memo 3a	7 days
99	Memo 4a	7 days
100	Memo 1b	21 days
101	Memo 2b	7 days
102	Memo 3b	7 days
103	Memo 4b	7 days
104	**Final Report**	40.875 days
105	Design Solution Chapter peer review	0 days
106	Evaluation Chapter peer review	0 days
107	Report writing	14 days
108	Report submission to client and writing instructor	1 day
109	Team editing of report	7 days
110	Report submission	0 days
111	**Final Design Presentation**	16 days
112	Prepare slides for final presentation	10 days
113	Slides in-class review	0 days
114	Prepare poster for design day	10 days
115	Presentation	0 days

Figure B3. Project Gantt chart from September 2023 to April 2024, showing tasks from Winter Term Memos to Final Design Presentation

Appendix C: Project Specific Materials

Two additional tests, the Solvita® Maturity test and a particle size distribution test, were performed to assess the success of the specific equipment used to process the Typha media. The success of composting was assessed with the Solvita® Maturity test and the success of milling was assessed with the particle size distribution test. Following these two tests, photographs of Trial 3 petunias are displayed.

C1 Solvita® Compost Maturity Tests

The Solvita® test was performed on both sources of compost (i.e. [redacted] and from SiAF). Shredded Typha was also included to provide insight into the results for non-composted media, as well as any improvements in maturity from the starting raw material. Five unique samples were chosen for testing and are listed below:

[redacted]

- Sample 3: SiAF – Typha + chicken manure, stored in an open bin
- Sample 4: SiAF – Typha + chicken manure, stored in sealed bag
- Sample 5: Raw Typha (Note: the Solvita® test is intended for compost and may not provide relevant data for non-composted samples)

[redacted]

Equipment required:

- Representative compost samples
- Pails or containers, 1L in capacity
- Solvita® Basic Compost Maturity Test, which includes:
  - Six incubation jars and lids with gas-tight gaskets
  - Six High-CO_2 detector probes
  - Six NH_3 detector probes
  - Colour charts for interpreting CO_2 and NH_3 results
- Water
- Paper towel

Procedure: Adapted from Guide to Solvita® Testing for Compost Maturity Index (Woods End Research Laboratory 2000)

1. Collect a representative sample of the compost by thoroughly mixing the entire batch by hand. Transport about 1L of the mixed batch into a container.

2. Ensure the moisture content of each sample is optimal by tightly squeezing a handful of the sample into a paper towel. This squeeze test should wet the paper towel but should not produce free water that causes dripping.
    a. If there is free water, the sample is too wet. Spread the 1L sample out and allow the excess moisture to evaporate overnight.
    b. If squeezing does not wet the paper towel, the sample is too dry. Slowly mix the sample with water added, as needed. Repeat the squeeze test to confirm the optimal moisture content.
3. Equilibrate the sample in the incubation jar overnight with a loose lid if it was taken from a frozen compost pile (Sample 1 and 2) or if it needed drying or remoistening (Sample 3 and 5).
    a. Fill the incubation jars with the sample to the fill line as indicated on the label of the jar. Ensure proper density by sharply tapping the bottom of the jar on a counter.
    b. Further compact fluffy or coarse samples by pressing firmly into the jar.
4. After equilibration is complete, load the remaining samples into their own incubation jar (Sample 4). Remove the lids of all incubation jars and allow all samples to sit, uncovered, for one hour before starting the test.
5. Once the hour is complete, remove the CO_2 and NH_3 probes from their foil packaging. Carefully insert both probes into the sample, ensuring the gel surface is not touched by fingers or the compost. Tightly seal the jars by screwing the lids on and allow to sit at room temperature for four hours.
6. After four hours, compare the colour on both gel probes for each sample to their respective colour charts (Figure C1). Record the number associated with the observed colour on both probes.

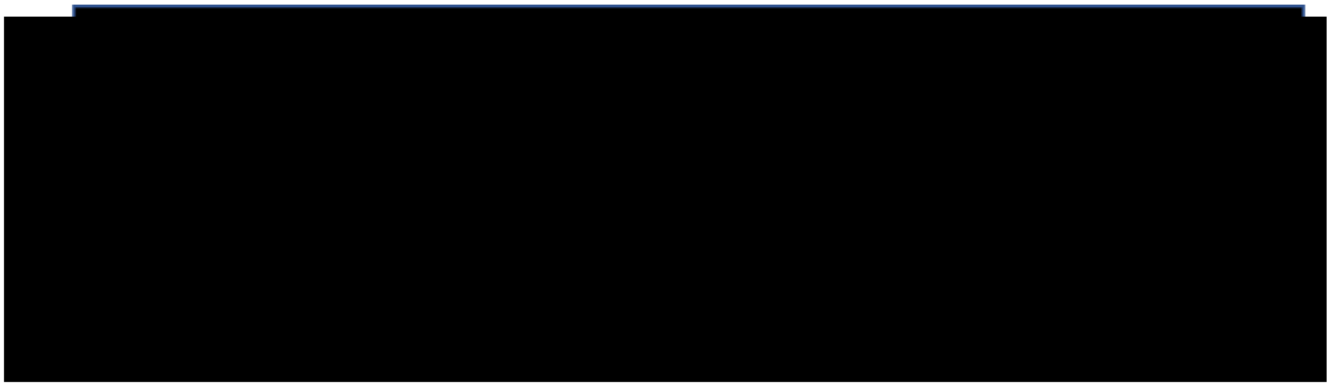


Figure C1. Colour charts indicating concentration of gases, (a) CO2 (Solvita 2021) and (b) NH¬3 (Evanylo 2020), to inform maturity index of a compost sample

At the beginning of the test, both probes are coloured according to the highest number of their respective chart (purple, or 8, for CO_2 and yellow, or 5, for NH_3). After the four-hour incubation period, a change in colour and decrease in number toward the right side of the chart indicates a higher concentration of the gas and therefore a low compost stability.

7. Use the two values obtained for the CO_2 and NH_3 to obtain a compost maturity index using Table C1.

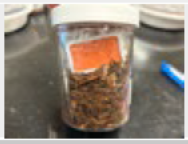
Table C1. Chart for interpreting compost maturity index using the Solvita® probe results (Woods End Research Laboratory 2000)

Solvita Ammonia Test Result is:		SOLVITA Carbon Dioxide Test Result is: 1	2	3	4	5	6	7	8
5	Very Low NH_3	1	2	3	4	5	6	7	8
4	Low NH_3	1	2	3	4	5	6	7	8
3	Medium NH_3	1	1	2	3	4	5	6	7
2	High NH_3	1	1	1	2	3	4	5	6
1	Very High NH_3	1	1	1	1	1	2	3	4

The test manual by Woods End Research Laboratory (2000) defines each index relative to its stage in the composting process. An index of 1 is indicative of a fresh and microbially active compost that is immature and unsuitable for use, and 8 signifies a stable and finished compost with no limitations for use.

Data:
The probe results and maturity rating of each sample are provided in Table C2.

Table C2. Colour reading and number rating on CO_2 and NH_3 probes for each sample

Sample #	**1**	**2**	**3**	**4**	**5**
CO_2 Probe Results					
Probe Colour	Orange-red	Red	Orange	Red	Red-Purple
Test Result	5	6	4	6	7
Probe Picture					
NH_3 Probe Results					
Probe Colour	Yellow	Yellow	Yellow	Yellow center, green perimeter	Yellow
Test Result	5	5	5	3	5

Sample #	1	2	3	4	5
Probe Picture					
Combined Results					
Compost Maturity Index	5	6	4	5	7
Compost Condition	Active Compost	Curing	Very Active	Active Compost	Finished Compost

Using Table C1 and the test manual to interpret the two obtained number ratings, Sample 2 was found to possess the most advanced stage of maturity. Its compost maturity index of 6 indicated it was in the curing stage. Compared to the other compost samples that were tested, it was most suitable as a growing media and for use in [redacted]

[redacted] Note that, although Sample 5 (Raw Typha) exhibited results associated with finished compost, it could not be chosen for inclusion in the design solutions as the Solvita® test is only valid for composted samples.

C2 Particle Size Distribution Test

The procedure for determining particle size distribution is adapted from ASTM D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis (2017). An approximate maximum particle size was determined to be 19mm. The preferred method of analysis is the moist procedure over the wet or dry procedures to avoid altering the sample.

Equipment required:

- Paper towel
- 495g of sample
- Scoop
- Cumulative collection bucket
- Transfer container - large enough so that material in the sieve can be transferred to the container without spillage
- Balance
- Primary sieve set with sizes 10mm, 4mm, 2mm, 850um, and 425um

- Secondary sieve set with sizes 250um, 150um and 106um
- Bottom pan and top lid for each set
- Sieve shaker apparatus (Retsch VWR International Inc.127291029A)

Procedure:

1. Visually assess sieve-set for any damage to the mesh which would affect results. Wipe off any debris with a paper towel.
2. Place the cumulative collection bucket on the scale. Tare the weight.
3. Mix the original sample and scoop 165g into the container.
4. Arrange the sieves from smallest on the bottom to largest on top with the capture pan on the bottom. Place on the sieve shaker apparatus.
5. Pour the sample into the top of the primary sieve set to allow the particles to separate into their respective sizes.
6. Place the lid on top of the sieve-set and secure to the shaker apparatus.
7. Shake the specimen in the sieve shaker at 250rpm for 10-20 minutes.
8. Remove the lid and ensure no material is retained in the largest sieve.
9. Remove the next sieve and turn it upside down into a transfer container. Gently brush off any retained material into the container.
10. Move the sample to the cumulative collection container. Record the cumulative mass of the sample. Repeat for all sieve sizes in the primary sieve set.
11. Take the material from the bottom pan of the primary sieve set and pour it into the secondary sieve set. Place the lid on top.
12. Manual shake sieve set for 3 minutes, alternating between shaking and tapping the set.
13. Repeat steps 9 and 10 for secondary sieve set.
14. Repeat all steps for a total of three samples.

Calculations:

Equation 9 is repeated to obtain the mass of particles retained in each sieve size. Each recorded mass is associated with the range of particle size from the smaller size sieve, which the particle could not pass through, to the larger size, in which the particle did pass.

$$MR_N = CMR_N - CMR_{N-1} \quad \text{Equation 9}$$

Where:

MR_N = mass retained on the Nth sieve, g

CMR_N = cumulative mass retained on the Nth sieve, g

CMR_{N-1} = cumulative mass retained on the sieve above the Nth sieve, g

C3 Validation: Germination Results Pictures

Supercascade Burgundy petunia seeds were germinated in each test media mix and photographed on February 29, 2024, after 4 weeks of growth. A photo of each 12-cell tray is displayed for each test media mix in Figures C2 to C6 just before data was collected.

Figure C2. Germination trial results. From left to right: mix 1 (35% MD1, 35% Peat, 30% Perlite), mix 2 (70% MD1, 30% Peat), and mix 3 (100% MD1).

Figure C3. Germination trial results. From left to right: mix 4 (35% MD 2, 35% Peat, 30% Perlite), mix 5 (70% MD2, 30% Peat), and mix 6 (100% Media Design 2).

Figure C4. Germination trial results. From left to right: mix 7 (35% MD3, 35% Peat, 30% Perlite), mix 8 (70% MD3, 30% Peat), and mix 9 (100% MD3).

Figure C5. Germination trial results. From left to right: mix 10 (35% Raw Typha, 35% Peat, 30% Perlite), mix 11 (70% Raw Typha, 30% Perlite), and mix 12 (100% Raw Typha).

Figure C6. Germination trial results. Mix 13 (Control, 70% Peat, 30% Perlite)

C4 Validation: Trial 3 Pictures

Trial 3 petunias (Orchid Mist), grown in each test media mix, were photographed on March 6, 2024. The photos were taken at week 10.71 of growth from seed with the last 5.29 weeks of growth in the test media mixes. Six plants are displayed for each test media mix in Figures C7 to C13.

Figure C7. Trial 3 petunias in mix 1 (left) and mix 2 (right)


Figure C8. Trial 3 petunias in mix 3 (left) and mix 4 (right)


Figure C9. Trial 3 petunias in mix 5 (left) and mix 6 (right)


Figure C10. Trial 3 petunias in mix 7 (left) and mix 8 (right)


Figure C11. Trial 3 petunias in mix 9 (left) and mix 10 (right)

Figure C12. Trial 3 petunias in mix 11 (left) and mix 12 (right)

Figure C13. Trial 3 petunias in mix 13

Appendix D: Bill of Materials

A record of materials required for the Media Designs, verification procedures and validation procedures is presented in Tables D1 to D3. Unknown costs of university equipment are indicated with N/A. The approximate total cost of this project is $80 429.74. However, only items identified by an asterisk (*) were purchased by the team making our cost $1 211.38

Table D1. Cost breakdown for creating the three Media Designs

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
Biomass machines	Schutte Buffalo Hammermill Model: H28 Serial: 1608 066	University of Manitoba	$24 866.99
	Grizzly 1-½ HP cyclone dust collector Model: G0443	University of Manitoba	$1 095.00
Drying oven/incubator	Binder Kb Series Refrigerated Incubator Model: KB115	University of Manitoba	$10 900.00
550 kg bale of shredded Typha	Strategic Systems Engineering	Typha Co.	$204.25
10 kg of chicken manure	Rona Acti-Sol Model: #53210	Typha Co.	$18.99
Composting services per Typha bale	Enviroclean	Typha Co.	$40.00
76 L storage totes	Home Depot Model: #2120-66157120	University of Manitoba	$9.97 x 4
Drying trays *	Jiffy Plastic Plant Trays 11in x 22in	Canadian Tire	$2.99 x 4
30in x 24in clear autoclavable waste bags (200pk)	Fisherbrand™ 18266	University of Manitoba	$249.69
Compost maturity test refill – 25 CO_2 and 25 NH_3 probes	Solvita SKU: 2265	Typha Co.	$609.00
Plastic jars (6pk)*	Solvita SKU: 3054-C	Solvita	$22.00
Subtotal:			$38 057. 76

Table D2. Cost breakdown for the verification procedures

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
Pak Choi (Chinese Cabbage) seeds (200 sds)*	Asian Delight Pak Choi 1348A	T&T Seeds	$14.83
Petri/culture dishes (20pk)	Sigma Aldrich Z358762	University of Manitoba	$40.70
50 mL conical sterile polypropylene centrifuge tubes (300pk)	Thermo Scientific™ Nunc™ Catalog number: 339653	University of Manitoba	$440.00
Extra-large plastic freezer bags (10pk)	Ziploc Model: 99874	University of Manitoba	$9.47
250 mL glass beakers (12pk)	Sigma-Aldrich Pyrex Griffin Beakers CLS100050	University of Manitoba	$106.00
Centrifuge	ThermoFisher Scientific Centrifuge Model: Sorvall Legend RT+	University of Manitoba	$6 800.00
Drying oven	VWR® Signature™ High-Performance Horizontal Air Flow Oven Model: 1390FM	University of Manitoba	$13 600.00
Balance	Uline Model No. H-9885	University of Manitoba	$438.00
Desiccator	United Scientific Desiccator, Glass, 8” Dia. Model: #T9FB3143813	University of Manitoba	$259.95
Bluelab combo meter (pH meter)	Bluelab CM1-2011-01095	Typha Co.	$436.00
Thermometric device	H-B Instrument Mfr # 604001200	University of Manitoba	$49.65
Buffer solution pH 4.00	Fisher Scientific SB101-500	University of Manitoba	$70.00
Buffer solution pH 7.00	Fisher Scientific SB107-500	University of Manitoba	$68.50
Nitrile gloves (100pk)	Sigma Aldrich Dermatril™ Z677272	University of Manitoba	$97.20
Safety glasses	Degil Model: #7052000	University of Manitoba	$4.99
Stirring rod (12pk)	Tektronix Mfr # 2242-1	University of Manitoba	$58.64

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
Calcium chloride	Thermo Scientific Cat. No. L13191.0B	University of Manitoba	$32.54
Glass funnels (12pk)	PYREX® Product Number: 6180-75	University of Manitoba	$21.65
100mL graduated cylinder	Sigma-Aldrich Pyrex graduated cylinder CLS3022100	University of Manitoba	$65.10
Potassium nitrate	Fisher Scientific Cat. No. BP368-500	University of Manitoba	N/A
Deionized water	N/A	University of Manitoba	N/A
125mm grade 1 qualitative filter paper (100pk)	Sigma Aldrich Whatman WHA1001125	University of Manitoba	$25.60
0.45-micron syringe filters, 25 mm diameter (50pk)	Thermo Fisher Scientific Cat. No. 13100111	University of Manitoba	$45.86
10 mL syringes (100pk)	Fisherbrand Cat. No. 14955459	University of Manitoba	$39.83
10 mL glass tubes	N/A	University of Manitoba	N/A
2in x 250ft roll of parafilm	PARAFILM® M P7543	University of Manitoba	$123.00
Flow Injection Analyzer	Lachat Instruments Model: ASX-410 XYZ AutoSampler	University of Manitoba	N/A
0.5 L measure (Diecast aluminum)	Halrosse Canada Labtronics Manitoba	University of Manitoba	$109.00
Distilled water	N/A	University of Manitoba	N/A
90mm filter paper (100pk)	Sigma-Aldrich Whatman WHA1001090	University of Manitoba	$22.00
Digital calipers	Mastercraft Model: #058-6800-4	University of Manitoba	$29.99 x 2
Fine test sieve No. 60 (250 um)	Sigma Aldrich Z289744	University of Manitoba	$108.00
Fine test sieve No. 100 (150 um)	Sigma Aldrich Z400114	University of Manitoba	$151.00
8in diameter test sieve cover	Sigma Aldrich Z400246	University of Manitoba	$57.10
400mm diameter test sieve set	Retsch ASTM E11	University of Manitoba	$7 016.54
Retsch Horizontal Sieve Shaker AS 400 Control	Retsch VWR International Inc.	University of Manitoba	$7 623.47

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
	127291029A		
Chemical testing*	Main package (EC, pH, CEC, C:N)	A&L Canada Laboratories Inc.	$286.80
	Stability package	A&L Canada Laboratories Inc.	$362.25
Shipping*	Flat rate box: medium	Canada Post	$26.24
250mL glass beakers (12pk)	Sigma-Aldrich Pyrex Griffin Beakers (250mL) CLS1000250	University of Manitoba	$108.00
		Subtotal:	$38 777.89

Table D3. Cost breakdown for the validation procedures

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
Grow wall rental	Harvest Today Size: The Mega 360 (101.625" X 85.75" X 4")	Harvest Today	$200/month x 6 months
Grow lights rental	SynceLED Model: Raging Kale II	Harvest Today	$50/month x 6 months
Greenhouse/grow room rental*	Department of Agriculture and Food Science	University of Manitoba	$115.00 x 2 months
Petunia seeds*	Orchid Mist (500 sds) B223C	T&T Seeds	$35.11
	Supercascade Burgundy (250 sds) B255B	T&T Seeds	$18.00
1.4 kg potting mix	PRO-MIX Premium Potting Mix Model # 4980110	Typha Co.	$7.98
Rooted petunia plugs	van der Meer Supertunia® Vista Bubblegum® and Supertunia® Royal Velvet®	Typha Co.	$70.00
9L of peat moss*	Golfgreen 159-1008-2	Canadian Tire	$9.44

Item	Brand/Manufacturer & Part Number/Model	Provided By	Cost & Qty
110L bag of perlite	HJS Wholesale Product Code: 450-105408-PV	University of Manitoba	$35.45
2-inch net cups with wide lip rims (50pk)*	AC Infinity ASIN: B09ZVNR5DV	Amazon	$25.99 x 5
2-inch net cup pots (30pk)*	ORIMERC ASIN: B0BL3CHKZY	Amazon	$11.99 x 2
Non-woven biodegradable nursery bags (200pk)*	MOTZU ASIN: B0899XZPQ3	Amazon	$33.58
Bleach	Clorox, 3.57L UPC: 55500017348	University of Manitoba	$7.47
1.36 kg water soluble plant food (20-20-20)	Miracle Gro Canadian Tire #159-0104-8	Typha Co.	$22.99
1L pH down solution	Green Planet SKU: PHD01-DG	Typha Co.	$20.99
Measuring spoons*	Dollarama	Dollarama	$2.99
Light cage	N/A	Dale Bourns	N/A
Sling psychrometer	Sper Scienctific 736710	University of Manitoba	$129.00
Roasting pans*	Dollarama Betty Crocker 828018893656	Dollarama	$1.75 x 7
Plastic drinking cups*	Dollarama	Dollarama	$1.25 x 8
Light Meter	Allied Scientific Pro Lighting Passport IC: 5123A-BGTBLE112	University of Manitoba	$1 295.00
		Subtotal:	$3 594.09