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Development of a Sustainable Potting Soil Mix for the NCC Nursery

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Abstract

The following experiment was performed in collaboration with the NCC of Barbados with the goal to develop a weed free, sustainable potting mixture. Three piles were created to be solarised: A high nutrient pile containing a manure to topsoil ratio of 20:80, a low nutrient pile with a 10:90 ratio and a 50:50 bagasse to topsoil/manure mixture. From these piles, six different soil mixtures were created and compared to the currently used potting soil. Coconut fibre was looked at as a sustainable alternative to peat moss in the potting soil mix. It was found that mixtures containing solarized soil showed a significant reduction in weed growth. Additionally, it was found that the six created mixtures had better water infiltration rates than the current potting soil. Finally, the soil mixture that contributed to the best qualitative plant growth by the end of the experiment was the most financial and environmentally sustainable as it contained coconut fibre over peat moss in lower quantities. Since there was no one "best mix" overall, and this study revealed many techniques that could be implemented, the NCC can use the results of this study to prioritize certain goals over others if needed.

Introduction

The National Conservation Commission of Barbados was founded in 1982 in order to protect the natural beauty of the island's parks and beaches. The Nursery at Codrington, or the NCC headquarters, is just one part of the NCC's scope within Barbados. Plants at the nursery are sold to fulfill the high horticultural demand for ornamental plants on the island. Plants are sold to local homeowners and businesses, to the government for use in public spaces and parks, as well as rented for events and tourist attractions.

In recent years at the NCC nursery, the potting soil mix into which propagated rooted cuttings are transplanted has been plagued with weeds. Soil mixes often have high levels of inconsistency, as topsoil sources used by the nursery are variable. Furthermore, the NCC would also like to replace imported materials with more locally-sourced soil amendments in order to reduce costs and encourage sustainable practices. Additionally, the current potting soil mix used at the nursery exhibits extremely poor drainage and large amounts of compaction. Workers have observed that the water often doesn't drain properly through the soil due to the compaction and water only infiltrates the first 5cm of the pot leaving deeper roots void of water and with a reduced capacity to uptake nutrients lower in the soil profile.

The current soil mix used by the nursery includes topsoil, horse manure, perlite, and peat moss in varying concentrations based on texture, feel, and relative amounts of other amendments (e.g. more horse manure in a mix means less peat moss, for example). These materials are used as they are readily available and typical materials used for potting soil mixes globally, and the mixing and production of this particular soil mix on a large scale is functional for the nursery.

Currently, equal parts topsoil and horse manure are sifted together in topsoil creation. Two bobcat buckets (1 m^3 each) of manure and topsoil each are added, equalling 4 m^3 in total. Two to three bags of perlite (107 L each) are used and 6-8 bags peat moss are used per 4 m^3 of topsoil/manure mix. The soil mixing process is not proportional; rather, it is done by feel and varies based on who mixes it. Sand is not used by the nursery due to the high cost of desalination in Barbados. However, the NCC would like to use more locally sourced amendments to reduce the expense of imported materials and to encourage more sustainable practices. Eventually, the nursery would like to eliminate imported peat moss and perlite from their mix completely. Bagasse, a solid byproduct of sugar cane during rum and sugar production, is especially of interest as a soil amendment at the NCC because it's readily available on the island due to the large sugar processing and rum industry. Plants at the NCC nursery are fertilized via a water soluble 20:20:20 mix every 2 weeks and a 12:12:17:2 pellet mix incorporated into the potting soil during initial transplanting. Our study will compare the growth of plants in soil mixes with differing amounts of imported materials and previously unused, more locally-sourced, counterparts, as well as topsoil and manure.

Literature Review

I. Solarization

Solarization is a process which uses the sun's energy to heat the soil with the goal of reaching a high enough temperature to kill weed seeds, pathogens, and insects such as nematodes (Masabni and Franco, 2016). Presently, the workers at the NCC nursery are having to weed around every two weeks as at this time the weeds begin to outgrow and outcompete the desired potted plant. Weeding is a tedious task for workers and takes away their valuable time. Ideally, solarization will help reduce the initial weed load saving the NCC nursery time and money. The NCC nursery receives topsoil donations from various construction sites on the island, thus they vary widely in quality, including amount and type of weed seeds and potentially including pathogens and/or garbage. Proper solarization will aid soil health by killing off weed seeds and other pathogens that may be present in the topsoil. This is a promising technique as the only input necessary is plastic sheeting to lay over the soil and time to wait for solarization to occur. As the plastic sheeting can be reused, solarization is more economical compared to more traditional, more expensive techniques to get rid of weeds and pathogens such as pre-emergent herbicides and pesticides (Elmore et al., 1997). Economics aside, solarization is also more ecologically friendly than chemical weed control techniques as it is not toxic to humans or animals, nor should it leave any unwanted residues. Using solarization over herbicides or pesticides creates a safeguard in the political sense, as the local government has the power to ban or restrict herbicides/pesticides, in which case the nursery would be forced to change their pest control practices, whereas the solarization technique is unlikely to ever be banned (Elmore et al., 1997).

Clear plastic sheeting should be used for solarization instead black, white, or plastic of any other color. Clear plastic creates a greenhouse environment, allowing light energy to enter the bag and, if reflected by the soil, be caught by condensation droplets found on the side of the plastic touching the soil. Black plastic absorbs all wavelengths of light, meaning most of the heat never penetrates below the sheeting, and energy is not reflected underneath the plastic layer. Black plastic is typically used for mulching, especially in temperate climates. Soil temperatures are lower when solarized with black plastic than clear plastic (Stapleton et al., 1993), and thus require longer solarization treatments than clear (Elmore et al., 1997).

Solarization can provide weed control by the seeds reaching their lethal temperature, by thermal killing of germinated seeds and by breaking the seed dormancy followed by thermal killing of the germinated seed (Abouziena, Haggag, 2016). Unfortunately, there is no standard temperature that kills all weed seeds (Dahlquist et al, 2007). Notably, solarization controls annual weed seeds much better than perennial weeds which are more resistant as rhizomes and vegetative root structures may resprout (Elmore et al., 1997). As soil depth increases, the risk of rhizomes and roots being left alive increases. According to “Weed Control in Clean Agriculture: A Review” the effects of solarization were greatest at the top 5-10 cm layer (Abouziena, Haggag, 2016). In this same Egyptian study soil temperatures reached up to 69°C and most soils increased in temperature by 10-21°C in the upper soil level using the solarisation method resulting in a significant decrease in weed seeds (Abouziena, Haggag, 2016). As outdoor temperature is variable around the world, contrasting studies show varying temperatures reached using solarization. In a different study based out of California, cooler than Egypt and Barbados, the soil was usually heated between 42-55°C in the top 5cm and between 32-37°C in the top 45cm. To put these temperatures into perspective in their ability thermally kill weed seeds, the study “Time and temperature requirements for weed seed thermal death” found that temperatures at or above 50°C proved lethal for all species in their experiment (Dahlquist and al, 2007). However, it should be noted that the thermal killing of solarization is reliant on temperature reached and the duration of time spent solarizing. In general, weed seeds left at lower temperatures can be thermally killed if left long enough but will degrade much faster, even within hours, at higher temperatures. In Joseph Masabnis’ “Easy Gardening: Composting to kill weed seeds” it states that weed seeds begin to degrade at 42°C and should be completely degraded if left a few hours at 60°C (Masabni, 2012). It is generally regarded that the plastic sheeting used for solarisation should be left in place for 4 to 6 weeks (Elmore et al, 1997). Other studies state that 5 weeks may be adequate for controlling most annual weeds but a length as long as 5 months may be required to kill perennial weeds (Abouziena and Haggag, 2016).

II. Soil Amendments

Amendments were added to the solarized topsoil and manure to ensure a more effective and sustainable potting mix for transplanting. While solarization is used to reduce weed growth in pots, addition of elements such as peat moss, perlite, coconut fiber, and bagasse will facilitate drainage, aeration, and overall plant health. Currently, the NCC nursery uses a potting soil mix consisting of topsoil, manure, peat moss, and perlite, resulting in a very compact and poorly draining soil. We include measurements of soil infiltration rate and compaction of the current soil mix along with our other soil mix results for comparison. For our potting soil mixes, we decided to work with coconut fiber, bagasse, peat moss, and perlite due to their reliable present and possibly future availability at the nursery.

Coconut fiber

The main purpose of the addition of coconut fiber to the potting mix is to facilitate drainage and aeration of the soil and to act as a sustainable substitute for peat moss, which is the primary soil amendment used at the NCC nursery. Despite its common use in gardening and potting mixes, peat moss is environmentally unsustainable, as it is mined out of depleting bogs and imported to Barbados mostly from Canada, making it expensive to purchase at almost double the price of coconut fiber (Satnik, 2018). Using coconut fiber in the potting mix provides a more environmentally and economically sustainable alternative to peat moss. Coconut fiber also has a higher cation exchange capacity than peat moss, improving retention of nutrients and decreasing fertilizer needs. The fibrous nature of coconut should help facilitate water movement down the soil profile, decreasing the amount of time needed for water to completely drain from the surface of the soil. The addition of coconut fiber to the potting soil mix will simultaneously add aeration due to its high porosity and retain moisture more than peat would, creating a more stable soil environment (Satnik, 2018).

Another consideration of using high levels of coconut fiber is the C:N ratio, where coconut fiber's high carbon content could result in initial nitrogen immobilization if used in quantities that are too high (Rosales et al., 1997). Temporary nitrogen tie-up occurs when high carbon content activates the breakdown of organic matter by microorganisms that use the available inorganic nitrogen, making it temporarily unavailable for uptake by the plants that need it (Rosales et al., 1997). A study by Holman, Bugbee, and Chard at Utah State University shows that plants grown on coconut fiber did not fare as well as those grown on peat moss potentially due to the immobilization of nitrogen by the high organic matter content of coconut fiber (Holman et al., 2005). When using coconut fiber or coir, mineral nitrogen in a bioavailable form should be supplemented by the addition of extra animal manure or inorganic fertilizer to the soil mix.

Bagasse

Bagasse is the fibrous byproduct of the sugarcane industry which remains after the juice is extracted from the sugarcane. It is most commonly known for its value as a feedstock for biofuel production, due to its heat energy potential and combustibility (Nassar et al., 1996). There is little research done on its repurposing for agricultural uses, but it is suggested that adding bagasse to soil can reduce fertilizer requirements by contributing certain nutrients directly to the growing medium (Dotaniya et al., 2016). Composted and processed bagasse shows positive results when added to soil mixes as an organic fertilizer, improving water holding and cation exchange capacity (Chacha, Andrew & Vegi, 2019). Although, the bagasse we used in our mixes was not initially composted, so its fertilizing benefits may not be reflected in our data.

Similar to coconut fiber, bagasse contains high amounts of carbon, which could temporarily immobilize nitrogen in the potting soil mix (Rosales et al., 1997). Although bagasse is rich in other nutrients, the immobilization of nitrogen may potentially need to be solved with the application of nitrogen fertilizers or with the addition of composted chicken manure, which is high in nitrogen. We expect that, for the purposes of our studies, bagasse will be most useful as an addition to the soil and manure mixture pre-solarization so that the bagasse can increase the temperature of the solarization pile and so that it has a chance to break down a little bit before serving as part of the planting medium.

Peat moss

Peat moss is a widely available and used soil amendment in potting mixes and is often used as a soilless growing medium. It decomposes slowly, allowing inorganic nitrogen to remain available for plant uptake, and can hold water very well ("Homemade Potting Mix," 2018). It was found in a study by Holman, Bugbee, and Chard at Utah State University that peat moss based growing media support growth of more vigorous and successful plants as opposed to those grown on coconut fiber-based media (Holman et al., 2005).

Despite its high effectiveness in growing vigorous plants, peat moss is a non-renewable resource and over-mining it could cause serious environmental and cultural damage to the areas in which it is found (Satnik, 2018). The peat moss which is available in Barbados is usually imported from Canada, emitting a large carbon footprint during transport. If coconut fiber, which is sourced locally, has the possibility to successfully eliminate the need for peat moss in potting mixes, then the overall sustainability of the potting mix will grow.

Perlite

Perlite is a sterile and pH neutral expanded volcanic glass. As a soil amendment, it is known to improve soil structure by providing drainage and aeration ("Homemade Potting Mix", 2018). However, it does not hold nutrients well, so the plants should have a good nutrient source added to the soil mix or topically after planting. It is often used as a lightweight replacement for sand ("Homemade Potting Mix", 2018).

Although the NCC nursery would like to eventually decrease their use of perlite, we decided that the use of perlite as opposed to sand for our research was necessary as a drainage facilitator. Sand is not currently used in their potting mixes due to its high cost and weight, as the nursery is aiming for a lighter mix, and perlite was the other effective drainage facilitating amendment available at the nursery at the time. Our soil mixes respect these conditions. For control purposes of the experiment, perlite was added to all potting soil mixes to assist in drainage, compaction, aeration, and to lighten up the soil mix overall.

Objectives and Hypothesis

***Objectives*:**

Our objective is to create an ideal soil mix for potting plants with the effect of a reduced weed load. For the sustainability aspect, we want to emphasize a process that is practically applicable and reduces labor requirements (soil preparation & weeding) in the NCC nursery facilities, use material constituents that are economically sustainable for the NCC nursery, and overall environmental sustainability. This includes efforts to use locally available material where possible.

***Hypotheses*:**

1. Defining the "best" soil mix will vary depending on the desired outcome and parameters (e.g. cost effectiveness, environmental sustainability, managing the weed load, overall plant health, etc.) Our goal will be to find a soil mix that balances out the varying aspects of utility.

2. Dividing plants into different categories based on their drainage and nutrient needs, using appropriate soil mixtures for each category, will give the plants a higher rate of success compared to the "one size fits all" method previously used. We expect to see an increase in plant vigour in transplanted cuttings.

3. Solarization of topsoils and manures prior to mixing will reduce the weed load of the final potting mix. It is expected that this will increase the plant cuttings' vigour as there will be less competition between the cuttings and weeds for essential nutrients and spacing.

4. It is expected that increasing drainage will benefit the majority of the plants grown at the NCC nursery.

5. Addition of bagasse to potting soil mixes will reduce weed load by increasing solarization efficiency (through enabling the topsoil mixture to reach a higher temperature faster.).

6. It is predicted that the designed potting soil mixtures will exhibit faster infiltration rates, increased drainage and lower compaction compared to the currently used soil mixture that contains large amounts of heavy clay that impedes the goals listed.

Methodology

Preliminary Solarization

Our aim with the initial solarization study was to compare the manures and to determine which manure was contributing the most to the growth of weeds. We used black plastic to cover the piles of topsoil and manure mix because we were told that this is the traditional method for solarization in Barbados. Also, we expected the temperature of the soil piles to increase as the solarization progressed.

Procedure:

1. Create five piles of soil mix as follows: topsoil only, premixed control (topsoil + horse manure,) and three manure mixes of sheep, horse, and chicken with topsoil (20% manure, 80% topsoil)
    a. Note: the control soil mix had been sitting in the sun prior to our arrival and the manure in it was most likely being rotted.
    b. The manures are all fresh, not composted.
2. Piles 10 cm tall, watered and covered with black plastic. Left in the sun to solarize.
3. 2 tbsp samples of each soil mix taken daily to observe weed germination and temperature; left to sprout under transparent plastic. 1 tbsp water is added to each sample.

Secondary Solarization

Solarization protocol followed:

1. Prepare the soil by some form of tillage to ensure a homogenous mixture free of clumps. A sieve and manual mixing was used for the purpose of this experiment.
2. Water the soil until it is saturated. Water helps conduct heat in the soil. Generally irrigating once is sufficient, this was the case in our experiment as barbadian soils are clay heavy though it may be required to irrigate again in cases where the soil is more sandy.

3. Lay the plastic sheeting down as close as possible to a smoothed out soil surface, air pockets between the soil and plastic will reduce soil heating. Clear plastic is recommended as it allows for the most heat to pass to the soil.
4. Secure edges of the plastic as to ensure heat and moisture retention. For the purpose of our experiment, rocks were used to hold the plastic edges down, though, this may not be practical on a larger scale.
5. Leave the soil to solarize. The climate and resistance of pests/weeds species will dictate the duration of the solarization treatment. For the purposes of the experiment at the NCC nursery the soil combined with the manure was left to solarize for two weeks. Longer durations (4-8 weeks) may be more desirable to let the soil heat to its full capacity. The manure was added to the soil for solarization as it was found to be a source of weed seeds following the preliminary trial. As well, the volatilized compounds from the manure may help kill pests during the solarization process (Elmore et al., 1997).
6. Remove the plastic and the soil is ready to be used for potting mixtures or in field.

Comparison of our experiment to real life application of solarization at the NCC:

The main difference between our experiment and the proposed method for the NCC is mechanisation. In our experiment the manure used was carefully chosen and sifted by hand. The practical application would involve a Bobcat machine pouring manure through the sifter, most likely resulting in a less homogenous product (more clumps). Topsoil and manure processing by hand is also likely to be more well-mixed than with a Bobcat, as it is easier to visually see if the manure is well integrated into the soil. However, using the Bobcat will allow greater quantities of the soil and manure to be sifted and mixed at a faster rate, which will save time and energy for the workers.

Solarization piles made:

1. Mixture of 10:90 topsoil to horse manure mix
2. Mixture of 20:80 topsoil to horse manure mix
3. Mixture of 50:50 topsoil to bagasse mix*
4. Control mixture of topsoil and manure currently used by the NCC

*50:50 topsoil to bagasse mix solarization was started one week after the other three mixtures due to constraints on material availability. Therefore, it was only mixed in with amendments after one week of solarization whereas the other mixtures were used after two weeks of solarization.

Notes on the choice of manure:

For simplicity, chicken and sheep manure were excluded in the secondary solarization. Sheep manure was excluded as we only had access to a burnt sheep manure which, in normal circumstances, would be available to the NCC in a non-burnt format making our observations not accurate to the real life scenario. Horse manure is currently being used by the nursery and was found to be easier to work with for the purpose of this experiment. Additionally, the chicken manure included shredded paper bedding which may be visually undesirable to consumers when buying potted plants or bags of potting mixture.

Although horse, sheep, and chicken manure were all tested in the initial solarization study, it was found that each manure type produced the same type and generally the same number of weed seeds. Although it is not certain if this is true for all weeds or just the ones that could germinate under the black plastic, the usage of sheep and chicken manures was eliminated from the next solarization stage, as the horse manure was most practical to work with. Consistency of manure type with the control soil mix also reduces the number of confounding variables in our subsequent research trials.

Soil mix creation

A holistic approach was taken when considering the combinations of mixes to test. The following aspects were considered in the creation of the mixes:

1. Availability and price of inputs
2. Nutritional needs
3. Drainage/moisture needs
4. Recommendations from current literature

Six different mixtures were created according to guidelines on creating potting mixes from scratch to facilitate comparison (“Homemade Potting Mix”, 2018). For the purpose of this experiment, all the trials include topsoil. While it may be beneficial to have soil-free potting mixtures, soil and manure are free resources available to the NCC. Thus, they are being used with the solarization treatment to reduce the potential problems with diseases and weeds that can occur with soil potting mixtures. As manure is an easily accessible and free resource to the NCC, it was chosen to be used to meet the nutritional demands of the plants. The manure was mixed with the soil during the solarization process as it was found in preliminary trials that all types of manures as well as the topsoil itself were sources of weed seeds. Ideally, the manure would have been composted prior to the experiment to reduce the weed load (Masabni, 2012). The downside of manure is the high variability of nutrients which can lead to potential nutritional problems with the plants.

Two different proportions of manure to soil were created to see the effect of nutrients on the four different plants (one with a 10:90 manure to soil ratio, the other with a 20:80 ratio,) some of which have low nutritional demands and others with high nutritional demands to facilitate recording the qualitative differences in growth. The other comparison being made in this experiment is the effects of peat moss vs. coconut fibre on plant growth. Peat moss was chosen as it was the nursery's previously used soil amendment and therefore has high accessibility and helps meet moisture retention/drainage needs of the plants. Coconut fibre was being used at the nursery but was not being mixed into the potting soil. It was chosen as a substitute for peat moss as it provides similar benefits as a plant growth medium, is easily accessible, cheaper, and more sustainable as coconut fibre is a renewable resource in tropical environments (Satnik, 2018). Along with comparing the two (peat moss vs coconut fibre), two varying proportions of these amendments were added to different potting mix trials (See table 1 for soil mixture components). Equal amounts of perlite were added to all potting mixes due to its previously mentioned benefits and, for control purposes, will therefore not be compared in this experiment.

Mix Number	Mix	Material ratios
1	High drainage/Low nutrient	1 part 10:90 soil mix ¾ part coconut fiber ½ part perlite
2	Low drainage/Low nutrient	1 part 10:90 soil mix ¼ part coconut fiber ½ part perlite
3	High drainage/High nutrient	1 part 20:80 soil mix ¼ part peat moss ½ part perlite
4	Low drainage/High nutrient	1 part 20:80 soil mix ¾ part peat moss ½ part perlite
5	High drainage/Low nutrient	½ part 10:90 soil mix ½ part bagasse mix ¾ part coconut fiber ½ part perlite
6	High drainage/High nutrient	½ part 20:80 soil mix ½ part bagasse mix ¾ part peat moss ½ part perlite

Table 1. Various soil mixes tested based on plant moisture and nutrient requirements. These mixes are based on research on basic DIY potting soil mixture components and ratio ("Homemade Potting Mix", 2018.).

Potting soil mixing and transplanting protocol:

1. Create soil mixes according to table 1, making enough to fill 12 pots with each mixture.
2. Divide soil into the 12 pots per mix.
3. Carefully transplant three rooted cuttings of each bougainvillea, lantana sage, baby sun rose, and poinsettia into three pots of each type of soil mix, equalling 72 transplanted plants total.
4. Create three pots of the control potting soil mixture (potting mix currently used by NCC Nursery) without plants.
5. Thoroughly water each potted plant initially after planting.
6. Place plants in hardening area for growth under shade cloth. For practicality purposes, the potted plants will be subject to the same watering and treatment as the rest of the plants in the hardening area. The only difference from regular NCC nursery protocol is that our potted plants will not be weeded in order to measure results of the solarization.

Plants chosen

Upon researching basic plant nutrient and soil drainage requirements, we decided to test the soil mixes on four different plants with varying needs based on what was available in the nursery. The soil mix categories will include four combinations of low drainage/low nutrient, low drainage/high nutrient, high drainage/low nutrient, and high drainage/high nutrient. In order to test the effects of the soil mixtures on plant growth, we have picked four plants that each fit ideally into one of these categories. First, lantana sage is tolerant of low drainage (although it prefers good drainage) and has low nutrient requirements ("How to grow Lantana", n.d.). Second, poinsettias prefer lower drainage (moist soils) and moderate to high nutrient input (Weisenhorn, 2018). Third, baby sun rose requires high drainage and low nutrient input ("Baby Sun Rose", 2019). Lastly, bougainvilleas prefer high drainage and moderate to high nutrient input and was considered a relatively hardy plant as asserted by the NCC nursery staff (Dyer, n.d.). These four plants will ideally show us how the nutrient content and drainage of the soils affect plant growth and will help to determine if there is a significant benefit to having four different potting soil mixes for use in the nursery or not.

Soil tests, weed load, and qualitative observation

Tests will be performed to assess the compaction and infiltration rate of each soil mix. Tests will be repeated to ensure reliability. These tests will provide information about the aeration and drainage qualities of each soil mix (NRCS, n.d.).

Water infiltration is the velocity at which water seeps into soil. Infiltration will be measured by recording the amount of time needed for a constant volume of water to leave the surface of the soil. Initial infiltration rates of dry soil are much more rapid than basic infiltration rates of previously wetted soil, as water molecules take up the space of air molecules (FAO Soil and Water, 1985). The second infiltration test provides a more practical rate (NRCS, n.d.), as most soils at the nursery will never be given the chance to dry completely. Both initial and basic infiltration tests will be performed to test the rate of water flow (mm flow per minute) throughout each mix. Compaction of soils must be taken into account for the basic (wet) infiltration tests, so soil depth from the rim of the pot will be recorded for each mix (FAO Annex 2, 1985). Water content must also be kept consistent among soil samples for the basic infiltration test, so soil samples should receive the same watering treatment as nursery plants. Higher soil compaction generally leads to a larger difference between the initial infiltration rate and the basic infiltration rate (DeJong-Hughes, 2018).

Soil compaction is the decrease of soil volume due to external factors (DeJong-Hughes, 2018). Soils with high compaction have lower aeration and gas exchange levels, drainage, and overall soil productivity due to decreased root penetration (Duiker, 2005). Soil compaction will be assessed by the reduction in soil volume over time as the typical watering routine is carried out on soil samples at the NCC Nursery.

High compaction can cause nutrient deficiencies, slow growth, low nutrient and water uptake, and wilting even when soil retains moisture (University of Saskatchewan, 2018). Compaction also indicates that air pores initially present after soil formation disappear. Many tropical plants require soils with high aeration and drainage, meaning soils with low compaction and many air pores. Thus, results of compaction and infiltration rates of each soil mix will indicate relative aeration and drainage levels.

The following procedures for infiltration and compaction tests, adapted from the NRCS of the United States Department of Agriculture for practicality (NRCS, n.d.), are outlined below.

Infiltration test:

1. Prepare pots containing a constant volume of each soil mix and the control mix (potting mix currently used by NCC Nursery). Make sure each pot has room from the level soil surface to the top of the pot to contain the water (2.5 cm). These pots do not contain transplanted cuttings.
2. Quickly pour a consistent volume of water over each soil mix so that the water sits on top of the soil. Start timer and pouring concurrently.
3. Record the amount of time it takes for no visible pools of water to remain on the surface of the soil. Repeat the process with each remaining soil mix sample.
4. Repeat this test a few times to compare infiltration rates. (The pots with soil are watered daily in the nursery as usual.)

Compaction test:

1. Prepare pots containing a constant volume of each soil mix and the control mix (potting mix currently used by NCC Nursery).
2. Measure the depth from the level soil surface to the top of each pot of soil mix after soil has been wetted. All initial measurements should be consistent (2.5 cm).
3. Take weekly measurements after performing infiltration tests so that the soil surface is level without manual leveling which may affect compaction and height of soils.
4. Pots are subject to daily watering as performed by the nursery staff.
5. Repeat height measurements weekly to record how the soil mixes compact over time.

Weeds are assessed as a total number from the pots of the same mix and plant type each week. This technique was used for ease of comparison and to facilitate a broader understanding of overall plant and soil health. Thus, the number of weeds in each specific pot will not be recorded; only the total number of weeds for all plants of the same soil mix.

Our qualitative observations and the final plant rankings were based on our subjective opinions. However, this is what a customer of the NCC nursery would do when choosing plants, and our study focused on practicality, so we included it as a measure. Qualitative observations will include the assessment of height, color, plant damage and disease, and soil appearance and wetness. Qualitative data are marked on a scale from 1-5 based on plant performance each week of measurement. The data marking scheme used is as follows:

1	Poor - Plants are yellowing, or dying back, or leaves are droopy and/or showing signs of deficiencies in all plants
2	Okay - Plants are yellowing, or dying back, or leaves are droopy and/or showing signs of deficiencies in 1-2 plants
3	Fine - One plant may exhibit yellowing, or dying back or droopy leaves
4	Good - All plants are growing healthily
5	Excellent - Leaves are green in colour, plant is vigorous, signs of new growth are available

Table 2. Plant vigor grading scale. Plants are assessed based on color, desiccation, signs of nutrient deficiency, and amount of new growth.

Results

1. Preliminary Solarization Trial: in the greenhouse at Bellairs Research Institute

	Day 1	Day 2	Day 3	Day 4	Day 5	Temperature change
Sheep	32.8	32.3	32.3	31.1	31.6	-1.2
Chicken	33.8	33.5	34.4	32.3	32.1	-1.7
Horse	31.7	31.0	31.7	30.5	31.2	-0.5
Topsoil only	31.8	31.2	31.5	30.2	28.8	-3
Control	31.9	31.1	31.0	30.6	31.0	-0.9

Table 3. Temperature of the various soil and manure mixes (degrees C.) The manure was mixed with topsoil in a 20:80 ratio. The control was taken from a premixed topsoil and horse manure pile which was already being used by the NCC nursery in their potting mix. The manure to topsoil ratio of the control pile is unknown, but is likely around 20:80.

<u>Final temperatures of some sample bags:</u>

After noticing that the clear plastic bags containing the soil samples taken from the piles were hotter and didn't have any weed seeds, we measured the temperature of a couple of them to confirm our newfound hypothesis of better solarization with clear plastic than with black plastic.

Results follow:

- Clear plastic bag with topsoil, sample from day 5: 38.3°C (9 days of clear solarization)
- Clear plastic bag with horse, sample from day 1: 43.2°C (13 days of clear solarization)

2. Final Solarization: in the field at the NCC nursery

	Week 1	Week 2
10:90 Manure to Topsoil	41.8 °C	43.0 °C
20:80 Manure to Topsoil	41.4 °C	40.2 °C
Control	43.1 °C	44.2 °C
50:50 Bagasse to Topsoil	41.9 °C	47.6 °C

Table 4. Temperatures of solarized soil piles (degrees Celsius) The control soil mixture was taken from the premixed manure and topsoil pile currently being used by the NCC nursery in their potting soil mix.

The mix that yielded the highest temperature during secondary solarization included bagasse. After 2 weeks, the temperature of the pile containing bagasse (47.6°C) was over 3 degrees C hotter than any of the other mixtures (the hottest being the control pile at 44.2°C.)

3. Infiltration Test

	Soil Mix 1	Soil Mix 2	Soil Mix 3	Soil Mix 4	Soil Mix 5	Soil Mix 6	Control
trial 1	9.23	12.63	17.05	29.73	12.17	15.83	72.52
trial 2	53.97	73.7	126.18	261.81	70.41	51.25	490.59
trial 3	478.45	177.53	209.42	89.78	120.78	202.42	4506.02
trial 4	87.1	113.11	254.08	80.65	100.42	62.65	579.17
trial 5	188.33	587.3	282.26	164.3	161.39	106.12	1508.61
Average infiltration time (seconds)	135.6625	66.465	88.9125	96.33	52.09	68.875	1689.71

Table 5. Infiltration rates of each soil mix in seconds. Infiltration rates are determined by the time from water addition to pots of potting mix according to methodology on page 11-12.

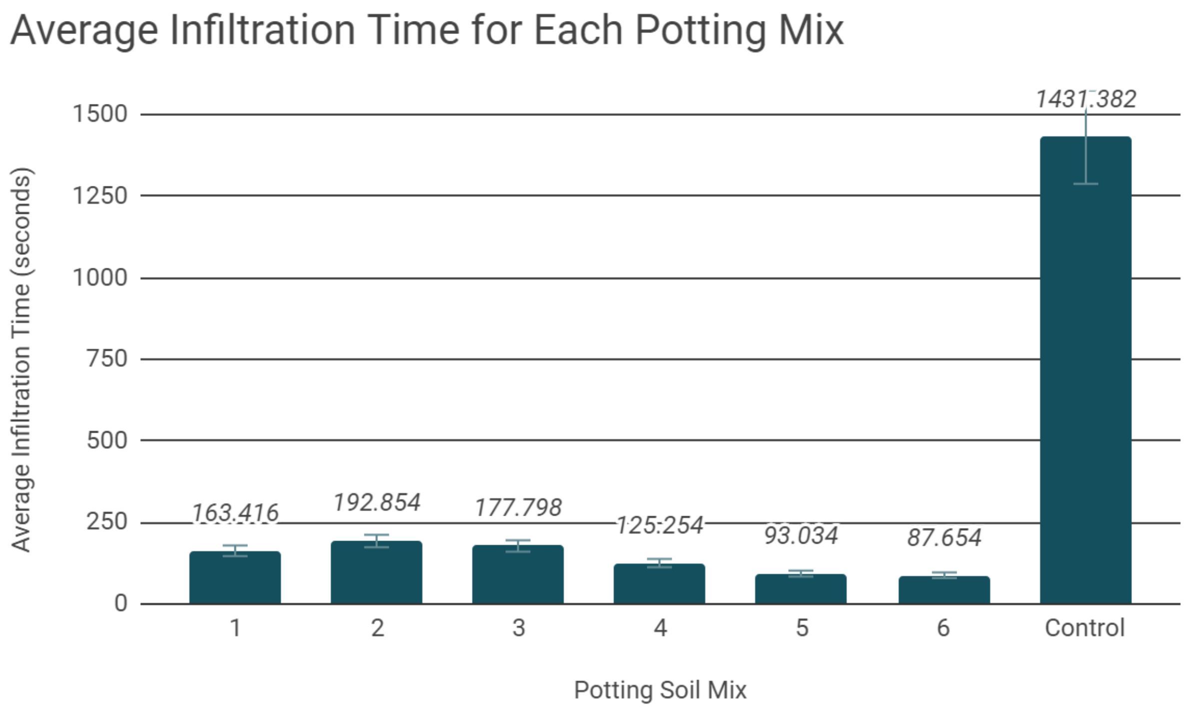

Figure 1. Average infiltration time for each potting mix. The infiltration test was repeated 5 times and an average of the measurements for each potting soil mix was taken. Results may vary due to environmental conditions, both climatic and potential variation in routine watering of the pots by the nursery staff, influencing wetness of each soil mix prior to potting.

The results show that the control pot containing the potting mix currently being used took, on average, over 7 times longer to infiltrate than any of the other soil mixes.

4. Compaction Test

	Soil Mix 1	Soil Mix 2	Soil Mix 3	Soil Mix 4	Soil Mix 5	Soil Mix 6	control
Week 1	1.6	1.4	0.8	0.5	1.2	0.2	0
Week 2	1.4	1.1	0.9	0.8	1.2	0.2	0.1
Week 3	1.5	1.1	1	0.8	1	0.3	0.1
Average	1.5	1.2	0.9	0.7	1.1	0.2	0.06
Standard Deviation	0.1	0.173	0.1	0.173	0.115	0.057	0.057

Table 6. Compaction difference (cm) from initial soil level of each pot of soil mix by week. Compaction levels of unplanted soil pots are measured by the difference in height from initial soil height (2.5cm from the rim pot) each week.

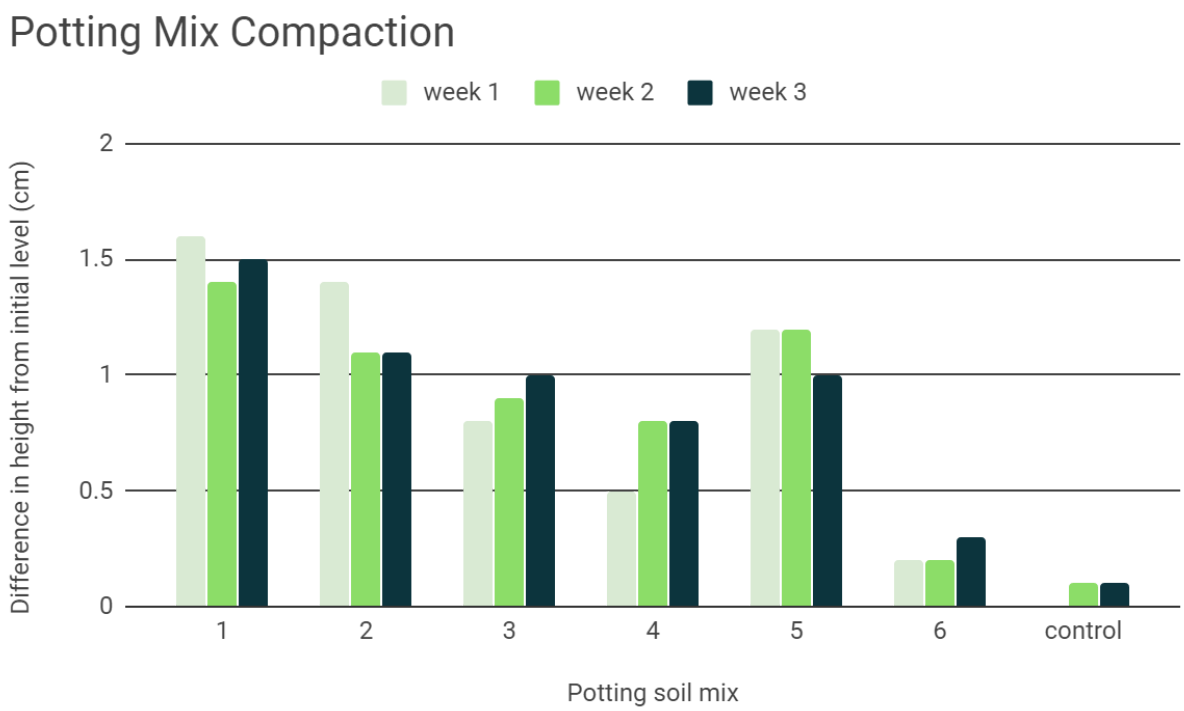

Figure 2. Potting soil mix compaction (cm) by week.

5. Weed load analysis

	Soil Mix 1	Soil Mix 2	Soil Mix 3	Soil Mix 4	Soil Mix 5	Soil Mix 6	Control
Week 1	2.75	0.5	3.25	1.5	3.25	2.25	12
Week 2	6.5	7.25	6.25	4.25	5	5	17
Week 3	7.75	6.75	8.5	5.25	8	5.75	18
Week 4	6.75	6.25	8.75	5.25	9.75	5.5	17

Table 7. Average number of weed seeds per potted plant of soil mix by week. Total number of total weeds visibly present in all plants of each soil mix type (12 plants in each) were counted and averaged.

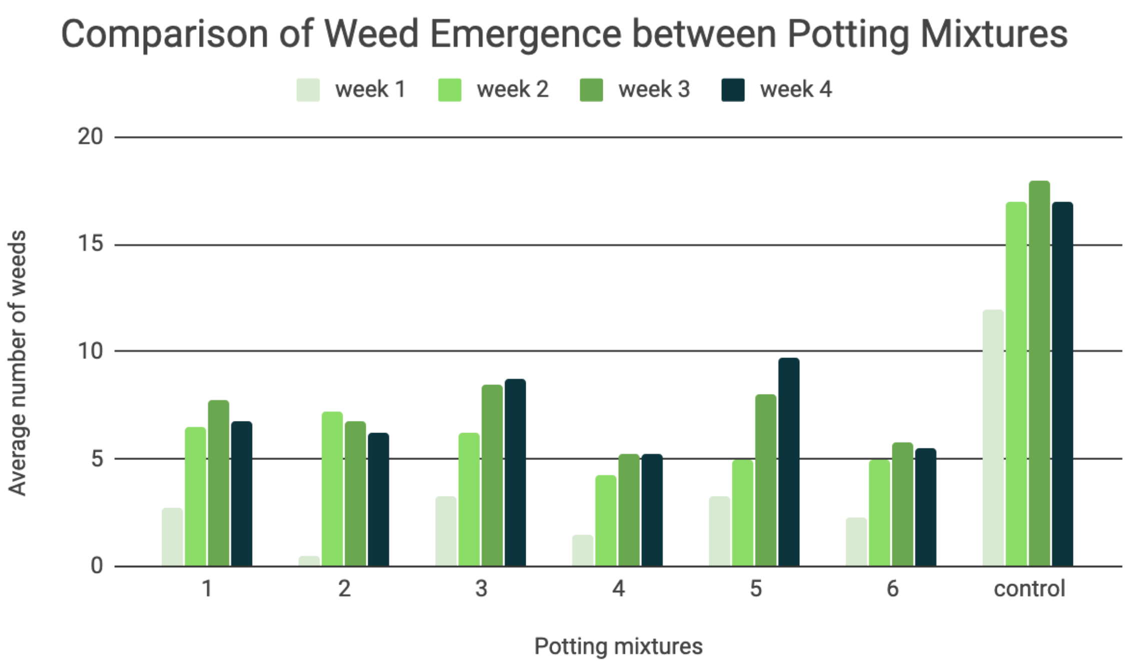

Figure 3. Comparison of Weed Emergence between Potting Mixtures. Displays week by week the number of weeds emerged for each potting soil mixture.

6. Pictures of plants for sale at the NCC

A. **B.** **C.**

Figure 4. These pictures are examples of the weed load that is currently found in the plants for sale at the NCC.


A. B.

Figure 5. Both pictures are plants potted in soil mixture #6. Picture A. displays a healthy baby sun rose as it has low nutrient requirements while picture B. displays the yellowing of a Bougainvillea.

7. Qualitative observations

Plant Type	**Overall soil ranking based on plant vigor, Week 4**
Poinsettia	2 > 1 > 3 > 4 > 6 > 5
Baby Sun Rose	5 > 6 > 3 > 1 > 4 > 2*
Lantana Sage	4 > 2 > 1 > 3 > 6 > 5
Bougainvillea	2 > 4 > 1 > 5 > 3 > 6

Table 8. Soil ranking based on plant vigor at Week 4. Ranking was based on the criteria listed in the methodology, as well as overall color, evidence of new growth, and visual evidence of dessication/disease. *One baby sun rose plant looked the best out of all plants, but the other two plants died.

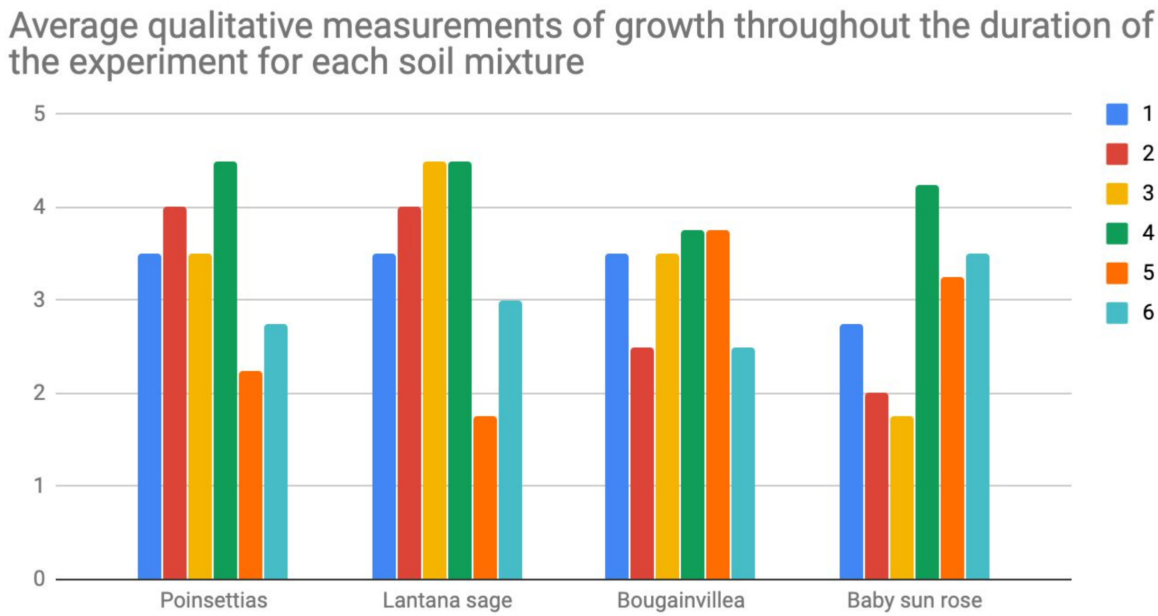

Figure 6. Average qualitative measurements of growth throughout the duration of the experiment for each soil mixture. Each week, plants were given a ranking from 1-5 following the outlines given in table __ for each soil mixture. This chart represents the average status of the plant for each soil mixture throughout the duration of the experiment.

8. Potted plant soil temperatures (poinsettia plants)

Soil mix	Temperatures (°C)	Average temperature
1	29.3, 30.2, 29.9	29.8
4	30.2, 29.7, 29.7	29.9
5	29.8, 29.1, 29.5	29.5
6	29.7, 30.2, 29.3	29.7
Control pot (no plant)	29.6	29.6

Table 9. Measured potted soil mix temperatures comparing bagasse to non-bagasse pots one week after transplanting. This was measured to ensure that the bagasse was not heating up the potted soil and potentially negatively affecting growth of the transplanted cutting.

9. Price Analysis

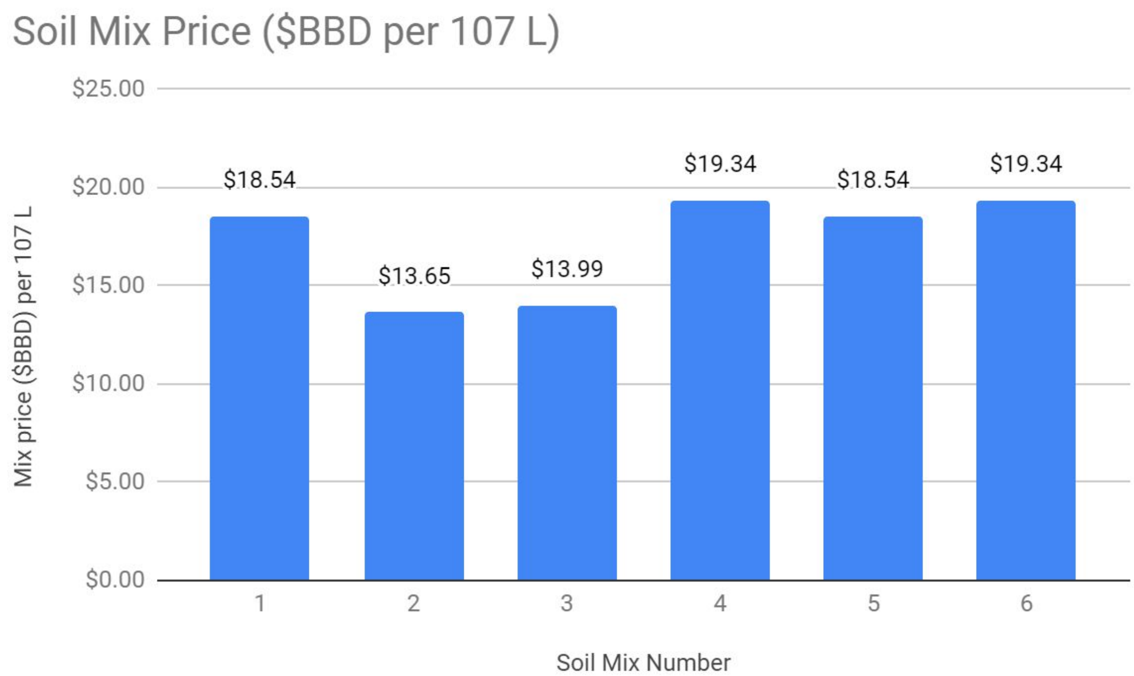

Figure 7. Price (in Barbados Dollars) of each soil mix per 107 L. Prices were calculated by 107L is used for comparison, which is the standard size for both peat moss and perlite bags.

Discussion

Solarization: which method worked best?

It was expected that the temperature of the soil in the preliminary trial would increase over time (Elmore et al., 1997), but it in fact decreased from Day 1 to Day 5 of temperature measurement (See table 3-Preliminary solarization). Weed germination was observed on all piles, with weed growth starting on Day 2 in the pile of soil mixed with horse manure. The last pile to germinate weed seeds was the premixed control pile which had been sitting in the sun for longer than the other topsoil and manure piles at the NCC. This suggests that the control mixture had already undergone a certain level of solarization on it's own just from being left out under the sun, thus killing off many weed seeds.

The soil samples that we took out of the piles each day and put into clear plastic bags to measure weed growth ended up having little to no weed growth, and were hotter than the actual piles undergoing solarization treatment. For example, the clear plastic bag containing topsoil was measured at 38.3°C, while the pile of topsoil itself cooled progressively throughout the study, ending at 28.8°C. This made it clear that solarization should be done with clear plastic under as much direct sunlight as possible (Stapleton et al., 1993).

Is there a significant difference in weed load from the soil mixes to the previously used mix?

Overall, we see that the solarization piles here were, on average, about 10°C hotter than in our earlier solarization experiment in the greenhouse, indicating that solarization was occuring more successfully. For example, the control topsoil and manure mix which was used in both experiments reached 41.9°C by the end of the first week under transparent plastic at the NCC, while under black plastic in the greenhouse, the control mix temperature was only 31.0°C on day 5 of solarization (see tables 2 and 3.)

The second solarization was closer to predictions as it was more successful. The temperature increased from Week 1 to 2 in all but one case (Table 4). Additionally, temperatures increased within the predicted range. July in Barbados (the month that the following experiments solarization trials occurred) has an average high temperature of 30°C. Therefore it was expected that the upper soil temperature would increase to 40-51°C, as per average increases suggested by previous literature, this temperature range was achieved in all cases (Abouziena, Haggag, 2016). At this range, it can be predicted that there should be a significant but not complete reduction in the weed load seeing as 50°C-60°C is generally regarded as the lethal temperature of all weeds (Masabni, 2012). This was exactly the case for our experiment, there was an average three fold reduction in all solarised soil mixes when compared to the control (Figure 3) but not all weeds were killed (Table 7).

Additionally, as mentioned previously, the decreased weed load benefit of solarisation is dependant on both the temperature reached and the duration of time spent at high temperatures. The following experiment was time limited so the solarisation duration was only 2 weeks despite the recommendation of at least 4 weeks (Masabni and Franco, 2016). Therefore, it may be the case that certain types of weeds, particularly hardy perennials did not have adequate time to become thermally inactive (Abouziena and Haggag, 2016). We noted that there were different types of weeds found in our solarised mixes compared to the control. Notably, there were no grasses growing in the solarised mixes while there were in the control mixtures. This can lead to the conclusion that the grass seeds were rendered thermally inactive in the solarisation process. This is a promising sign for the NCC where grasses can be seen growing taller than the potted plants if not weeded consistently, and grass roots tend to overpower the roots of the transplanted cutting and surrounding soil (See Figure 4: Picture A. and B. exhibit grass weeds). However, we have no way to guarantee that the topsoil we used in our mixtures came from the same place as their topsoil mixture that was being used at our time of planting as mentioned previously topsoil is sourced from various construction sites on the island. Therefore it could be the case that the initial top soil in the control had larger amounts of grass seeds to begin with.

It was found, however, that the piles containing bagasse reached the highest temperatures during solarization as compared to the other piles. After 2 weeks, the temperature of the pile containing bagasse (47.6 °C) was over 3°C hotter than any of the other mixtures (the control pile was the second hottest at 44.2°C.) This result was as expected due to the high energy potential of bagasse. However, contrary to our predictions, the added bagasse did not have a significant effect on reducing the weed load in the solarised pots. It was expected that both bagasse containing mixes, soil mix #5 and #6 would have a significant reduction in weed load. However, it was found that #5 had the second most number of weeds in Week 3 and was equal to the highest number of weeds in Week 1. The other bagasse containing soil mixture #6 fared better as it was the second best in Week 2 and 3 (Figure 3 and Table 5). The reason for the poor results is because we began solarization of the bagasse and topsoil mixture one week after solarization of the topsoil and manure mixtures commenced, the solarized bagasse and topsoil mixture was incorporated into the potting mixes when it had only reach 41.9°C and thus had reached the temperature that the other piles reached after two weeks of solarization, but not its peak temperature of 47.6°C (Table 4). This could explain why the bagasse containing soil mixes don't show significant reduction in weed growth .

Due to the high C:N ratio of both Bagasse and Coconut fibre, nutrient deficiencies are predicted to occur when these materials are combined with lower percentages of manure as the nitrogen will be immobilised and not plant available, resulting in lower plant vigor (Rosales et al., 1997.) This was certainly noted in the soil mixes containing bagasse. A concern was that heat from the bagasse was causing the transplanted cuttings to wilt and look pale (Nassar, Ashour & Wahid, 1996.). In order to rule out the possibility of the decreased vigour being from the continued breakdown of and release of heat from bagasse in the pots, we took temperatures of some pots to compare and there was no significant difference between bagasse and non-bagasse containing pots (see table 9.) Therefore, the variation in plant vigor is thus likely due to a C:N ratio that is too high in the mixtures including bagasse (lower manure content and higher carbon content from bagasse. Addition of more manure and/or nitrogen fertilizer could be useful in ameliorating plant health and appearance.

Comparing the manure content of each soil mix with the amount of weeds present, it seems that having a higher horse manure content reduced the overall number of weeds. The average numbers of weeds by Week 4 were slightly lower in soil mixes containing 20:80 manure than those of 10:90 manure (Figure 3; weed load graph). While mix #3 had a 8.75 weeds on average by Week 4, mixes 4 and 6 had 5.25 and 5.5 weeds present respectively, which were the two lowest weed loads of any of the soil mixes. Mixes 1, 2, and 5, which all had a ratio of 10:90

manure to soil content, had 6.75, 6.25, and 9.75 weeds on average per pot by week 4 (Table 7). Thus, the mixes containing a higher ratio of manure to topsoil presented less overall weeds on average by Week 4. Based on these results, we can assume that more weeds seeds were contributed from the topsoil than the manure itself, and having a higher manure content would be beneficial for the creation of a soil mix with less weeds. However, mixes 1, 2, and 5 all contained only coconut fibre in the absence of peat moss, while 3, 4, and 6 only contained peat moss and no coconut fibre. Therefore, the true ability of the manure content to reduce the overall number of weeds could be influenced by the presence or absence of other soil amendments, so more tests with the combination of coconut fibre and peat moss within the same mix should be carried out to analyze the benefit of both amendments in conjunction.

Are the characteristics of soil mixes consistent with what we expected? (H/L Drainage, nutrient, etc.)

The characteristics that soil mixes were designed to have did not always align with the predictions. Results of the infiltration, compaction, qualitative analysis observations, and plant rankings held interesting results. Analysis of the results revealed that some of the soil mixes did not perform according to their predicted drainage and nutrient content types. We designed mixes 1 and 5 to have high drainage and low nutrient content (HD/LN), mix 2 to have low drainage and low nutrient content (LD/LN), mixes 3 and 6 to have high drainage and high nutrient content (HD/HN), and mix 4 to have low drainage and high nutrient content (LD/HN).

Drainage was analyzed by the results of the compaction and infiltration tests. To preface, only one basic (dry) infiltration rate was performed in this study, as soil samples were kept in the same environment as other plants, and thus, received the same watering treatment. The four other tests provide secondary infiltration rates. All soils contained the same daily amount of moisture upon infiltration testing, although the actual amount of water varied week by week. Thus, data from all tests can be compiled, as all soil types being compared each week held the same amount of moisture before infiltration testing was undertaken. As predicted, the control had the slowest rate of infiltration. The average infiltration time was 1,432.382 seconds for the control mix used by the NCC. The next highest infiltration rate, mix 2, had an average rate of 192.854 seconds; almost 7.5 times faster than the control. Without a doubt, the soil mixes created for this study had much faster infiltration, which could alleviate growth problems such as insufficient water and nutrient uptake and/or poor root growth (NRCS, n.d). Comparing the mixes designed to have high drainage levels (1, 3, 5 and 6) had average infiltration rates around the same as those designed for low drainage (2 and 4). However, it can be visually seen that the bagasse containing soil mixtures (5 and 6) had the fastest infiltration rate, this is likely because they contained half the amount of water absorbing clay topsoils (Figure 1). This correlates with our expectation that soil mixture 5 and 6 would have high drainage levels, as faster infiltration can be loosely correlated with the expectation that drainage would also be faster.

Compaction tests revealed that the control soil did not compact, as much as our mixed soils, contradictory to the trend that soils with lower infiltration rates have lower compaction levels (Duiker, 2005). Compaction tests revealed that soils with coconut fiber compacted more than those with peat moss (Table 6). Soils 1, 2, and 5, all containing coconut fiber, sunk an average of 1.5cm±0.1, 1.2cm±0.173, and 1.1cm±0.1) from initial potting level by Week 3. Comparing these compaction levels to the soils containing peat moss (3, 4, and 6 at 0.9cm±0.1, 0.7cm±0.173, and 0.2cm±0.057 respectively), the soils containing coconut fiber had a lesser volume than before watering. Thus, peat moss is better in this case to alleviate soil compaction. The length and long cut of the coconut fibre that was used in this trial may have improved infiltration as predicted according to the literature (Satnik, 2018), yet the compaction (and thus aeration) may have been reduced as compared to peat moss because of its size and inability to separate soil particles once wet. Therefore, the coconut fibre uses is not a “substitute” for peat moss as an amendment, as the soil texture, compaction levels, and infiltration rates differ. All soils compacted more than the control, which compacted an average of 0.06cm±0.057. While this may be counter to our hypothesis, one conclusion that can be drawn from this is that the control was already more compact to begin while the other soils initially had more air holes in the soil were slowly being compacted overtime due to the pressures of watering. We hand-mixed soil mixes 1-6 on the day of the first measurements, while the control had been mixed previously and left to sit. The next step, comparing the difference between basic and secondary infiltration rates, cannot be analyzed, as only one instance of the basic infiltration rate was recorded due to the nursery environment. Thus, the assertion that higher soil compaction levels generally lead to a larger difference between the initial infiltration rate and the basic infiltration rate (DeJong-Hughes, 2018) cannot be assessed in comparison to the data of this study. Soils with high compaction have lower aeration and gas exchange levels, drainage, and overall soil productivity due to decreased root penetration (Duiker, 2005), yet recorded plant vigor results did not correlate (Tables 4, 8).

While nutrient content was not specifically measured, plants in mixes #5 and 6 showed signs of nutrient deficiency based on the tips of leaves, overall color, and vigor in bougainvillea and sage (Figure 5), (Hosier & Bradley, 1999). This is likely due to the combination of the high C:N ratio of bagasse and since mixes 5 and 6 had half the manure to soil mixture and half of the 50:50 bagasse and topsoil. Thus, the nutrient content of these soils were 5:95 (#5) or 10:90 (#6) manure to topsoil and bagasse combined. Furthermore, baby sun rose, which prefers soils with low nutrients, grew best in soil mix #5 and 6 providing further evidence that these mixtures lacked nutrient availability.

Which soil mix is best for the growth of each plant type?

Plant vigour in each soil mixture was not consistent throughout the experiment. The following part of this paper will examine if the predicted soil mixture that would match the plants needs was realised. Emphasis will be placed on data taken from Week 4, as it is assumed that plant conditions during the initial weeks are less significant if they were more vigorous by the end of the study. The final product, not the process, will move a consumer dollar. For the NCC, selling plants is the goal. Reading the following section, it is important to emphasize that observations are based off of qualitative analysis; therefore, they are subject to inherent bias. In many cases, there was not often a soil mixture that was clearly best for any of our experimental plants, and this will be discussed in depth. As such, pronouncing one soil mixture as the overall best is to be taken with a grain of salt as all the soil mixtures had advantages and disadvantages.

Plants were chosen based on their nutrient and drainage needs. Lantana sage was chosen to fit the low drainage, low nutrient (LD/LN), correlating to soil mixture #2 profile ("How to grow Lantana", n.d.). However, in the final week soil mixture #4 low drainage, high nutrient (LD/HN) was qualitatively chosen to be the best (Table 8). Throughout the duration of the experiment soil mixture #3 high drainage, high nutrient (HD/HN) and #4, low drainage, high nutrients (LD/HN) had the best growth with a ranking of 4.5 relating to between good and excellent (Figure 5). Overall, it can be said that #4, low drainage, high nutrients (LD/HN) was the best soil mixture for lantana sage.

Poinsettia was chosen for the low drainage, high nutrient (LD/HN) profile correlating to soil mixture #4 (Weisenhorn, 2018). Looking at the overall growth, this hypothesis was realised, though by Week 4 the poinsettias in soil mixture #2, #1, and #3 were ranked as looking more vigorous compared to #4 (Figure 6). Therefore, the results do not lead to a clear best soil mixture for Poinsettias.

Baby sun rose needs correlated to the high drainage, low nutrient (HD/LN) profile which is found in soil mix #1 and #5 ("Baby Sun Rose", 2019). By the final week, soil mixture #5 followed by #6 were qualitatively the most vigorous (Table 8). This final result can be well explained as both of these were found to have the fastest infiltration rate as discussed previously and were labelled as having a high drainage capacity which baby sun rose prefers. Furthermore, as previously mentioned, baby sun rose performs well in low nutrient conditions and soil mixture #5 had the least amount of nutrients of all mixtures at a manure to topsoil ratio of 5:95 and #6 following at 10:90. However, soil mixture #4, low drainage, high nutrients (LD/HN) had the best overall growth throughout the duration of the experiment, which has the complete opposite profile of what was expected (Figure 6). It is possible that the plants might have initially benefited from having more moisture and more nutrients during the stress of transplanting though this is unlikely as most sources that succulents benefit from waiting 1-2 days to water as to let the roots acclimatize (Sproule, n.d.).

Furthermore, baby sun rose was the most difficult to transplant due to its long, fibrous roots that were prone to breakage. For instance, soil mix #2 produced the best overall baby sun rose plant in terms of color, new growth, size, and least signs of stem desiccation. However, the other two plants of soil mix #2 were either completely or nearly dead, placing soil mix #2 in the last ranking order (Table 8). Since the contrast in results was so stark, it is likely that the root systems were damaged during transplanting, or potting bags did not contain enough space for roots to grow adequately.

Bougainvillea was expected to grow the best in the high drainage, high nutrient (HD/HN) soil, which correlates to the soil mixtures #3 and 6 (Dyer, n.d.). By the final week, soil mix #2 qualitatively held the healthiest plants; #2 has the complete opposite profile of what was expected to be the best. Additionally, #2 had poor qualitative ranking each week, with an average of 2.5 for all weeks (Figure 6). Throughout the duration of the experiment, soil mixes #4 and #5 had equal ratings for the healthiest plant. Thus, there is no 'best' soil mix for Bougainvillea. The predicted best soil mixtures, 3 and 6, were not the best throughout the process nor by the end of Week 4. The soil mixtures that performed the best in the experiment, #2 at the end and #4 and #5 overall do not have any key factor in common that may have benefitted the bougainvillea. However, most bougainvilleas were alive, showed signs of new growth, and had good color. By the end of the study, bougainvilleas were the most difficult to rank based on physical similarity, since they were all growing relatively well compared to other plant types, which showed a stark contrast from the best to the worst. Thus, it follows the assertion made by the NCC that bougainvillea is a hardy plant which can survive in many types of conditions, and that the bougainvilleas planted in the current NCC soil mix are vigorous.

Throughout the experiment, soil type #4 was found to be the best soil type for the four types of plants (Figure 6) as it always ranked equal or above all other soil mixtures. This was likely the easiest soil for the plants to be initially transplanted into as it had a fast infiltration rate and contains high amounts of nutrients which closely matches the previous environment the plants were in, easily infiltrated sand and large amount of nutrients due to biweekly fertilization. Nevertheless, for the purpose of the NCC it is the final plant product which holds the highest importance.

By the final week, soil type #2 held, on average, the highest rank order for all four types of plants grown in this study as it was ranked #1 for both Poinsettias and Bougainvilleas, and #2 for Lantana sage (Table 8). With a low drainage, low nutrient profile it was also expected to rank high with the Baby Sun Rose but as discussed previously one of the plants was extremely vigorous in soil mix #2 but the other two had likely been mishandled during transplanting which lead to complete or partial plant death.

Which soil mix is most economically viable, and does this align with the best soil mix for plant growth?

By chance, soil mixture #2 correlates to the cheapest soil mixture out of all the mixes designed for this experiment. Furthermore, it meets the NCCs goal in using more locally sourced materials as it swaps peat moss for coconut fibre making it a highly attractive mix. However, the practicality of using the coconut fibre in large mixtures is low as it was a difficult material to work with due to its long strands that were bunched together. A significant amount of manual labour was required to separate the strands. Unless there was an easier, ideally mechanized way to separate the strands was designed, it would likely not be able to accommodate their large scale mixing. The cost difference between coconut fibre and peat moss is low: $38.05 for a 107 L bag of peat moss and $35.66 for an equivalent 107 L bag of coconut fibre. Thus, it may be cheaper labour-wise for the NCC to continue the use of peat moss. In the future, a transition to coconut fibre would be the more environmentally sustainable option (Satnik, 2018).

While soil mix #2 may be the cheapest soil designed in our experiment, it is still more expensive compared to the NCC's current soil mixture. This is largely due to the higher amounts of perlite found in our soil mixes. However, it is clear that the additional perlite had an extreme positive effect on increasing the soil infiltration rate (Figure 1), which will have a positive effect on the plant growth that would likely outweigh the extra costs. It was noted by the NCC's staff that the plants used in this experiment seemed to be quicker at bouncing back following transplanting. A faster turnover rate of plants going from the hardening area following transplanting to being ready to market could relate to increased sales.

Similarly, the reduction in weed load by solarisation makes the cost of labour to set it up and the initial cost of plastic worth it. The savings to be made are in decreased time spent weeding and increased plant purchases from customers. Weeds can completely take over the pot (Figure 4), making the plants visually unpleasing to the consumer. The NCC have had complaints from customers regarding the weed load in the plants for sale. Therefore, a decreased weed load would likely boost sales. As can be seen in the pictures found on the left side of Figure 4, grass weeds dominate the pots. The rhizomes found in grasses make it impossible for workers to simply weed once as in two weeks the grasses will have regrown. Therefore, to eliminate the problem from recurring the NCC staff have to completely re-transplant into new soil which would vastly increase labour time.

Conclusion

The main goal of this experiment was to create a weed free sustainable potting mixture. A holistic view of sustainability was taken combining factors regarding the environment, cost, and effect on plant growth being observed. Solarization was chosen as a sustainable technique to decrease weed load and the experimental data proved that it was successful in decreasing the weed load. The NCC would benefit in decreased labour time and increased plant sales from solarising their potting mixtures so we would recommend the adoption of this technique in the future.

It is clear that the current soil mixture used by the NCC has issues regarding poor infiltration. Correcting this will be key to boosting plant growth in the future, increasing plant sales and profits. Increased amount of perlite and bagasse were both shown to help increase infiltration rates and we would therefore recommend to increase the use of these materials in future potting soil mixtures.

Due to constraints involving limited time and the overall size of the study, factors influencing plant health may be confounding. For instance, bagasse was only available one week after setting up the other solarisation piles meaning that at the time of planting it had one week less to solarise compared to the other trials. As well, the initial rooted cuttings used were not uniform in size and health. The poinsettias for example were prone to toppling as they were transplanted at a more mature age compared to the other plants.

The bagasse containing soil mixtures were shown to have faster infiltration rates and therefore could potentially be used as an alternative to perlite to increase drainage and decrease compaction. If the NCC were able to continuously source a free bagasse, it would be possible to decrease the amount of costly perlite by replacing it with bagasse. However, it is still up in the air whether a free source of bagasse will be available in the long term. In this experiment bagasse was used as a substitute for the manure soil mixture rather than a substitute for perlite as its increased infiltration times was only realised by analysis of experimental data. In the case where bagasse is required to be purchased, it may not make financial sense to be using bagasse over the free source of topsoil and manure. If bagasse was to be used it would likely need to be accompanied with larger amounts of nutrients as its large C:N ratio will leave most plants nitrogen deficient, this was the case for all the experimental plants excluding baby sun rose which thrives in low nutrient environments. Increased nutrients could be achieved by increasing the amount of manure in the mix or increased fertilisation. Due to time limitations, this experiment was not able to prove that the additional heat from bagasse decreased weed load but seeing as it significantly increased the solarisation piles temperature it would likely to be a useful addition to decreasing weed load for the NCC in the future.

While this study did not determine a "best" potting soil mix in terms of overall infiltration, compaction, qualitative analysis, weed reduction, and price, potting soil #2 still held the highest ranking after qualitatively analyzing all plant growth, has the lowest cost for the NCC of the new soil mixes created, and replaces imported soil amendments with once sourced more locally. Additionally, results in the solarization and infiltration trials revealed important insights on the soil health of the current plants at the NCC, and the causes of high weed load, low aeration, and drainage problems have been made apparent in this study.

Because there is no single "best mix," the NCC Nursery can utilize findings from this study to improve their soil mix when and how they see fit. If the initial priority is weed reduction, wide scale solarization can be implemented, which would require an initial investment of large plastic and labour, but later savings in terms of repotting, labour costs for plant care, and would increase customer satisfaction and sales. If priority is placed on overall plant health, the utilization of more perlite or bagasse in the soil mix at the NCC would create better aeration and drainage conditions for newly-transplanted rooted cuttings. If priority is placed on sustainability and cost, replacement of imported perlite and peat moss with amendments like coconut fiber and bagasse prove to be beneficial in terms of ameliorating plant health and price. This study has revealed the causes behind soil-based problems at the nursery and has analyzed some processes and materials to address them. After the results of this study, the NCC can experiment in utilizing these materials and practices in the ongoing process of upgrading their their potting mix in whichever ways they best see fit.

Recommendations

Composting

Composting speeds up the degradation process of organic material via microbes in a warm, moist, and well-aerated environment (Dalzell et al., 1987). The compost or humus created supplies nutrients and improves moisture-retention of soils. Using composted rather than uncomposted manure is more effective at building soil nutrient levels, providing residual nutrient support to plants, and reducing nutrient losses to the ground via nitrate leaching (Hepperly, 2013). Composting manure and bagasse together prevents the leaching of nitrogen into soils, increased fertilizer profile, and a decreased C:N ratio with the breakdown of organic carbons and the retention of nitrogen as opposed to off-gassing via volatilization (Bernal et al., 1996). Establishment of a composting scheme at the NCC Nursery for manure and bagasse would he very beneficial to soil health in terms of fertilization and could reduce costly fertilizer inputs.

Topsoil sourcing

"Donations" of topsoil from various construction sites on the island are a source of inconsistency amongst potting soil mixes. The possibility of presence of contaminants in the topsoil could have an impact on the transplanted potted plants. The types of weed seeds present in topsoil vary, some affecting the growth and soil constituency of the potted plant more than others. This is a factor to consider when reviewing our solarization results. The topsoil we used to create our potting mixes may not have been sourced from the same site as the topsoil used in the control mix, thus may alter observed weed growth. Also, pathogens or pests could reside in the topsoil, presenting potential issues to the growth of transplanted cuttings. Ideally, topsoil would be sourced from sites that are known to be free of pathogens, pollutants, and copious amounts of weed seeds. Solarization could potentially help reduce weed and pathogen load, but primary prevention by selecting good topsoil is the ideal solution. Solarization is more effective for annual weed seeds whereas perennial weed seeds tend to be more hardy, thus selecting topsoil from sites where the weeds are less vigorous is ideal (Masagni, 2018.)

Coconut Fibre and Coconut Coir

Studies have shown that using fine coconut coir (also called "coco peat") is an effective substitute for peat moss (Satnik, 2018.) In our experiments, we used long coconut fibers which improved infiltration of water but did not help with soil compaction (as the soil texture remained clay-like) or in overall plant growth. Also, mixing the long coconut fibers into the potting mix took time and energy that may have not been worth it. Perhaps including finer coconut coir would provide the benefits of good infiltration, while also improving soil texture by reducing compaction. Coconut coir is a much more sustainable alternative to peat moss and should still be greatly considered as a potting mix amendment.

Solarization

Ideally, solarization would be carried out for a complete four weeks in order to ensure that as many weed seeds and pathogens are eliminated. Adding bagasse into solarization piles did increase the temperature of the soil mixture, contributing to faster and more efficient solarization. Perhaps an ideal mixture to be solarized will include topsoil, manure and bagasse. If manure is composted separately, then it does not have to be added before solarization of the topsoil and may be added later as a fertilizing soil amendment.

Soil compaction

Although we measured soil compaction and hypothesized about its relationship to water infiltration rate, looking into how compaction of the nursery's current potting mix may be impacting root growth could be beneficial. Overly compact and heavy soils may prevent roots in certain plants from being able to grow and expand to their full capacity. Proper development of roots ensures better uptake of water and nutrients. Less compact and heavy potting soil may yield a more extensive root system, allowing plants to access water and nutrients more readily resulting in healthier plants. Also, since the plants grown in the nursery are designed to be replanted after they are bought, it is important for them to have a well-established and large root system.

Mixing procedure

As current creation of each batch of potting soil mix is relatively inconsistent, we advise that soil amendments should be applied by proportion in whatever unit the NCC deems fit. Mixing should be standardized in order to ensure quality and consistency. Mixing of composted manure, which would be more malleable and less dry than the current manure used, with topsoil and bagasse before solarization can be undertaken in the field. Further amendments (such as perlite, peat moss, coconut fiber, and coconut coir) can be incorporated in the nursery workspace.

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