RMCG

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Reuse and recycling of substrate for hydroponic strawberries

Stage 1 Report

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Table of Contents

Summary i

1 Background 1

2 Project objectives and approach 3

2.1 OBJECTIVES 3

2.2 STAGED APPROACH 3

3 Stage 1 – Scope and method 4

3.1 STAGE 1 – RESEARCH SCOPE 4

3.2 STAGE 1 – RESEARCH QUESTIONS 4

3.3 STAGE 1 – METHOD 4

4 Stage 1 – Findings 5

4.1 PREFERRED ATTRIBUTES OF STRAWBERRY HYDROPONIC SUBSTRATES 5

4.2 SUBSTRATE ANALYSIS 6

4.3 TESTING SUBSTRATE PROPERTIES – STAGE 1 ASSESSMENT 7

4.4 HYDRAULIC PROPERTIES OF SUBSTRATES – LABORATORY TESTING AND INVESTIGATION 10

4.5 TESTING FOR PATHOGENS 11

4.6 SUBSTRATE STERILISATION TECHNOLOGIES 13

4.7 ECONOMIC ANALYSIS 15

5 Conclusions from Stage 1 17

6 Next stage project research priorities 19

References 20

Appendix 1: Individual Substrate – Desktop SWOT Analyses 21

Appendix 2: Chemical properties of substrates 25

Appendix 3: Initial investigations into the hydraulic properties of coir and wood-fibre 28

Appendix 4: Sterilisation techniques – Overview SWOT analysis 38

ACKNOWLEDGEMENT OF COUNTRY

Tasmania is Aboriginal land. We acknowledge the palawa and pakana, the Tasmanian Aboriginal people, as the Traditional Owners and continuing custodians of the lands, seas and waterways of lutruwita, Tasmania on which this project has been conducted. We recognise their continuing connection to land, waters and culture and pay our respects to their Elders past and present, and we acknowledge emerging leaders. Moreover, we express gratitude for the knowledge and insight that Traditional Owners and other Aboriginal and Torres Strait Islander people contribute to our shared work in Australia.

We pay respects to all Aboriginal and Torres Strait Islander communities. We recognise that Australia was founded on the genocide and dispossession of First Nations people and acknowledge that sovereignty was not ceded in this country. We embrace the spirit of reconciliation, working towards self-determination, equity of outcomes, and an equal voice for Australia's First People.

Summary

Tasmanian strawberry growers investigate more sustainable production systems – Stage 1 report.

Fruit Growers Tasmania (FGT) is leading a project, funded by the Department of Natural Resources and Environment (NRE Tas) through the Agricultural Development Fund. The project is investigating the feasibility of reducing, reusing, or replacing hydroponic coir-based substrates in the strawberry industry. The project is delivered in cooperation with three commercial partners; they are Costa, Hillwood Berries, and Tasmanian Berries. Burlington Berries provided information in support of the research. RMCG is providing research and development services.

The overall research objectives are:

1. Understand the merits and issues of reusing coir in the context of Tasmanian hydroponic strawberry production systems
2. Identify product sterilisation techniques compatible with commercial on-farm use and whether they are essential for the reuse of spent (used) coir
3. Experiment with suitable Australian and or local organic biproducts to maintain or improve the properties of recycled coir and reduce reliance on coir imports
4. Determine the economic benefits of recycling coir to commercial users.

The project will be undertaken in four stages.

- Stage 1 – Defining the characteristics of alternative substrates
- Stage 2 – Small-scale trials
- Stage 3 – Larger-scale trials
- Stage 4 – Economic analysis.

Stage 1 of the project aimed to define the characteristics of alternative substrates and undertake desktop research into the feasibility of reusing coir, prior to undertaking trials as part of Stages 2 and 3 of the project. This report presents the findings from stage 1.

Wood fibre substrates appear to be the most suitable alternatives to coir, however, they may have some production differences which will need to be examined during Stage 2.

Stage 1 also determined that using spent coir appeared feasible given the lack of physical degradation and pathogen profile, however, trials in Stage 2 will determine whether there are any other factors that might impact using coir for more than one season. Sterilisation options for substrates identified as most suitable are microwaving, using ozone gas and composting. Each of these options requires further economic and technical analysis if it is determined that sterilisation is required.

An economic framework was developed allowing berry producers to compare gross margins as influenced by different substrates, their cost and their use (1 year, 2 years, in grow bags, in troughs). It found that wood fibre substrates may be economically feasible, assuming any production differences are able to be managed effectively.

Stage 1 research questions and findings were:

- What are the desired attributes in a substrate?
  - Adequate water-holding capacity, air-filled porosity, compressibility, sustainable recovery of spent materials and the ability to be produced locally are the key desired characteristics of substrates (all characteristics are detailed in Section 4.1).
- What are the characteristics of alternative substrates?
  - Alternative substrates were identified, and their characteristics examined by SWOT analysis. Alternate substrate characteristics varied substantially between substrates
  - The SWOT analyses are shown in Appendix 1, and summarised in Section 4.2.1.
- What are the preferred alternative substrates to coir?
  - Wood fibre products were identified as the most suitable alternatives, especially when mixed with coir
  - Wood fibre products possess advantages over other identified substrates. This is detailed in Section 4.2.2
  - Composted pine-bark substrates also warrant further investigation in the next stages of the project.
- What are the characteristics of used (spent) coir (after one growing season)?
  - The characteristics of used coir was found to be similar to that of fresh coir, both from a physical and biological (pathogen load) perspective. This is detailed in Sections 4.3 – 4.5. More research is required to further examine the characteristics of used coir
  - The results demonstrated the potential in using coir substrates for more than one growing season.
- What sterilisation options are available for substrate?
  - Microwaving, using ozone gas and composting were identified as the most suitable sterilisation options for substrate
  - Chemical options are not preferred by project partners due to WH&S issues
  - An overview SWOT analysis was undertaken and can be found in Appendix 4
  - Each of these sterilisation options will require further technical and economic analysis, if it is determined that sterilisation is required.
- What are the baseline costs of sourcing coir for single-use hydroponic production systems?
  - Baseline costs of sourcing coir (at the time of research in late 2022) was between $180 and $220 per cubic metre, delivered on-farm. Coir prices have since decreased, primarily due to decreases in shipping costs
  - Research showed that coir costs (including freight) fluctuate substantially due to various factors, including global economic conditions, fuel prices, trade policies, and shipping industry dynamics. Global shipping prices are the key price contributor to coir prices in Australia. For instance, in 2021-22, when the project was conceived, costs were extremely high and freight times unpredictable and longer than before the Covid pandemic. This correlated with decreased shipping availability and increased shipping prices
  - The recent decrease in coir price has influenced the view of some berry producers on the need for immediate coir replacement. Others believe that an alternative should be investigated further as a risk management strategy to mitigate against any possible future interruptions or cost increases in coir supply.
- How resilient is the cost of coir substrate materials to different price shocks and or supply chain/availability shocks?

- Freight and transport costs are the key price contributor to coir landed in Australia and vary more than the price of coir itself as a raw material. Any global supply chain shocks which impact shipping prices will inevitably have a substantial impact on the price of coir delivered to Australia, given coir originates in coconut-producing countries within Asia. Timing of supply is also a concern when there are interrupted supply chains.

- What suitable materials are available in Tasmania which can be used to augment coir as a hydroponic substrate?
  - A wood fibre product and composted pine bark were identified during Stage 1 as possible options, and these may be suitable when mixed with coir. A wood fibre product is currently produced (pilot commercialisation stage) in Victoria and a second wood fibre option is under development in Queensland
  - The coarser wood fibre (GrowFibre) product is available in Tasmania and is shipped from Victoria
  - A pine bark substrate is currently produced in Northeast Tasmania from forestry 'waste' and is under investigation to be trialled in Stage 2.
- What is the cost of accessing alternative materials, and how does this change with location and freight costs?
  - Wood-fibre products range from $40 - $130 per cubic metre, excluding freight (Refer to SWOT in Appendix 1)
  - Products that are able to be compressed are lower cost to ship and may remain viable against coir if not produced in Tasmania
  - Some wood-fibre products are able to be compressed (Australian Wood Fibre product), whilst others are not. De-compressing product however requires specialised equipment.
- Which materials should be trialled in the formula of the mixed substrate in stage 2 of the project?
  - It is recommended to continue with forestry 'waste' based (wood fibre and composted pine bark) alternative substrates in Stage 2 and refine the physical properties by mixing optimum proportions of coir and alternative substrate
  - During stage 2, it will need to be determined whether mixing wood fibre or pine bark with spent coir results in better substrate performance than that of spent coir alone. If this is the case, stage 3 will aim to identify the optimal mixing ratio
  - The trialling of substrates must consider changes in the production system such as troughs, different irrigation applications, mixing and potentially sterilising of substrates and 'end of life' solutions for spent substrates. The effect of different substrates on crop performance must be monitored throughout the season for Stage 2. Further investigating substrate properties is required for Stage 2 as well as providing feedback to alternative substrate producers.

Next steps for the project are detailed in Section 6 and include:

- Further research on using spent coir for hydroponic strawberry production
- Determining the feasibility of hydroponic strawberry production using wood fibre and pine park substrate materials
- Considering the transition from grow-bags to troughs in the above.

1 Background

SUBSTRATE USE IN TASMANIA'S BERRY INDUSTRY

In 2020-21 the Tasmanian berry industry was valued at $209m (DPIPWE, 2020), representing approximately half of the total value of fruit production in the state and almost 9% of the total gross value of Tasmanian agriculture. Berry production in Tasmania has grown at an average rate of 15% per annum for the previous eight years and is predicted to keep growing predominately due to the major potential for the high-value Rubus berries (raspberries and blackberries).

Hydroponic production systems, such as those used by the burgeoning Tasmanian berry industry, use nutrients solutions instead of soil substrates and therefore require artificial media, such as peat, rockwool or coconut fibre, to provide physical support for plants (Bhattarai et al., 2008;).

Coconut fibre, or coir, is the most commonly used media in hydroponic berry production. The raw material is a waste product of the coconut industry, coming largely from Southeast Asia. Global demand for coir has increased significantly over the past decade owing to its good characteristics as a substrate in hydroponic systems (Schmilewski, 2017).

COIR – A SINGLE USE SUBSTRATE?

To date, there has been limited research on the reuse of coir in hydroponic systems. A study by Diara, et. Al (2012) determined that the feasibility of reusing exhausted substrates, without having an impact on crop performance, depended on the physical-chemical properties of the material, and the tolerance of the crop to abiotic and/or biotic stresses. Several other authors have investigated crop response to the cultivation of plants in spent substrates compared to virgin substrates with conflicting results. Abd-Elmoniem and El-Behairy (2004) found a reduction of crop yield and/or produce quality in re-used media, whereas other authors found no or minimal differences between virgin and re-used substrates (Rea et al., 2008, Celikel and Caglar, 1999, Giuffrida et al., 2007).

In 2019, a study was conducted by Doris Blaesing (of RMCG) on coir waste management for hydroponics in berries (Blaesing 2019). The study investigated opportunities for the reuse of spent coir and provided recommendations for its reuse. It was highlighted that to identify the most cost-effective way to deal with used coir, on-farm trials should be conducted. This was recommended so that trials used existing production systems to determine the technical and operational challenges of reusing spent coir, on its own or mixed with other, 'fresh' substrates. The research concluded that further investigation was needed to determine how to overcome challenges and manage risks e.g. pests and diseases, maintain adequate air-filled porosity and water holding capacity, and labour needs.

With recent innovations in sterilisation methods developed for non-hydroponic systems and the opportunity to change to reusable troughs instead of plastic bags, reuse of spent coir on-site has become more feasible. This will enable a transition away from pre-bagged coir systems, enabling coir to be reused more easily, complemented with other suitable materials, and/or wholly replaced with other substrate materials. It also reduces overall plastic waste by removing coir bags from the production system, as troughs can be used for approximately five years, before being recycled. Still, the issue of troughs allowing higher water evaporation, contact of berries with substrate resulting in yield losses, as well as labour and disinfestation of troughs, need to be investigated.

TRANSITION FROM GROW BAGS TO TROUGHS

Some strawberry growers commenced transitioning from using grow bags (coir in polyethylene wrap) to a trough-based production system in 2022[1]. This was driven by a desire to reduce plastic waste. The transition away from pre-bagged coir enables spent coir to be reused more easily, combined with other suitable substrate materials, and/or wholly replaced with other substrate materials. It also removes the annual plastic waste element associated with coir bags from the production system.

Using troughs will reduce the cost of disposing of plastic waste from grow bags as troughs can be used for several years and then be recycled via nursery industry recycling programs.

The PopPr Program was developed by Greenlife Industry Australia (GIA) and the Australian Packaging Covenant Organisation (APCO). This program was a national recovery program for polypropylene plant packaging, including plant pots, trays, tags and stakes. In response, members of the greenlife industry led the development of an extended producer responsibility (EPR) initiative for the recovery of plant packaging, for processing back into plant packaging. The PoPPr Program, which helped to contribute to the acceleration of this initiative, therefore concluded early in July 2022.

IMPROVING RESILIENCE AND REDUCING WASTE

Tasmania's commercial strawberry production systems rely on the use of coir for a single production season. This approach to substrate management provides commercial producers with certainty that the substrate material is known to be free of pests and diseases and generally has reliable physical and chemical characteristics. However, this process requires ongoing and reliable access to high-volume, low-cost supplies of coir and results in high volumes of used organic waste each season.

The Covid transport logistics crisis between 2020 and 2023 posed a threat to the Tasmanian berry industry. Based on consultation with the major Tasmanian producers, extended timeframes between ordering and receival on farm (up to six months), coupled with an increase in coir costs (primarily driven by shipping freight cost increases) posed a significant threat to the industry, potentially limiting the industry's growth. Since the end of 2022, anecdotally coir costs have decreased markedly, and are relatively on par with costs prior to the pandemic. However, another supply chain interruption may have a severe impact on the industry.

To increase industry resilience against these issues and reduce the sector's environmental impacts, the industry proposes to:

i. Assess the suitability of coir for potential reuse in commercial production systems
ii. To identify viable alternative substrate materials with shorter supply lines to reduce the sector's environmental footprint and support the development of a circular economy.

[1] Note: when the project concept was developed and project submitted in 2021, the shift to a trough-based production system was not envisaged by industry; this occurred during 2022. This is an ongoing shift which is currently being trialled by several project partners across varying scales. As of early 2024, most strawberry production is still occurring in grow bags.

2 Project objectives and approach

2.1 OBJECTIVES

The objectives of this research project are:

1. Understand the merits and issues of reusing coir in the context of Tasmanian hydroponic strawberry production systems
2. Identify product sterilisation techniques compatible with commercial on-farm use and whether they are essential for the reuse of spent coir
3. Experiment with suitable Australian and or local organic by-products to maintain or improve the properties of recycled coir and reduce reliance on coir imports
4. Determine the economic benefits of recycling coir to commercial users.

Success criteria for the research are:

- Defining the characteristics of spent coir and alternate substrates
- Confirming the most appropriate sterilisation methods
- Development of one or more recycled coir substrate blends that meet the needs of end users.
- Analysing production results on a commercial scale
- Conducting an economic evaluation of the performance of the mixed substrates
- Measurement and confirmation of benefits
- Conduct extension activities to develop industry awareness of project and research findings
- Facilitate the commercial adoption of research findings
- Reduced vulnerability to shocks and supply chain disruptions on imported coir material.

2.2 STAGED APPROACH

The project will be undertaken in four stages.

- Stage 1 – Defining the characteristics of alternative substrates
- Stage 2 – Small-scale trials
- Stage 3 – Larger-scale trials
- Stage 4 – Economic analysis.

This staged approach ensures that the deliverables produced at the end of each stage meet their purpose and that project stakeholders are properly prepared for the next stage of the project. Moreover, having clearly defined stages allows the principal investigator Fruit Growers Tasmania (FGT) to link progress directly to each phase and intervene if the project falls behind schedule.

This report provides the results from Stage 1.

3 Stage 1 – Scope and method

3.1 STAGE 1 – RESEARCH SCOPE

Stage one of the project focused on defining the characteristics of coir and alternate substrates, including pathogen load and physical characteristics, and whether it is feasible to use these materials in commercial horticultural production. The characteristics of used (‘spent’) coir were also investigated, to determine what amendments or treatments would be required to enable it to be used for more than one growing season.

As some trials were in place using alternative substrates before this project began, we took the opportunity to undertake some testing on substrate options during Stage 1, even though this was not originally planned until Stage 2.

The research scope was widened to factor in the transition to using troughs, given substrate behaviour is linked with the bag/trough it is contained within.

3.2 STAGE 1 – RESEARCH QUESTIONS

Stage 1 of the project strived to answer the following questions:

- What are the desired attributes in a substrate?
- What are the characteristics of alternate substrates?
- What are the preferred alternative substrates to coir?
- What are the characteristics of used coir (after one growing season)?
- What sterilisation options are available for substrate?
- What are the baseline costs of sourcing coir for single-use hydroponic production systems?
- How resilient is the cost of coir substrate materials to different price shocks and or supply chain/availability shocks?
- What suitable materials are available in Tasmania that can be used to augment coir as a hydroponic substrate?
- What is the cost of accessing alternative materials, and how does this change with location and freight costs?
- Which materials should be trialled in the formula of the mixed substrate in stage two of the project?

3.3 STAGE 1 – METHOD

The methods for stage 1 included:

- Desktop review of preferred characteristics in a commercially viable substrate, considering:
  - Physical, chemical and biological characteristics
  - Logistical (production origin, compressibility) characteristics
  - Availability
  - Costs.
- Desktop review of substrates available in Australia (coir and identified alternatives) (SWOT analysis)
- Identify preferred alternative substrate(s)
- Testing properties (physical, chemical, biological, pathogen profile) of fresh coir, used coir and preferred alternative substrate(s)
- Review of substrate recycling techniques used in Australia and in other countries
- Desktop review of available substrate sterilisation techniques (SWOT analysis)
- Economic modelling of substrate material freight costs
- Develop a comparative gross margin economic assessment model to allow for comparison of different substrate options for strawberry crops in Tasmania.

4 Stage 1 – Findings

4.1 PREFERRED ATTRIBUTES OF STRAWBERRY HYDROPONIC SUBSTRATES

A literature review was previously undertaken by RMCG[2] to identify preferred attributes of substrates for hydroponic berry production. This informed the selection of potential suitable alternative substrates and the characteristics that were assessed. Figure 4-1 summarises the findings from the previous literature review, which were developed generally for berry production, and adaptations for substrate requirements specifically for strawberry production were considered.

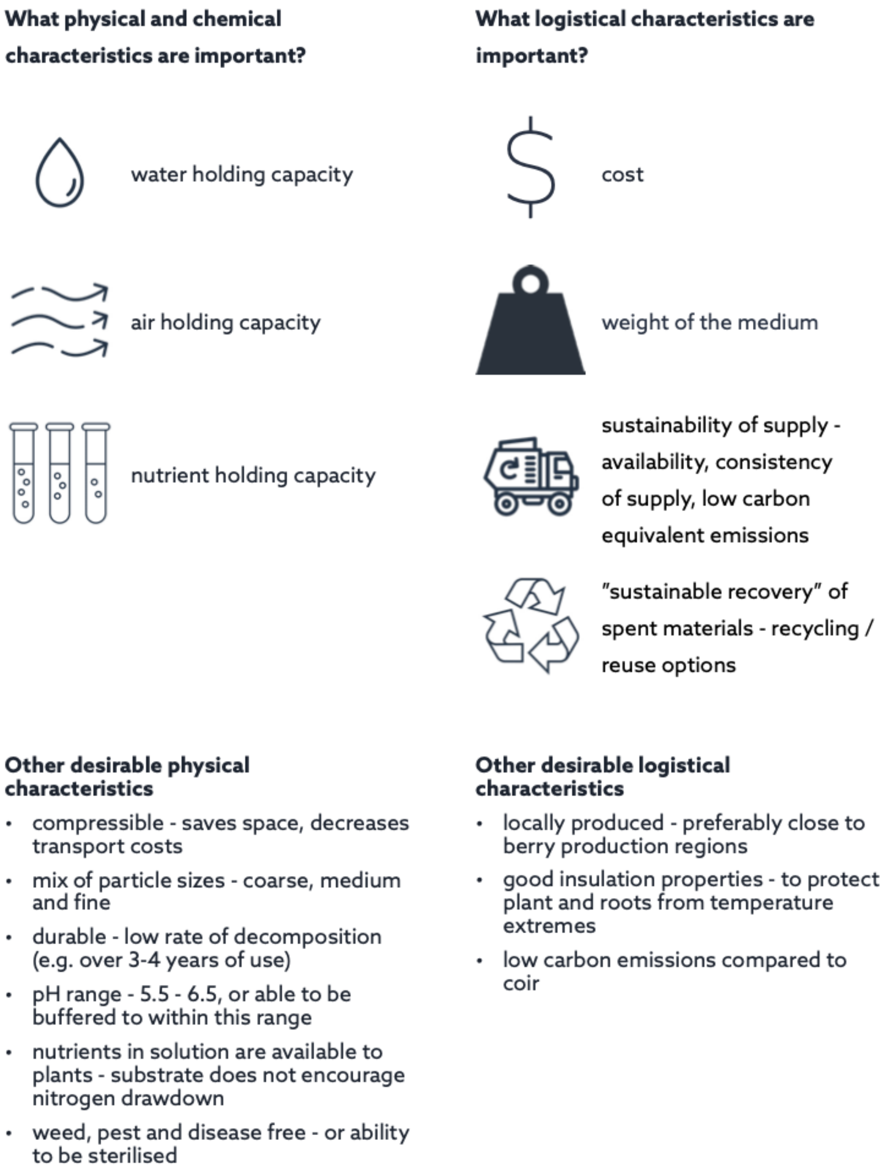

Figure 4-1: Desired characteristics required for commercially feasible strawberry hydroponic substrates (source: RMCG and Hort Innovation, 2022)

[2] The literature review and Figure 4-1 were developed through the Hort Innovation levy funded project *RB21002 – Alternative growing media for hydroponic berry production – a desktop review*

4.2 SUBSTRATE ANALYSIS

4.2.1 DESKTOP REVIEW OF AVAILABLE SUBSTRATE OPTIONS

A desktop scan of available substrate materials in Tasmania and Australia was undertaken, with a SWOT analysis developed for each identified material (refer to Appendix 1 of this report for individual SWOT analyses).

The SWOT analyses was undertaken for the following identified hydroponic substrates:

- Coconut coir (pith and chips)
- Perlite
- Vermiculite
- Rockwool
- Pine bark
- Rice hulls
- Coarser woodfibre (GrowFibre – coarser grade)
- Finer wood fibre (Australian Wood Fibre)
- Woodfibre (HydraFibre®).

The scan included analysis of substrate materials for the following characteristics, as well as other relevant information:

- Physical/structural attributes (water holding capacity, air-filled porosity, structural durability)
- Biological characteristics (pathogen/disease presence, durability of substrate)
- Logistical characteristics
  - Weight of the substrate material
  - Transportability considerations, such as compressibility of the substrate
  - Production origin of the substrate.
- Reusability/recyclability of the substrate
- Renewable production of the substrate.

4.2.2 IDENTIFIED PREFERRED ALTERNATIVE SUBSTRATE

Based on the SWOT analyses, wood-fibre substrates emerged as the most promising alternative substrate to coir. It should be specified that there are several different wood fibre substrate options available, all of those identified are listed in Appendix 1 and were analysed individually. There are different methods in producing wood fibre substrate which leads to products with different characteristics. The broad advantages of wood fibre over other potential alternative substrates are detailed below:

- Wood fibre is a renewable, organic material – this represented a reuse and recycling advantage over non-organic, non-renewable substrate options e.g. rockwool
- Local production already occurs within Australia (with potential for production within Tasmania). Locally produced wood fibre has an inherent increased resilience to global supply chain shocks compared to coir, as prices are not directly linked with international shipping costs
- Tasmania (and also Australia more broadly) has a large timber industry – demonstrating the potential for production volumes of wood fibre substrates to scale-up to meet industry demand if a broader transition of coir to wood fibre took place
- Excellent air-filled porosity characteristics
- Water-holding capacity specifications at an adequate level
- At the time of analysis, costs of wood fibre substrates were similar to coir.

Table 4-1 compares key characteristics between coir and wood fibre substrates.

Table 4-1: Coir and wood-fibre substrate characteristics (source: RMCG & Hort Innovation 2022)

ASPECT	COIR	COARSE WOOD-FIBRE (GROWFIBRE)
Air-filled porosity	13-28%	30 – 35%
Water holding capacity	Approximately 40%	20 – 25%
Bulk density	80 kg/m^3	100 – 150 kg/m^3
pH range	6.0 – 6.8	5.0 – 7.5
Durability	For strawberries: generally used only for one growing season	Not yet known
Country of origin	Southeast Asia (Sri Lanka / India / Indonesia / Philippines)	Australia
Cost (at the time of data gathering in 2022)	\$180 - \$220 per m^3	\$130 per m^3 (excluding freight) – plus indicative freight costs of \$50 per m^3

4.2.3 POTENTIAL OF USING COMPOSTED PINE BARK AS ALTERNATIVE SUBSTRATE

A small-scale trial by one of the project partners, which occurred late in Stage 1, also identified a local composted pine bark substrate as a potential replacement for coir if used in a 50:50 or 30:70 ratio mix with coir. Composted pine bark is likely to differ from existing wood fibre products as it is not processed in the same way (wood fibre products are heat treated). As the composted pine-bark substrate produced in Tasmania was identified late in Stage 1, its properties will be assessed more thoroughly during Stage 2 of the project.

4.3 TESTING SUBSTRATE PROPERTIES – STAGE 1 ASSESSMENT

4.3.1 SUBSTRATES TESTED

Samples of substrates in use at each of the project partner farms (Costa Berries, Hillwood Berries and Tasmanian Berries) were taken in September 2022. This was undertaken to better understand the characteristics of substrates at the start of the growing season, and allowed for the following:

- Comparing variations of the same substrate (i.e. coir) across different farms and storage conditions
- Comparing different substrates.

Chemical testing was conducted by AgVita to determine the chemical characteristics of substrates and how they might vary between farms. Physical properties were tested by RMCG.

Most of the substrates tested were coir, in varying conditions as listed below. Both fresh coir and spent coir (used for at least one year) samples were taken.

Two of the project partner farms (Costa and Hillwood) also had the coarser wood fibre, GrowFibre, on hand, which they were trialling on small scales. GrowFibre substrate was also included in the chemical and physical testing.

Details on the condition of the tested fresh coir from each of the farms are below:

- Costa Berries:
  - Fresh coir: dry and taken from unplanted troughs
  - Fresh wood fibre (GrowFibre): dry and taken from a grow-bag

  - Spent coir: taken from disposed grow-bags (used for one growing season).
- Tas Berries:
  - Fresh coir: from unplanted bags on strawberry tabletops, which had been irrigated with nutrient solution
  - Spent coir: taken from disposed grow-bags (used for one growing season).
- Hillwood Berries:
  - Fresh coir (1): wet (bag from outside of poly tunnels) but had not been irrigated with nutrient solution
  - Fresh coir (2): taken from troughs on tabletops, which had been irrigated with nutrient solution
  - Fresh wood fibre (GrowFibre): dry and taken from a covered bulk pile
  - Spent coir: taken from bulk coir compost pile.

4.3.2 PHYSICAL PROPERTIES

Table 4-2 and Figure 4-2 to Figure 4-4 show the results of the physical testing of the substrates, and groups the average results by substrate category (fresh coir, spent coir, wood-fibre).

Given the substrates had to be taken from each project partner farm in substantially varying conditions (i.e. some dry, some wet, some recently fertigated etc), the results are not considered to be a true comparison of substrate characteristics. The comparative results were used however to sense-check assumptions and desktop information. The results from physical testing will be used to inform future testing in Stages 2 and 3 of the project.

GrowFibre had a greater air-filled porosity % than fresh and spent coir (Table 4-2). This finding aligned with expectations based on the SWOT analyses. Additionally, spent coir appeared to have a lower air-filled porosity than fresh-coir, which may make sense given that some structural degradation is expected to occur, with smaller fines potentially clogging up pores within the substrate.

Water-holding capacity was broadly similar across each of the substrate types tested, noting that the samples tested were in varying levels of wet/dryness.

Figure 4-2 to Figure 4-4 highlight the variation of physical characteristics within each substrate type, depending on the condition of the substrate e.g. whether new or used.

Table 4-2: Average (mean) results of physical testing of different substrate types, undertaken in September 2022

	AIR-FILLED POROSITY %	WATER HOLDING CAPACITY %	SUBSTRATE VOLUME %
Fresh coir	42%	20%	38%
Spent coir	36%	25%	39%
GrowFibre	53%	22%	26%

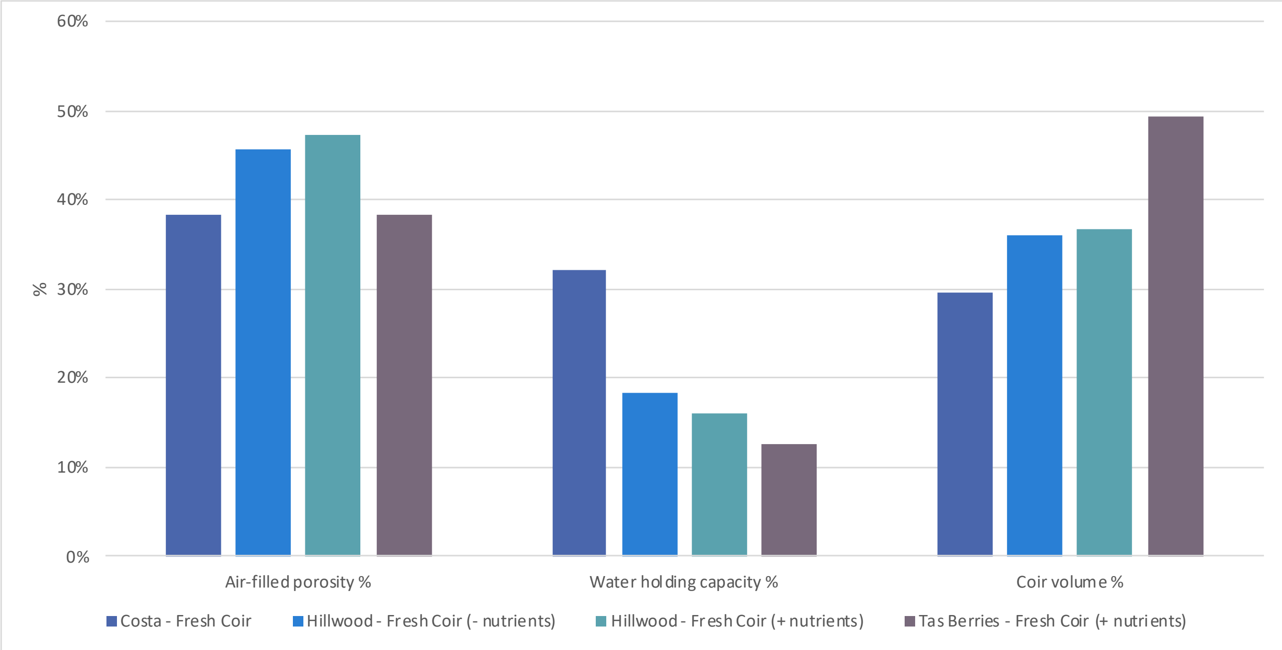

Figure 4-2: Fresh coir sample comparisons – physical properties

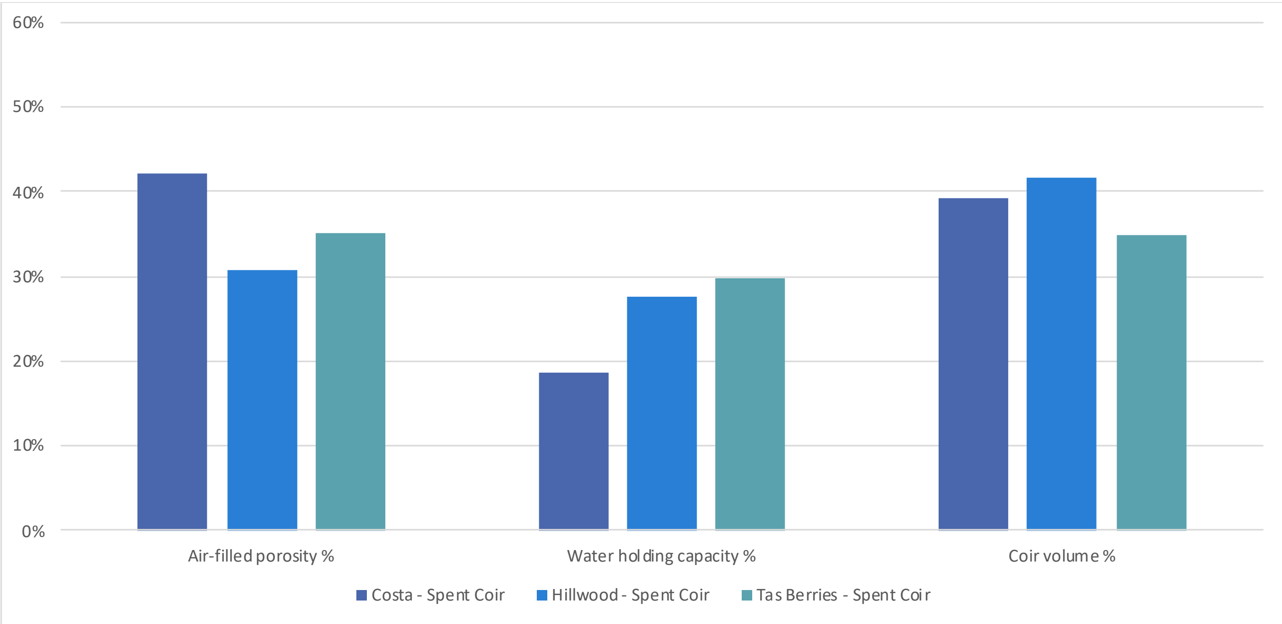

Figure 4-3: Spent coir sample comparisons – physical properties

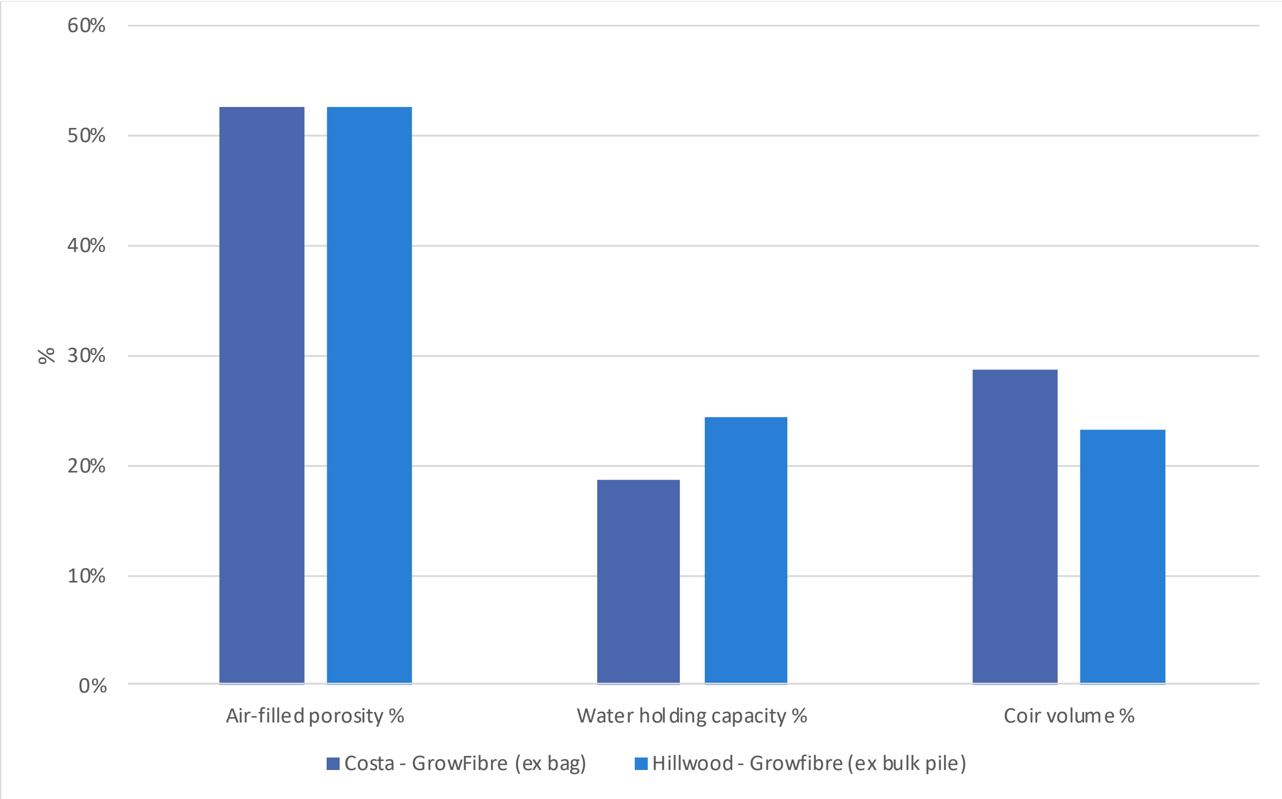

Figure 4-4: GrowFibre sample comparisons – physical properties

4.3.3 CHEMICAL PROPERTIES

Fresh coir substrates were tested for a range of nutrients, pH, salinity, and cation exchange capacity composition. This was undertaken to determine the difference in chemical profile between coir taken from the project partner farms.

The results of the chemical properties testing can be found in Appendix 2. The results showed that there was a large variation between nutrient concentrations across each sample taken, with no clear relationship ascertained. pH, salinity and cation exchange capacity readings all varied between the samples tested.

Further testing will be undertaken during Stages 2 and 3. Given the substantial differences between the condition of the substrates, whether or not they had been recently fertigated etc, these results are intended to be used as a baseline for future comparison when samples are taken from trials held under Stages 2 and 3 of the project.

4.4 HYDRAULIC PROPERTIES OF SUBSTRATES – LABORATORY TESTING AND INVESTIGATION

During Stage 1, it was determined that further technical knowledge of the physical characteristics of substrates and how these change as the substrate aged was required.

Dr Marcus Hardy from the University of Tasmania (UTAS) undertook an initial investigation (under laboratory testing conditions) into the hydraulic properties of substrates and how these might change as the substrate ages. The research was undertaken using substrates in troughs, and so did not consider substrate properties when in bags. Hydraulic properties investigated include drainage rates, water-holding capacity, porosity etc. and is directly linked to the physical characteristics of the substrates. Substrates (fresh coir, spent coir and finer-grade GrowFibre) were supplied to UTAS from project partner farms for this investigation.

Project partners had observed a perceived decrease in water-holding capacity and air-filled porosity as coir aged on-farm, so a degradation of physical structure characteristics (such as air-filled porosity and water-holding capacity) was expected to be demonstrated by the hydrological testing. However, the initial structural investigation by UTAS showed no change in physical properties between fresh and used coir under laboratory testing conditions (Appendix 3, Initial investigations into the hydraulic properties of coir and wood-fibre. Report by Dr Marcus Hardy, UTas).

Wood fibre was found to have poorer hydraulic properties (measured as plant-available water-holding capacity) than coir. Even in a 50% / 50% mix with coir, wood fibre substrates drained and thus dried out more quickly than coir alone. The lateral movement of water was also poor in wood fibre and wood fibre mixes.

It was also observed that wood fibre compacted at the bottom of the troughs resulting in a dry top half and wet bottom half of the substrate in the trough. Coir drainage capacity was not found to change over time.

The results demonstrated that from a hydraulic perspective, there were no discernible differences between fresh and used coir when grown in troughs. This suggested that the growers' observations about the decreased performance of used coir may be caused by a reduced flow of water through the old coir as it 'pugged' up in situ. This is likely due to smaller 'fines' moving down the substrate profile and clogging up larger pores over time, reducing porosity. The results therefore suggest that mixing the used coir prior to reuse may be beneficial.

4.5 TESTING FOR PATHOGENS

Substrate samples were collected from project partner farms. In addition to project partner farms, Burlington Berries also provided access to substrate samples from their farm. The samples were sent to the South Australian Research and Development Institute (SARDI) for pathogen PCA / DNA testing. The test has been developed for a wide range of typical soil borne disease pathogens that can infect strawberry roots.

The level of pathogen DNA detected was relatively low. The main pathogen was *Pythium (clade F)* which is a water mould. *Pythium* spp. are pathogens often found in nursery and field production systems. Charcoal rot (*Macrophomina phaseolina*) was found at negligible levels. It is a pathogen that can cause severe losses in strawberries grown in soil. It is also known to infect some types of vegetables e.g., beans. Surprisingly, two minor potato disease detections occurred (Common Scab and Root-knot Nematode). Diseases could have entered the hydroponic system via irrigation water or transplants. Commercial project partners considered both pathways to be unlikely. The transplants (plug-plants) they are using are not grown in soils and they consider their water sources to be clean. Further investigation into the potential sources of pathogens in substrate will occur in Stage 2.

Samples from one farm (farm three) had practically no pathogen detection. This farm uses bi-monthly low dose peroxide flushing of the irrigation lines. This may be one reason for the lack of pathogens in the tested samples. They also receive good quality water from an irrigation scheme. The other farms also receive good quality water; however, their storage dams could be receiving run-off water from surrounding paddocks. Water is filtered before being fertigated, so pathogen intrusion via irrigation water is deemed unlikely.

There was no established trend concerning pathogen presence across substrate types or ages.

Stage 2 of the project will include further testing of used substrates as well as water sources.

Table 4-3: SARDI pathogen testing results for different substrate types

Substrate type				Blackleg (Dickeya, Pectobacterium bacteria) pg DNA / g soil	Common Scab (Streptomyces bacteria) pgDNA/g Sample*	Charcoal rot (Macrophomina phaseolina) kDNA copies/g Sample*	Water Moulds' (Pythium clade F) pgDNA/g Sample*	Northern root-knot nematode (Meloidogyne hapla) pgDNA/g Sample*
First Year Coir	Farm 1	Bags	1st Year Coir	0	0	0	0	319
	Farm 2	Bags	1st Year Coir	0	0	0	2778	0
	Farm 3	Trough	1st Year Coir	0	0	1	0	0
	Farm 4	Bags	1st Year Coir	0	0	1	1473	0
2nd Year Coir	Farm 1	Bags	2nd Year Coir	0	0	0	437	0
	Farm 4	Bags	2nd Year Coir	0	5	0	1387	0
GrowFibre wood-fibre	Farm 2	Trough	GrowFibre 100%	0	0	0	0	0
	Farm 1	Bags	GrowFibre 100%	0	0	0	234	0
	Farm 3	Trough	GrowFibre 100%	0	0	0	0	0
Coir/GrowFibre Mixes	Farm 2	Trough	Coir:GrowFibre 50/50	0	0	0	456	0
	Farm 2	Trough	GrowFibre + Perlite	0	0	0	4	0
	Farm 2	Trough	Coir/GrowFibre/Perlite	0	0	0	715	0
	Farm 3	Trough	Coir:GrowFibre 50/50	2	0	0	0	0

4.6 SUBSTRATE STERILISATION TECHNOLOGIES

Even though pathogens do not appear to be a major issue for re-using coir, finding sterilisation or recycling options may still be important for the reuse of substrate rather than discarding it after one or two years (which is current practice for hydroponic strawberries).

A SWOT analysis was undertaken on several potential sterilisation processes aimed at transforming coir into a disease-free substrate for potential reuse between growing seasons. The processes analysed include:

- Microwaving
- Using ozone
- Hydrogen peroxide
- Phosphorous acid derivatives
- Steaming
- Composting.

Findings from this overview analysis are available in Appendix 4.

Further refinement is needed to shortlist those technologies for technical and economic assessment at both small-scale to test proof of concept, before in-situ and/or on farm at a commercial scale.

This list of compatible sterilisation options varies from highly experimental approaches using prototype machines potentially suited for in-situ use, to well-understood approaches with high labour and time costs which are likely to limit their commercial suitability for this application.

Consultation with industry partners established that chemical sterilisation is not a preferred sterilisation option, due to concerns around workplace health and safety (WHS) and disposal requirements. Several established and emerging sterilisation options were identified and analysed more closely: microwaving, using ozone, on-site/off-site composting.

4.6.1 MICROWAVING

Microwaving is an emerging sterilisation alternathatwhich appears to be effective against many plant pathogens. Initial investigations suggests that it could be cost-effective as an in-situ option, given it eliminates labour costs of handling spent substrate. Current estimates are that microwaving could be undertaken at a cost of $2 per metre length, with 1-4 hours required for every 100m. The estimated turnaround from plant removal to re-planting is around 4-5 weeks, so microwaving would have to be sufficiently quick to occur within that period. There are several logistical considerations that would need to be worked through for microwaving to potentially work in-situ efficiently, such as manoeuvrability around brackets.

4.6.2 OZONE

There have been some trials and research using ozone as a sterilisation agent with mushroom substrates, with positive results. Ozone is a relatively safe chemical to use, with no negative human health impacts unless used at a very high concentration. It may also be used in-situ as ozonated water could be pumped through existing drip irrigation infrastructure into the substrate, following plant removal and prior to re-planting. Further assessment is required to determine its effectiveness on specific strawberry plant pathogens.

4.6.3 ON-SITE OR OFF-SITE COMPOSTING

While project partners prefer in situ sterilisation to avoid the labour costs of coir removal and refilling of troughs, it must be considered that after a second (or third reuse, if possible), there will still be 'waste substrate' at some stage.

Composting using the correct technology is an effective and reliable method of sterilisation. It can be done off-site or on-site to produce a reusable substrate or substrate amendment.

Composting technology can be used to:

- Sterilise substrate for reuse in berry production, and
- Recycle 'waste substrate' together with other 'waste organics' for other uses e.g. soil amendment for horticulture to provide soil health benefits.

Off-site composting involves removal of use coir from poly tunnels (annual for strawberries), stockpiling and bulk transport to the processing/treatment facility, e.g. Dulverton Waste Management in Spreyton, and transport back to the farm for re-use.

On-site composting involves removal of used coir from poly tunnels, treatment in small batches and stockpiling for re-use.

Example of a small-scale on-site composting unit

A small-scale composting unit can be used to pasteurise organic material. Information on the small-scale composting unit includes:

- One 40ft unit would be able to process about 600t per year
- One unit would cost about $100,000 +/- 20%
- Maturing bays may not be required, if the aim is pasteurisation only. However, a storage area may be needed and space for substrate mixing
- Cost estimates for civil and site works related to hardstand processing and maturing bays may be in the range of $50 – $100k
- Lease arrangements and ongoing support by the supplier for the in-vessel composting units may be possible
- A small front loader/bobcat is required.

Figure 4-5 shows an example.

Figure 4-5: Example composting processing set-up

4.7 ECONOMIC ANALYSIS

4.7.1 COIR AVAILABILITY, PRICING AND FREIGHT/TRANSPORT COST CONTEXT

Freight and transport costs

Freight costs for coir fluctuate due to various factors, including global economic conditions, fuel prices, trade policies, and shipping industry dynamics. For instance, at the start of the project, costs were extremely high and freight times were longer than before the Covid pandemic (based on conversations with growers). They have now settled down.

International shipping costs can be obtained and compared in several ways:

- Contacting Freight Forwarders and Shipping Companies
- Customs and Trade Data
- Freight Rate Comparison Tools
  - https://www.superlinklogistics.com/post/7-best-price-comparison-websites-for-international-air-freight-and-ocean-freight
  - https://www.freightos.com/freight-resources/freight-rate-free-calculator/
  - https://reveelgroup.com/features/peer-shipping-indexes/

National transport prices per unit (e.g., per pallet or 20/40 ft container) fluctuate mainly depending on the route and the cost of fuel.

Individual coir importers negotiate freight and transport rates for overseas and national transport. They add these costs to the FOB (Free on Board) costs for the coir. Importers of coir usually quote a CNF (Cost and Freight) price to berry and other producers i.e. cost of coir per unit purchased and delivered.

Coir availability and prices

Coir prices have been changing considerably during the term of the project. We therefore were not able to provide price information that would hold up for even six months.

Individual importers/sellers negotiate bulk coir prices (CNF) with individual companies. These prices are not disclosed publicly. The economic framework developed for the project therefore provides the option for each project partner to enter their current CNF costs (cost of coir and shipping).

Generally, coir prices have been relatively stable. The reason for the large price variation for coir imported into Australia is largely due to shipping costs, which since 2020 have been volatile.

An overview of coir shipments to Australia can be obtained here:

- https://www.volza.com/p/coconut-coir-fiber/import/import-in-australia/

An analysis of the coir fibre market and prices over time can be obtained here:

- https://www.wm-strategy.com/australia-coir-market
- https://coconutcommunity.org/page-statistics/market-review/market-review-of-coconut-fiber-november-2023

4.7.2 ECONOMIC ANALYSIS FRAMEWORK

Economic analysis

An economic framework (MS Excel-based) allowing a comparative gross margin analysis was developed. The analysis is based on variable costs only. The aim was to allow the commercial project partners to determine how alternative substrates, substrate mixes or reusing coir for a second year might impact the overall economic feasibility of the production system (in grow bags or troughs).

The comparative economic analysis tool has been drafted and provided to project partners for feedback.

Some assumptions were used for developing the initial framework, given the current lack of commercial data using fresh coir substrate alternatives. They were:

- Similar yield output and durability/longevity of substrate (however, growers can input their own expected yields using different substrate)
- The same grow bag or trough dimensions and thus substrate volumes are used
- Plant health is not affected
- Production inputs and all aspects of labour costs do not vary between substrates
- The wood-fibre substrate is produced within the state at a distance not too far from berry-producing regions (approximately 100-200km)
- No differences between sterilisation or recycling/waste costs
- Fixed costs remain the same.

Transport costs of substrates were not included in the comparative gross margin analysis. However, the framework allows for rates to be updated so that a comparison can be made for each season if required.

The Stage 1 comparative gross margin assessment between coir and a wood-fibre substrate, including the above key assumptions, suggested that a wood-fibre substrate may be economically competitive with the current production system using coir. The results showed that the gross margin of growing strawberries using wood fibre was similar to that of strawberries grown in coir.

The Stage 1 comparative gross margin analysis tool can be updated once more information on growing in wood fibre is available and assumptions can be refined to allow for a more detailed economic analysis.

A threshold analysis was included within the initial economic analysis framework to show the ‘threshold’ levels (yield, fruit and substrate price) the growing system would need to operate at, for the alternative substrate to be viable. These findings need to be verified with the project partners and refined once more is known about the wood fibre substrates.

Initial substrate trial findings

Very small trials were established by project partners prior to the initiation of this project to develop a better understanding of substrate behaviour. Findings suggested that there were production cost differences between using coir and wood fibre. These included:

- The wood fibre substrate required more water than coir and thus more fertiliser was used from the fertigation system
- The wood fibre substrate had a negative effect on yield
- There was a difference between the performance of wood fibre in grow bags and in troughs; troughs performed better.

Therefore, in these small trials wood fibre performed differently to coir. The comparative gross margin analysis (described above) assumptions will be refined as more information is generated from trials in stages 2 and 3. Economic analysis will also be undertaken comparing fresh and used coir in stages 2 and 3.

5 Conclusions from Stage 1

Conclusions to Stage 1 questions are listed below.

Stage 1 addressed the following questions:

- What are the desired attributes in a substrate?
  - Adequate water-holding capacity, air-filled porosity, compressibility, sustainable recovery of spent materials and the ability to be produced locally are the key desired characteristics of substrates (all characteristics are detailed in Section 4.1).
- What are the characteristics of alternative substrates?
  - Alternative substrates were identified, and their characteristics examined by SWOT analysis. Alternate substrate characteristics varied substantially between substrates
  - The SWOT analyses are shown in Appendix 1, and summarised in Section 4.2.1.
- What are the preferred alternative substrates to coir?
  - Wood fibre products were identified as the most suitable alternatives, especially when mixed with coir
  - Wood fibre products possess advantages over other identified substrates. This is detailed in Section 4.2.2
  - Composted pine-bark substrates also warrant further investigation in the next stages of the project.
- What are the characteristics of used (spent) coir (after one growing season)?
  - The characteristics of used coir was found to be similar to that of fresh coir, both from a physical and biological (pathogen load) perspective. This is detailed in Sections 4.3 – 4.5. More research is required to further examine the characteristics of used coir
  - The results demonstrated the potential in using coir substrates for more than one growing season.
- What sterilisation options are available for substrate?
  - Microwaving, using ozone gas and composting were identified as the most suitable sterilisation options for substrate
  - Chemical options are not preferred by project partners due to WH&S issues
  - An overview SWOT analysis was undertaken and can be found in Appendix 4
  - Each of these sterilisation options will require further technical and economic analysis, if it is determined that sterilisation is required.
- What are the baseline costs of sourcing coir for single-use hydroponic production systems?
  - Baseline costs of sourcing coir (at the time of research in late 2022) was between $180 and $220 per cubic metre, delivered on-farm. Coir prices have since decreased, primarily due to decreases in shipping costs
  - Research showed that coir costs (including freight) fluctuate substantially due to various factors, including global economic conditions, fuel prices, trade policies, and shipping industry dynamics. Global shipping prices are the key price contributor to coir prices in Australia. For instance, in 2021-22, when the project was conceived, costs were extremely high and freight times unpredictable and longer than before the Covid pandemic. This correlated with decreased shipping availability and increased shipping prices
  - The recent decrease in coir price has influenced the view of some berry producers on the need for immediate coir replacement. Others believe that an alternative should be investigated further as a risk management strategy to mitigate against any possible future interruptions or cost increases in coir supply.

- How resilient is the cost of coir substrate materials to different price shocks and or supply chain/availability shocks?
  - Freight and transport costs are the key price contributors to coir landed in Australia and vary more than the price of coir itself as a raw material. Any global supply chain shocks that impact shipping prices will inevitably have a substantial impact on the price of coir delivered to Australia, given coir originates in coconut-producing countries within Asia. Timing of supply is also a concern when there are interrupted supply chains.
- What suitable materials are available in Tasmania that can be used to augment coir as a hydroponic substrate?
  - A wood fibre product and composted pine bark were identified during Stage 1 as possible options, and these may be suitable when mixed with coir. A wood fibre product is currently produced (pilot commercialisation stage) in Victoria and a second wood fibre option is under development in Queensland
  - The coarser wood fibre (GrowFibre) product is available in Tasmania and is shipped from Victoria
  - A pine bark substrate is currently produced in Northeast Tasmania from forestry ‘waste’ and is under investigation to be trialled in Stage 2.
- What is the cost of accessing alternative materials, and how does this change with location and freight costs?
  - Wood-fibre products range from $40 - $130 per cubic metre, excluding freight (Refer to SWOT in Appendix 1)
  - Products that are able to be compressed are lower cost to ship and may remain viable against coir if not produced in Tasmania
  - Some wood-fibre products are able to be compressed (Australian Wood Fibre product), whilst others are not. De-compressing product however requires specialised equipment.
- Which materials should be trialled in the formula of the mixed substrate in stage 2 of the project?
  - It is recommended to continue with forestry ‘waste’ based (wood fibre and composted pine bark) alternative substrates in Stage 2 and refine the physical properties by mixing optimum proportions of coir and alternative substrate
  - During stage 2, it will need to be determined whether mixing wood fibre or pine bark with spent coir results in better substrate performance than that of spent coir alone. If this is the case, stage 3 will aim to identify the optimal mixing ratio
  - The trialling of substrates must consider changes in the production system such as troughs, different irrigation applications, mixing and potentially sterilising of substrates and ‘end of life’ solutions for spent substrates. The effect of different substrates on crop performance must be monitored throughout the season for Stage 2. Further investigating substrate properties is required for Stage 2 as well as providing feedback to alternative substrate producers.

6 Next stage project research priorities

Stage 1 of this project has identified several substrate materials available to Tasmanian businesses that may support commercial strawberry production, but further research work is needed to assess their suitability for this purpose. This is especially the case for substrates still in development such as wood fibre.

Stage 1 also determined that using spent coir appeared feasible given the lack of physical degradation and pathogen profile, however, trials in Stage 2 will determine whether there are any other factors that might impact using coir for more than one season.

The next steps for this project include the following:

Establish the viability of hydroponic strawberry production using spent coir

- Do the physical and chemical properties of coir change over time with use in situ and how does this impact substrate performance?
- What are the key management changes required to grow spent coir?
- Does spent coir require amendment with alternative substrates? Or any other treatment?
- Should plants be left to over-winter in spent coir before the second season, or should new plants be planted in spent coir?
- What are the key strawberry pathogens of concern in spent coir substrate, and how can they be tested for and controlled for reuse? (Based on stage 1 results, establish testing of irrigation water as well as substrate, to investigate the potential source of *Pythium sp.*), Testing of irrigation water and potting mix used by runner producers may also be warranted
- Are sterilisation techniques warranted, given pathogen load in used substrate? If so, what are the costs, efficacy, and constraints of different sterilisation techniques for spent coir?

Determine the feasibility of hydroponic strawberry production using wood fibre and pine bark substrate materials

- What are the key substrate performance characteristics needed for strawberry production, including ease of re-use and associated costs?
- What is the suitability of alternative substrate materials (individually and/or combined) to meet these performance characteristics?
- What management changes are required when using wood fibre and pine bark substrates?
- Does wood fibre/pine bark perform better in a mix with coir?
- If mixed with coir, what is the optimal mix of alternative substrate material to coir?
- What is the overall gross margin economic impact?
- What changes could be made to the wood fibre and pine bark substrates that may improve their characteristics for strawberry production?

Transition from grow-bags to troughs

- What are the substrate behaviour differences in troughs versus bags (water usage, fertigation, yield differences)
- What are some substrate management changes required to enable growing in troughs to be commercially feasible across whole farms?
- How does growing in troughs impact different substrates?
- When considering using used and mixed substrates, what is the overall economic impact of growing in troughs?

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Appendix 1: Individual Substrate – Desktop SWOT Analyses

The SWOT analyses have been adapted from the Hort Innovation levy-funded project completed by RMCG - *RB21002 – Alternative growing media for hydroponic berry production – a desktop review*

Table A1-1: Coconut coir (pith and chips) SWOT Analysis

STRENGTHS	WEAKNESSES
▪ Excellent water-holding capacity ▪ Sufficient air-filled porosity ▪ Biodegradable (can be composted) ▪ Low bulk-density ▪ Can be used as stand-alone substrate or mixed with others ▪ Overall excellent combination of technical qualities ▪ Can be compressed up to 6x its normal state size – excellent for transportation ▪ Renewable material (produced from coconut husks) ▪ Various particle sizes produced from coir – both pith and chips.	▪ Produced internationally – must be shipped into Australia (anecdotal information suggests up to 50% of the cost to growers is in shipping during 2022) ▪ Shipping costs remain volatile and subject to global supply-chain interruptions ▪ High cation exchange capacity - requires buffering (calcium nitrate) to remove large amounts of sodium ions bound to ensure it is a neutral substrate ▪ Increasing timeframes of supply – in 2019 it took approximately 9-10 weeks from order to delivery on-farm, in 2022 this is 6-7 months ▪ Variable quality at times ▪ High costs of handling/recycling spent coir ▪ Increasing competition for coir from other hydroponic industries.
OPPORTUNITIES	**THREATS**
▪ Scope for increased re-use of spent coir substrate within production system – mixing with fresh substrate in Rubus crops. Spent strawberry coir substrate could be then used in Rubus crops (pending root separation, sterilisation).	▪ Increased competition from other hydroponic industries for coir causing an increase in price ▪ Shipping/supply chain disruptions leaves industry at severe risk ▪ Increases in price.

Table A1-2: Perlite substrate SWOT analysis

STRENGTHS	WEAKNESSES
▪ High air-filled porosity % ▪ Good wicking action to reduce risk of root rot ▪ Relatively inexpensive ▪ Can potentially be re-used – is able to be steam pasteurised ▪ Sold mixed with coir to enhance draining ▪ Relatively inexpensive.	▪ Low water-holding capacity – dries out very quickly between waterings. Needs to be mixed with other substrates (such as vermiculite) ▪ Dust from perlite a known risk to human health ▪ Prone to algal growth ▪ Light-weight – can wash away in hydroponic system causing blockages ▪ Not renewable – made from volcanic rock ▪ Unable to be composted – must be disposed of in landfill, also renders other substrates mixed with perlite non-recyclable.
OPPORTUNITIES	**THREATS**
▪ Can be used as additive to many substrates to increase drainage.	▪ Increased competition for raw material.

Table A1-3: Vermiculite substrate SWOT analysis

STRENGTHS	WEAKNESSES
▪ Light weight ▪ Sufficient availability ▪ Relatively inexpensive.	▪ Cannot be steam-sterilised (disintegrates during heating) – limited reuse options ▪ Retains too much water, can suffocate plant roots if used on its own ▪ Needs to be mixed with other substrates.
OPPORTUNITIES	**THREATS**
▪ Could be used as an amendment and mixed with other, lower water-holding capacity substrates.	▪ Restrictions to production.

Table A1-4: Rockwool substrate SWOT analysis

STRENGTHS	WEAKNESSES
▪ Light weight ▪ Sterile ▪ Insulates well against heat ▪ Easily available ▪ Considered by many commercial growers to be technically the ideal substrate for hydroponic production ▪ Rockwool can hold water and retain sufficient air-space (at least 18%) to promote root growth ▪ Can be re-used – steam sterilising of slabs between crops.	▪ Unable to be recycled when substrate unable to be reused and must go to landfill ▪ Never truly decomposes ▪ Relatively higher price to coir ▪ High pH – constant pH adjustment in solution may be required. ▪
OPPORTUNITIES	**THREATS**
▪ If economically viable sterilisation process is created, rockwool can be re-used multiple times and made highly durable.	▪ Increased costs to dispose would decrease economic viability.

Table A1-5: Pine bark substrate SWOT analysis

STRENGTHS	WEAKNESSES
▪ Once considered a waste product – circular economy ▪ Berry production areas are relatively close to pine forestry areas – reduced transport costs ▪ Pine resists decomposition better compared to other tree bark ▪ Biodegradable product – can be used as mulch or composted after substrate use ▪ Good air-filled porosity ▪ Relatively cheap and easy to source in all production regions.	▪ Becoming more expensive and greater difficulty sourcing currently ▪ Absorbs water very easily and may become waterlogged ▪ pH is acidic – requires buffering ▪ Nitrogen drawdown a common issue in wood-based substances not heat-treated – there is a tendency to become N-deficient as a result of high levels of N immobilisation – increased fertigation costs to compensate.
OPPORTUNITIES	**THREATS**
▪ Investigate treatment options to fix nitrogen drawdown issue.	▪ Increased demand from other industries (i.e. nursery) for pine-bark could increase price.

Table A1-6: Rice hull substrate SWOT analysis

STRENGTHS	WEAKNESSES
▪ By-product of rice production/milling ▪ Free-draining – low to moderate water-holding capacity ▪ pH slightly acidic – good for most plants ▪ Air-filled porosity % suitable for most crops.	▪ Not pre-sterilised – needs to be boiled ▪ Tendency to build up salt in the substrate – must be replaced after 1-2 crops ▪ High levels of manganese often – issue if pH not managed correctly ▪ Low cation exchange capacity.
OPPORTUNITIES	**THREATS**
▪ Can be used as part of a mix for shorter-rotation crops.	▪ Competition for product, as it can also be used for other purposes (i.e. animal bedding) may increase price and decrease availability.

Table A1-7: Coarser wood-fibre substrate – GrowFibre – SWOT analysis

STRENGTHS	WEAKNESSES
▪ Locally produced in Victoria from pine plantation residues, Australia as GrowFibre (technologies to treat wood was first used in US and Germany) ▪ High air-filled porosity 30-35% ▪ Water-holding capacity 20-25%[3] ▪ Renewable – made from Pinus radiata (Monterey pine) wood chips sourced from plantations in Gippsland, Victoria ▪ Coarse material ▪ Produced through thermal and mechanical defibration of wood chips, produces a sterile material ▪ Indicative price of $130 per m3, ex works ▪ Anecdotal information from trials suggests yield performance is roughly equivalent to coir.	▪ Anecdotal information suggests there may be reduced capillary action (horizontal water movement) in substrate – potentially causing uneven water distribution ▪ Top portion of substrate dries out quicker than coir – increased watering frequency in shorter-duration required. Can be an issue for short-rooted less-established seedlings ▪ Low compressibility (only to 1.4 times its expanded form) ▪ Slower plant growth and establishment.
OPPORTUNITIES	**THREATS**
▪ GrowFibre material, being coarser than coir, may have increased structural durability ▪ Finer diameter wood fibre processing technology exists in Germany and is planned to be used in Australia – may improve substrate water holding capacity and overall yield-capability ▪ Substantial pine forestry production in QLD, NSW and TAS present opportunities to open production facilities in local proximity to hydroponic Rubus producing regions.	▪ Due to low compressibility, it is not currently financially competitive in comparison to current substrate (coir) costs if production centres are not in close proximity (i.e. same state) to berry producing regions. Anecdotal information from growers suggest it is currently not economically feasible to sell product produced in Melbourne to Tasmanian growers ▪ Competition for wood products a potential threat ▪ Sustainability of timber supply.

3 AGS the identified wood-fibre substrate Brochure. Accessed 1st September 2022. <https://www.agsolutions.net.au/_files/ugd/c85030_c5735490105146a882287898b8611da0.pdf>

Table A1-8: Finer wood fibre (Australian Wood Fibre) – SWOT analysis

STRENGTHS	WEAKNESSES
▪ Finer diameter fibres than GrowFibre, currently produced in Queensland ▪ Extra air-filled porosity in comparison with coir may assist early root development ▪ Has been used in 25:75 mix with coir in raspberry and blueberry production in NSW with no yield difference noted ▪ Relatively cheaper cost - $40-80/m3 ▪ Can be compressed.	▪ Cannot be used on its own due to clumping issues. Clumping means the product going into each individual pot is not universal ▪ Specialised equipment required to decompress product.
OPPORTUNITIES	**THREATS**
▪ Could be mixed with coarser material (such as GrowFibre) which may solve the clumping issue ▪ Explore other substrate blends with locally produced materials (rice hulls).	▪ Competition for wood products a potential threat ▪ Sustainability of timber supplies.

Table A1-9: HydraFibre – produced in United States – SWOT analysis

STRENGTHS	WEAKNESSES
▪ Higher air-filled porosity than coir ▪ Can be compressed for transport ▪ Renewable product ▪ Strong adoption in US nursery industry.	▪ Compressed bales require specialised machine supplied by Agrinomix from Ohio, US, to be 'spun back out' into its usable form ▪ Must be used in a mix with coir (at maximum 50% ratio) due to challenges with irrigation, fertigation and container filling ▪ Durability may be as little as 1 year ▪ Only produced in US currently.
OPPORTUNITIES	**THREATS**
▪ Could be mixed with coarser wood-fibre substrate, such as GrowFibre.	▪ Growers not purchasing the required machine to convert it from compressed into usable form means it would be not viable.

Appendix 2: Chemical properties of substrates

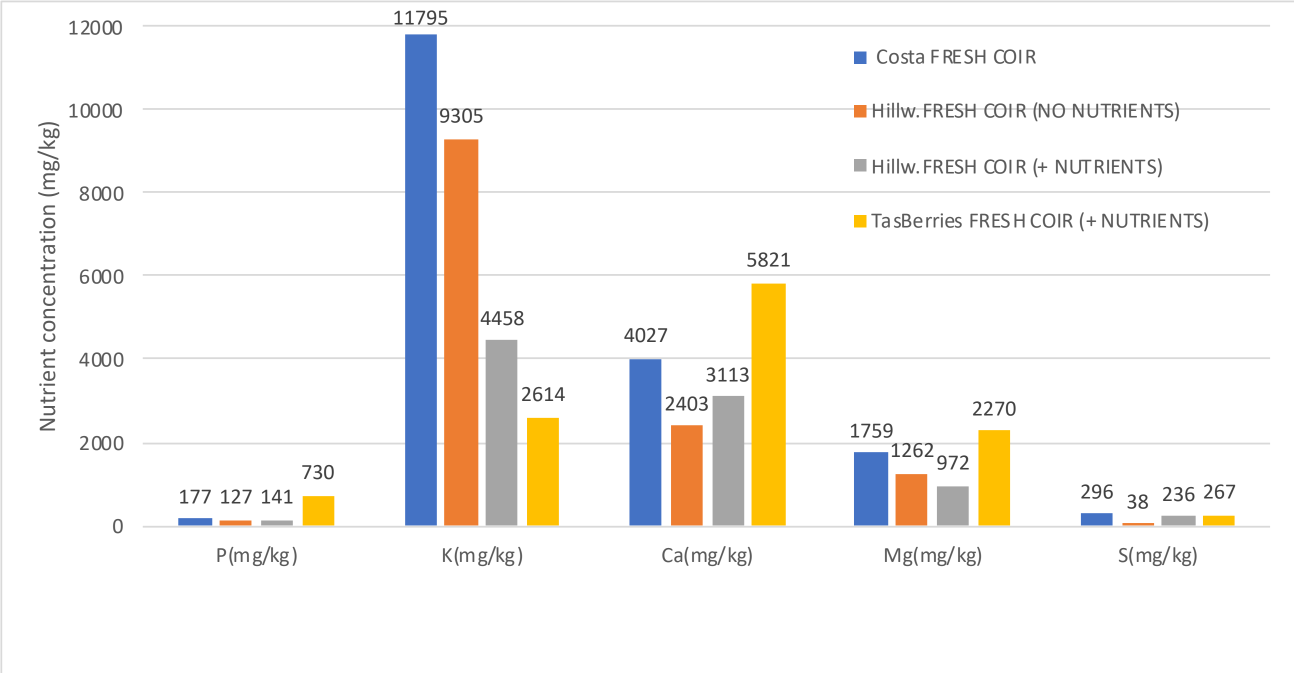

Figure A2-1: Nutrient (P, K, Ca, Mg and S) concentration of fresh coir samples from industry partner farms

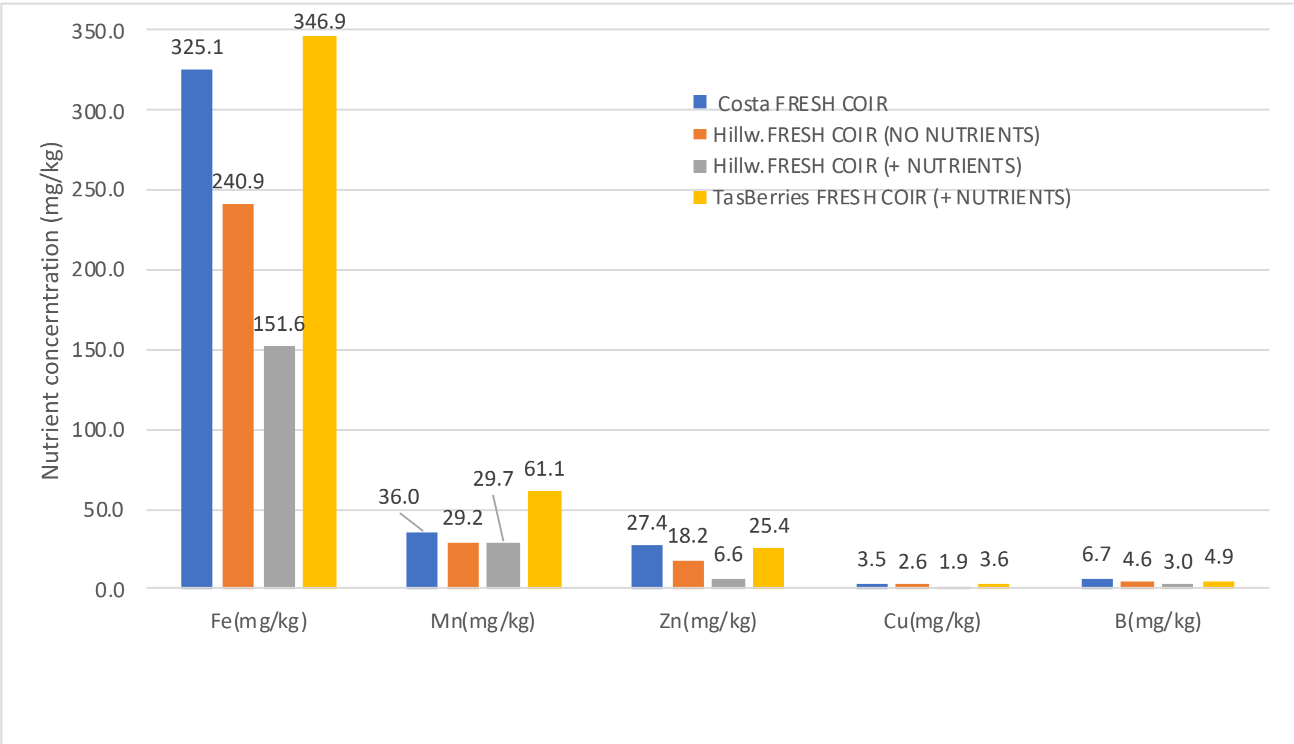

Figure A2-2: Nutrient concentration (Fe, Mn, Zn, Cu and B) of fresh coir samples from industry partner farms

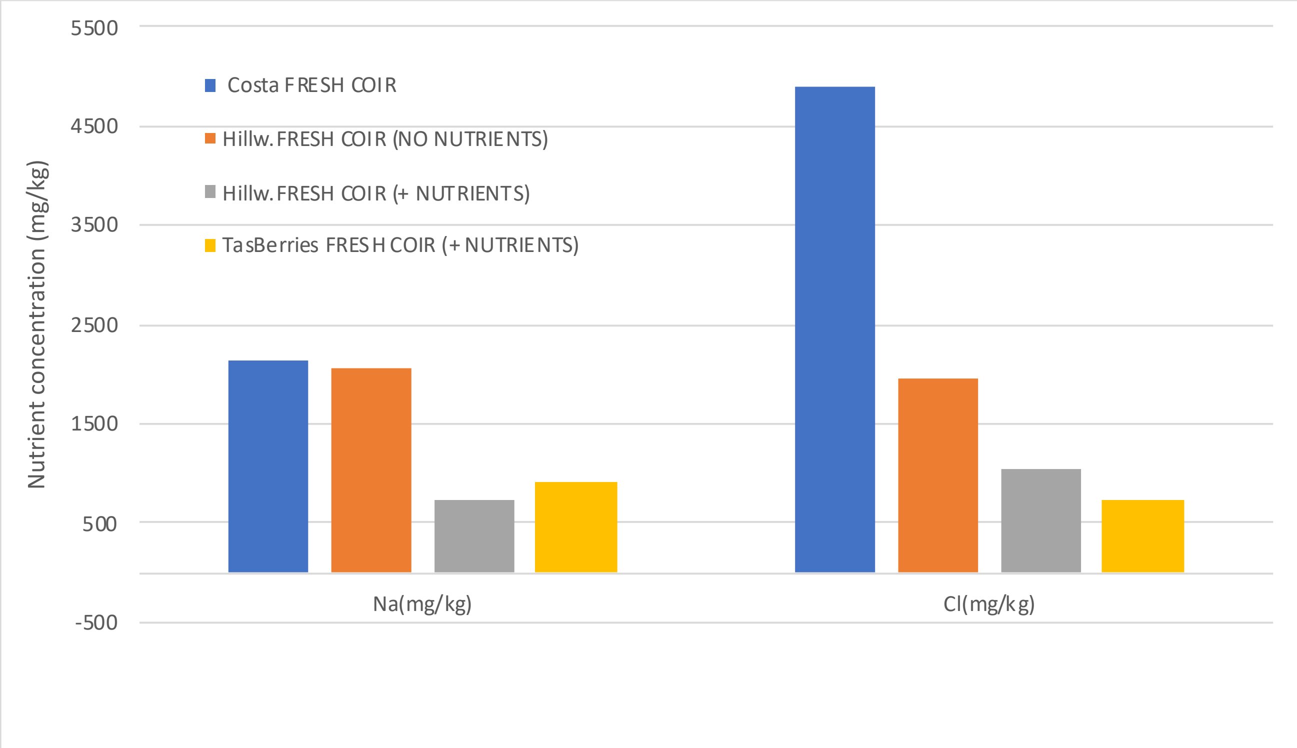

Figure A2-3: Nutrient (Na and Cl) concentration of fresh coir samples from industry partner farms

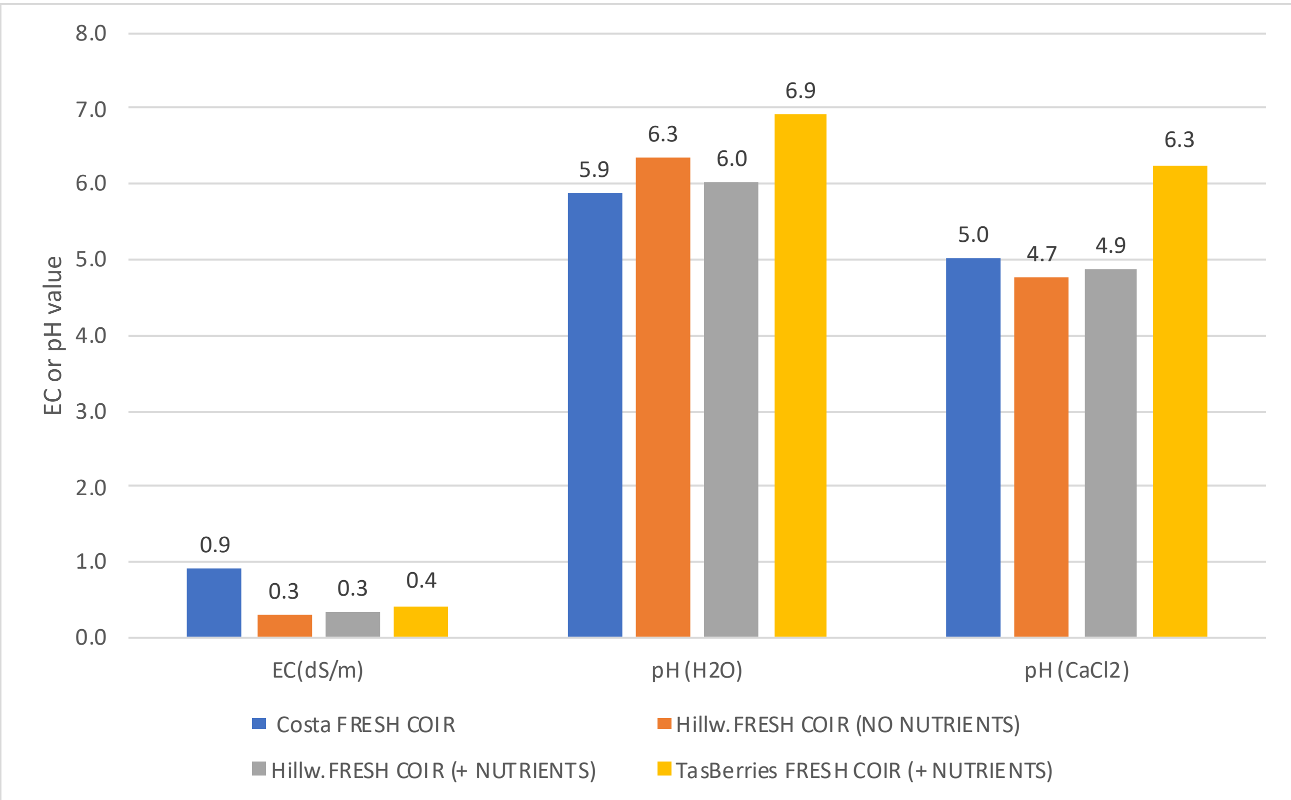

Figure A2-4: Salinity and pH of fresh coir samples from industry partner farms

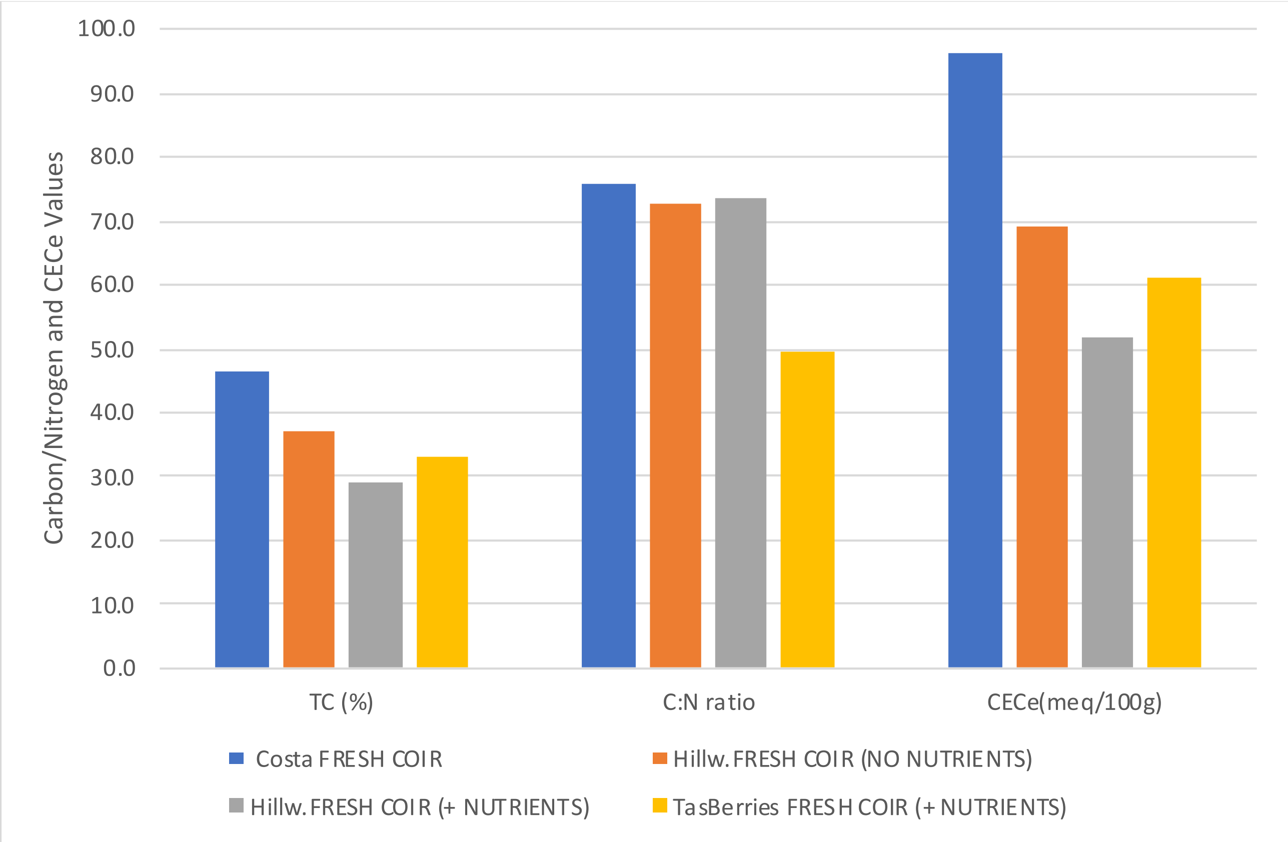

Figure A2-5: Total carbon, carbon : nitrogen ratio and effective cation exchange capacity results

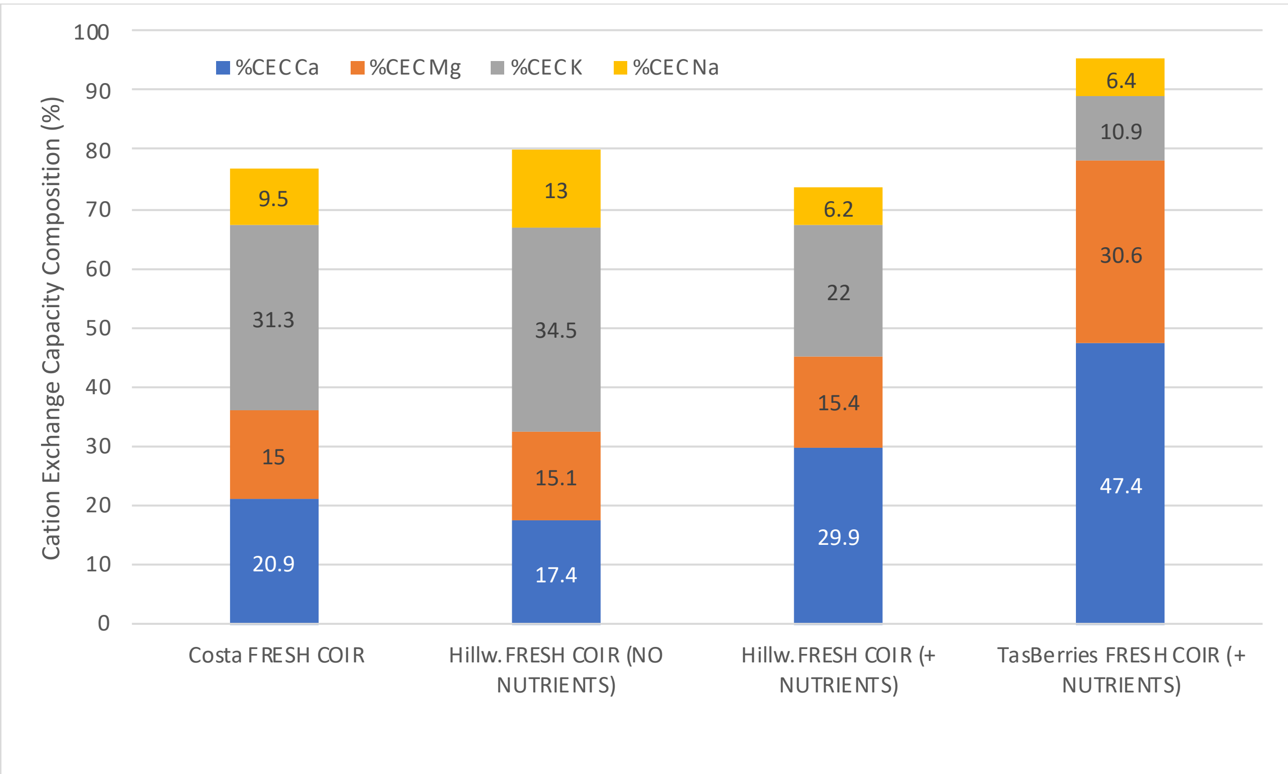

Figure A2-6: Cation exchange capacity composition – calcium, magnesium, potassium and sodium results

Appendix 3: Initial investigations into the hydraulic properties of coir and wood-fibre

Dr Marcus Hardie, UTas

Scope

This report is a brief, preliminary investigation into the hydraulic properties of coir and wood fibres on behalf of Fruit Growers Tasmania. It is not intended as a rigorous, statistically valid, publishable, far-reaching study, but rather a preliminary trial to determine if (i) existing methods for analysing the hydraulic properties of soils could be used to investigate coir and wood fibre, (ii)identify major differences between products in order to target future studies, and (iii) provide data to support student glasshouse trials.

Note: sections on Introduction, Methods, Treatments and statistical analysis are to be completed as part of the student's assessment.

Treatments

- NEW100 – 100% new coir
- NEW75 -75% new coir mixed with 25% wood fibre (by weight)
- USED100 - 100% coir after 1 crop and harvest (?)
- USED75 -75% used coir mixed with 25% wood fibre (by weight)
- USED50 – 50% used coir mixed with 50% wood fibre (by weight)
- WOOD100 – 100% wood fibre.

Methodology

- Soil water retention by KuPf evaporation (Wendroth et al., 1993; Wendroth & Wypler, 2008)
- Permanent wilting point by pressure chamber analysis (Cresswell, 2002)
- Macroporosity (Hardie et al., 2013)
- Bulk density (Cresswell & Hamilton, 2002)
- Saturated hydraulic conductivity (McKenzie & Cresswell, 2002; McKenzie et al., 2002)
- Unsaturated hydraulic conductivity (Wendroth & Wypler, 2008).

Results

Bulk Density

Table A3-1: Bulk density

	MEAN	STANDARD DEVIATION
NEW100	0.096	0.002
NEW75	0.134	0.004
USED100	0.085	0.005
USED50	0.111	0.007
USED75	0.090	0.006
WOOD100	0.204	0.010

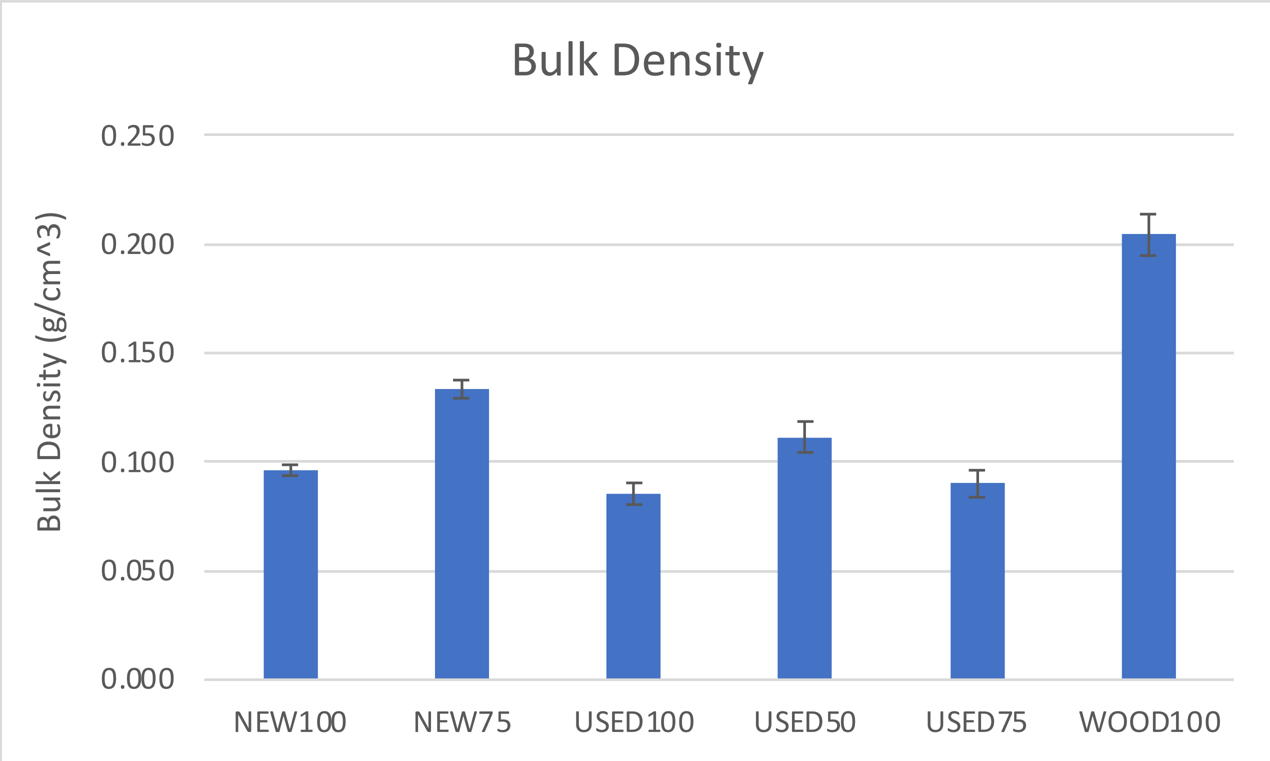

Figure A3-1: Bulk density

The wood fibre had higher density than all the coir-based products (Figure A3-1). There was no difference between the density of the new and used coir. Coir, wood fibre and mixed products have a considerably lower density than is normally observed for soil, which typically ranges between 0.9 to 1.6 g/cm3.

Saturated Moisture Content

The saturated moisture content is numerically like total porosity which cannot be calculated from bulk density as is normal practice, without prior knowledge of the particle density of the different products.

Table A3-2: Saturated moisture content

	MEAN	STANDARD DEVIATION
NEW100	826	40.00
NEW75	623	18.60
USED100	914	40.36
USED50	686	20.90
USED75	857	62.31
WOOD100	407	18.85

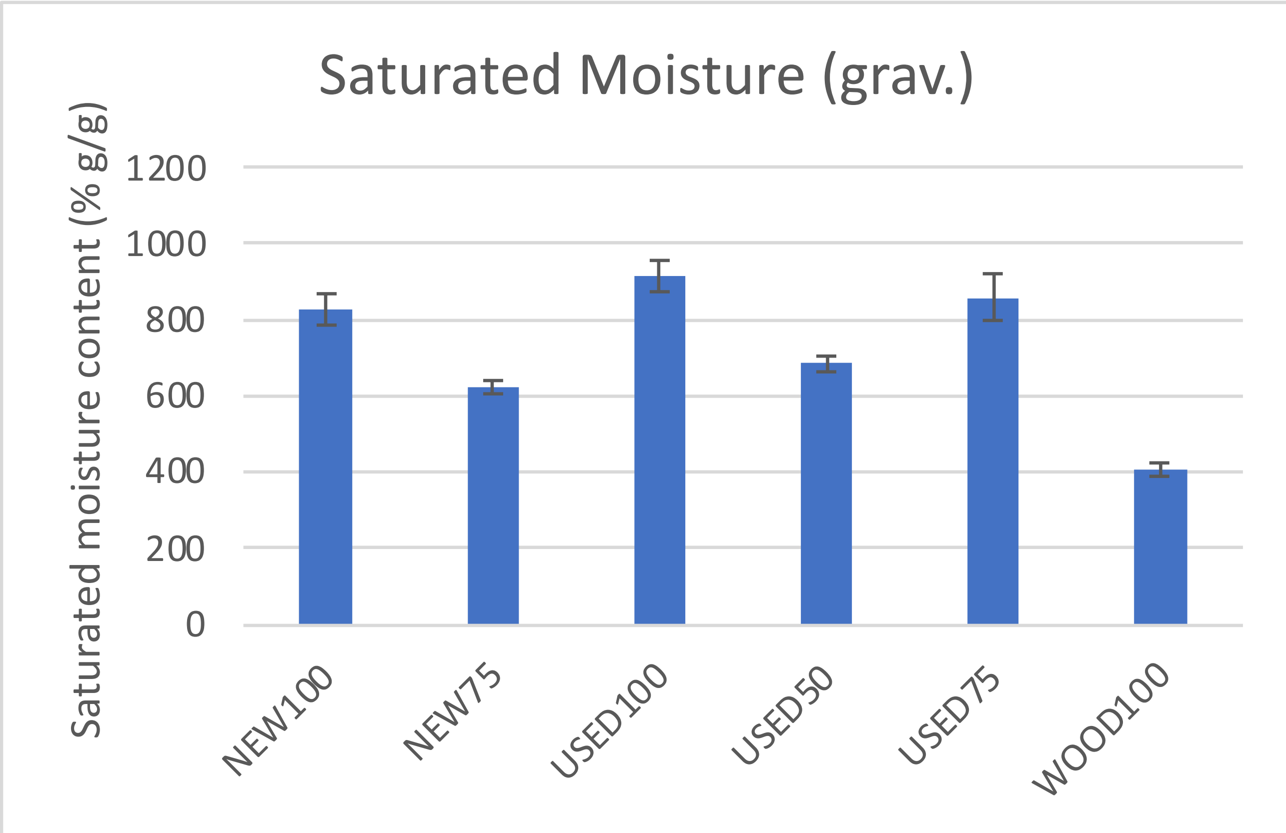

Figure A3-2: Gravimetric saturated moisture content

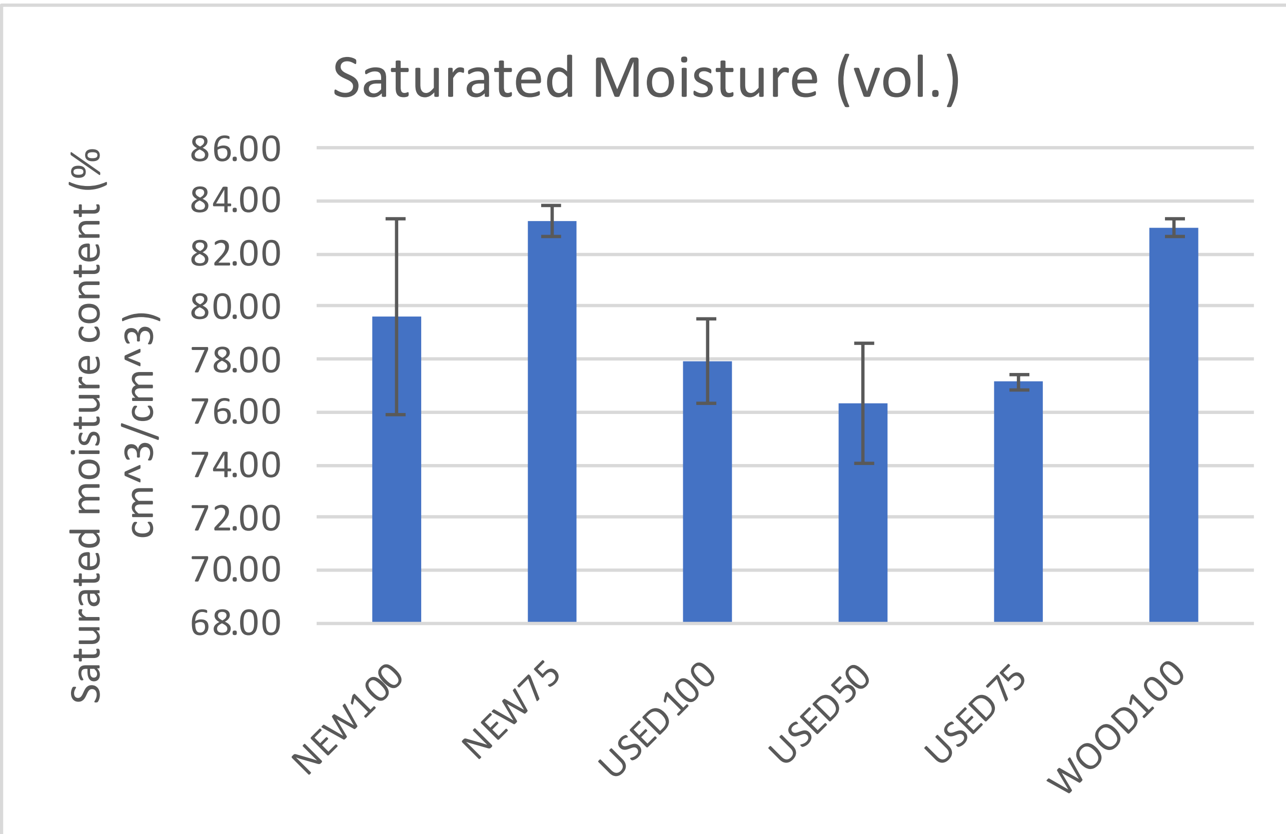

Figure A3-3: Volumetric saturated moisture content

Gravimetric analysis considers the amount of water stored per mass of coir or wood fibre, whereas the volumetric analysis considers the amount of water stored for a given volume of coir or wood fibre.

Gravimetrically the coir contains 800-900 times its own weight in moisture, whilst the wood fibre holds around 400 times its own weight in water (Figure A3-2). Differences in the gravimetric saturated moisture content between the new and used coir appeared minimal, whilst there is some suggestion that the new coir had slightly higher volumetric moisture content than the used coir.

Notably the mixed products appeared to have lower volumetric saturated moisture content than the 100% products, yet similar saturated volumetric moisture content due to differences in particle density and bulk density of the different products.

Soil Water Retention

The retention function of coir samples was found to be bimodal, such that normal fitting of the van Genuchten curve for data analysis resulted in poor model fit and poor representation of water availability (Figure A3-4).

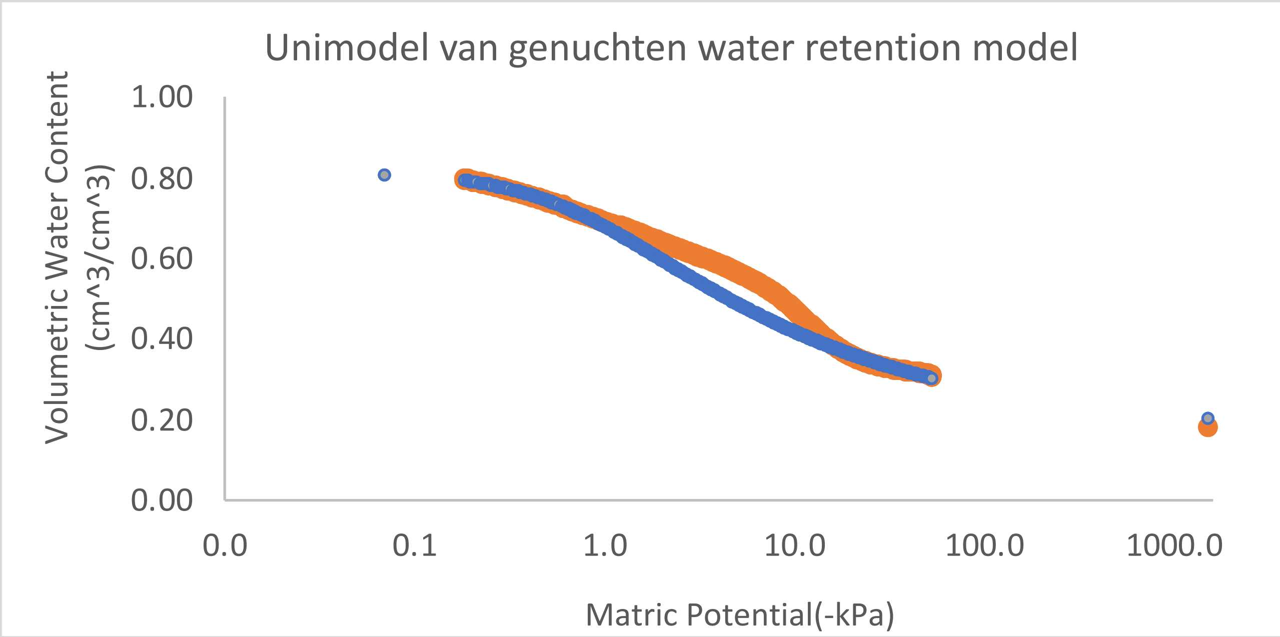

Figure A3-4: Example fitting of van Genuchten unimodal model to the coir retention data for a NEW100 sample.

Orange is measured data, blue is fitted van Genuchten curve (R2 0.966).

The bimodal nature of the soil water retention curves indicates two stages or phases of water release with the later stage (Figure A3-5 between 5-30 kPa) resulting in the greater water release.

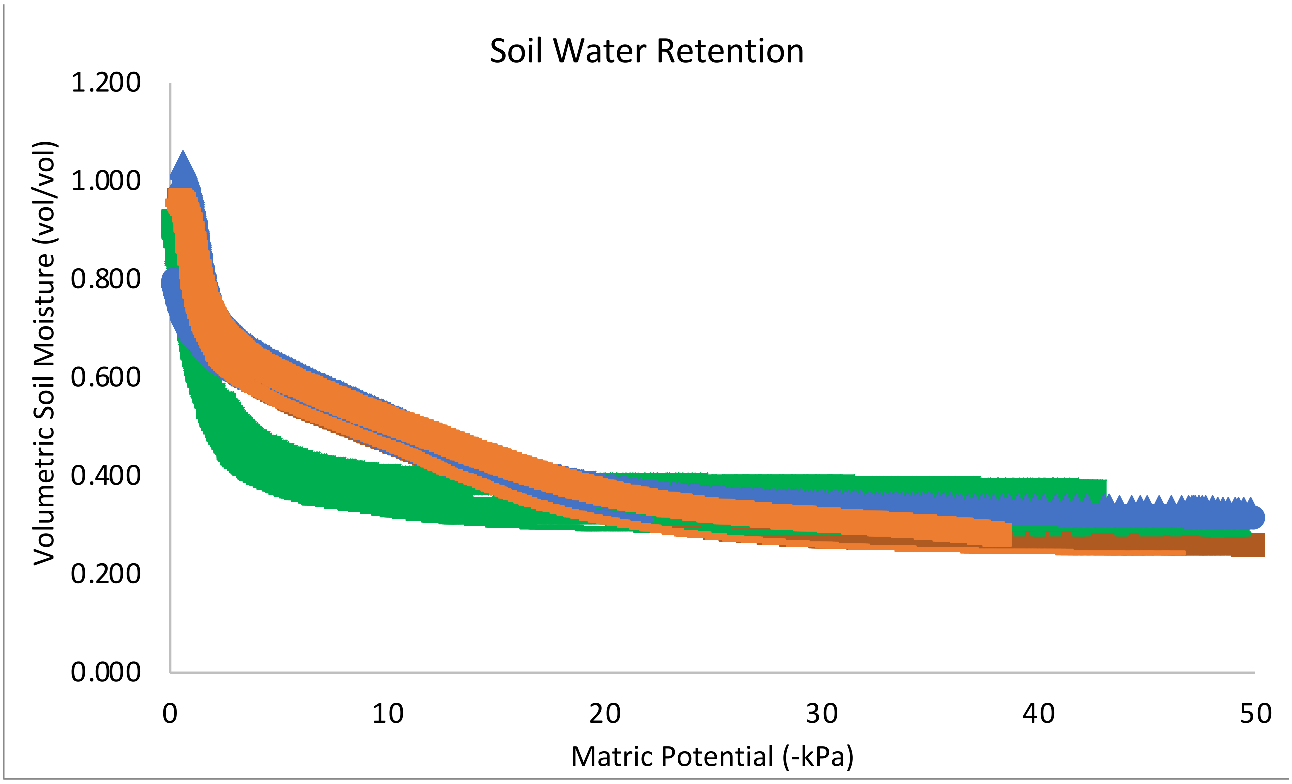

Figure A3-5: Soil water retention curves for USED100 coir – Red/orange, NEW100 coir – blue and WOOD100 – green.

The retention curve shows (Figure A3-5) the bimodal distribution of the coir in which the first stage of water loss between 0-3 kPa is due to gravitational drainage which accounted for around 30% of the total soil water. This gravitational drainage is likely to be a result of large (>300 um) 'accommodation' pores resulting from the loose packing of the material. In the second phase of water loss between -3 and 20 kPa, around 40% of the total soil water appears to be easily extracted for plant growth. Soil water in this second phase is likely to result from small accommodation pores (300 um to 15 um) between coir particles and fibres and possibly loosely held water on the outer margins of the coir. Notably there is little is any moisture available to plants between -20 kPa and the permanent wilting point -1500, despite the coir still holding around 30% (unavailable) soil water. This indicates that while the coir may still appear to be moist at matric potentials lower than -20 kPa there would be minimal if any available moisture for plant growth or survival.

The retention properties of the wood fibre differ to that of the coir, the soil water retention function distribution is unimodal in which around 50% soil water is drained by gravity from large accommodation pores between 0 and -5 kPa. Between field capacity (-10 kPa) and the permanent wilting point (-1500 kPa) the wood fibre contains little if any available soil water for plant extraction. The wood fibre acts very much like coarse sand in which in a soil all the water retained in the product is lost to gravitational drainage before becoming available to plant, this may however differ in bagged production systems.

Saturated Hydraulic Conductivity

Table A3-3: Saturated hydraulic conductivity

CORE	TREAT	HEAD (CM)	Q (CM)	KSAT (MM/HR)
152	NEW100	3	5.4182	708.45
361	NEW100	3	3.5578	465.2
141	NEW75	3	5.0642	662.17
NO10	NEW75	3	2.0994	274.51
164	USED100	3	11.724	1532.96
559	USED50	3	25.571	3343.52
NO15	USED50	3	29.6	3870.33
247	USED75	3	23.375	3056
110	WOOD100	3	7.4158	969.65
294	WOOD100	3	9.5	1242.17

The saturated hydraulic conductivity rates for the coir and wood fibres were surprisingly high. Hydraulic conductivity greater than 120 mm/hr is considered very rapid in soil (Hazelton & Murphy, 2007). Notably the used coir appears to have higher saturated hydraulic conductivity than the new coir, possibly due to root growth creating continuous pores or decay of material resulting in pore creation. The wood fibre has similar if not higher saturated hydraulic conductivity to that of the new coir.

Unsaturated Hydraulic Conductivity

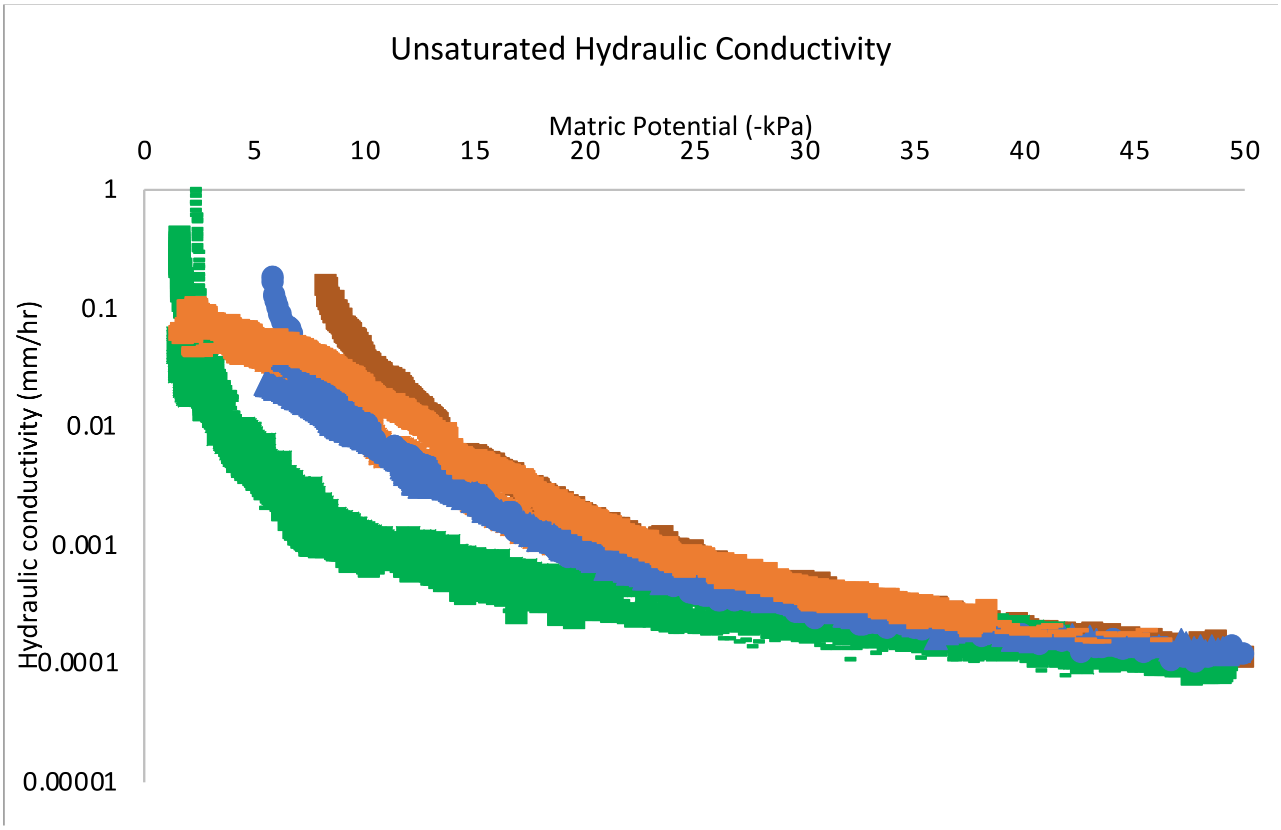

Figure A3-6: Unsaturated hydraulic conductivity, USED100 - brown/orange, NEW100 - blue, and WOOD100 – green.

Note the method for determining unsaturated hydraulic conductivity gets a little speculative as it approaches saturation (0 kPa). There is essentially no difference between the unsaturated hydraulic conductivity of the USED and NEW coir. This indicates that after gravitational drainage (<-10 kPa), movement of water through all three products to the roots is very slow (0.1 to 0.001 mm/hr) with the wood fibre being the slowest. Notably between field capacity (-10 kPa) to -50 kPa the flow rate drops 2 orders of magnitude, such that flow rates within the coir within the latter half of the PAWC range (-100 to -1500 kPa) must be almost non-existent. The wood fibre demonstrates a 4 order of magnitude reduction in unsaturated hydraulic conductivity between -2 kPa and -50 kPa, in which flow rates have effectively ceased at matric potentials dryer than -10 kPa, such that flow within the wood fibre between -5 kPa and -30 kPa is 10 times slower than the coir.

Soil water limits

Analysis suggests the drainable porosity and thus macro-porosity is similar (35% to 41%) between the three materials and product combinations (Figure A3-7). This suggest that all products and product combinations have similar capacity to drain exec water and provide sufficient aeration for root growth. Notably, there is no indication that the used coir has reduced drainage capacity compared to the new coir.

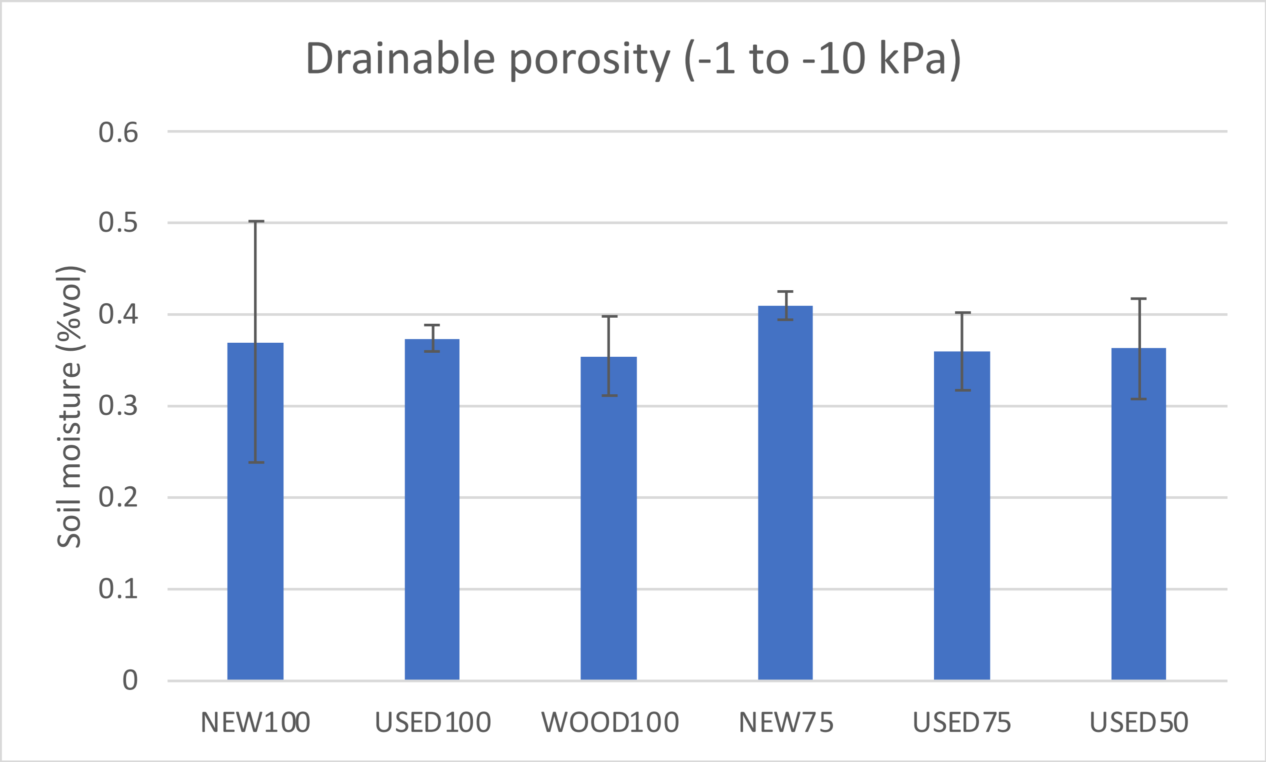

Figure A3-7: Drainable porosity or macro-porosity between -1 and -10 kPa

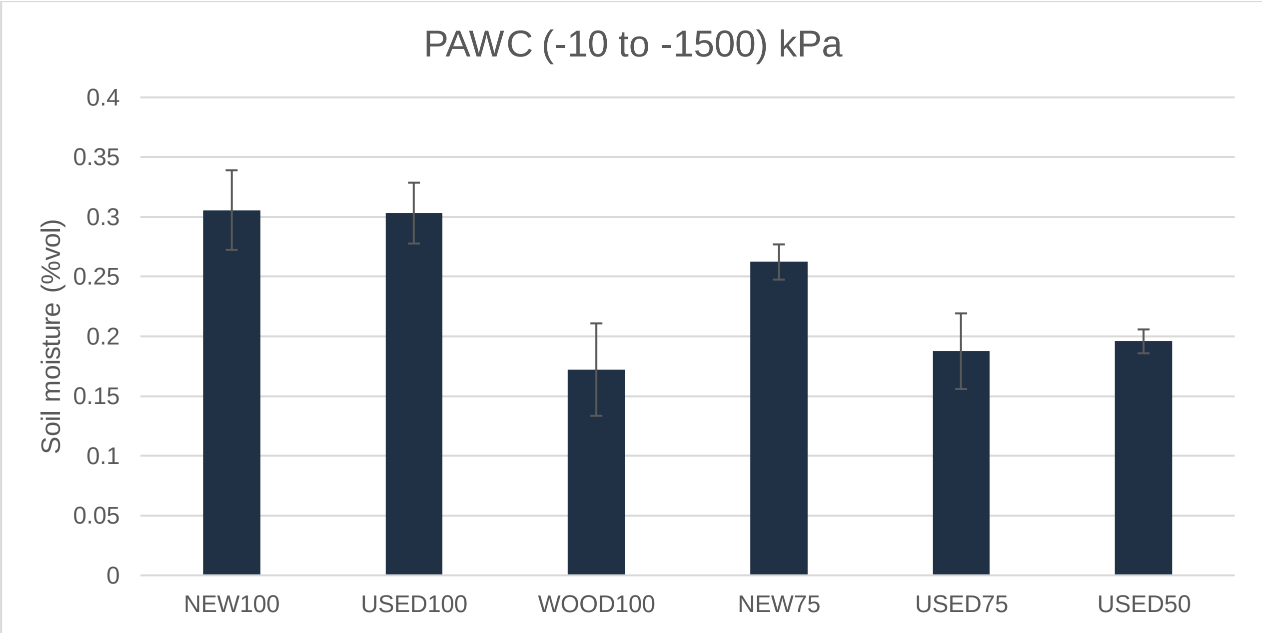

Figure A3-8: Plant available water content (PAWC) between -10 and -1500 kPa

There was no difference between the plant available (-10 and -1500 kPa) between the new and used coir (Figure A3-8). The difference in PAWC between the 75 used and the new coir is unexplained. Notably the WOOD100 treatment had substantially less (about half) PAWC than the NEW100 and USED100 coir. These results should be interpreted with caution as a 5-10 cm deep bag of coir does not function like in-situ soil, as gravitational drainage is likely to be restricted to about -1 kPa, not -10 kPa in the coir, and the lower limit of plant function is likely to be higher than -1500 kPa.

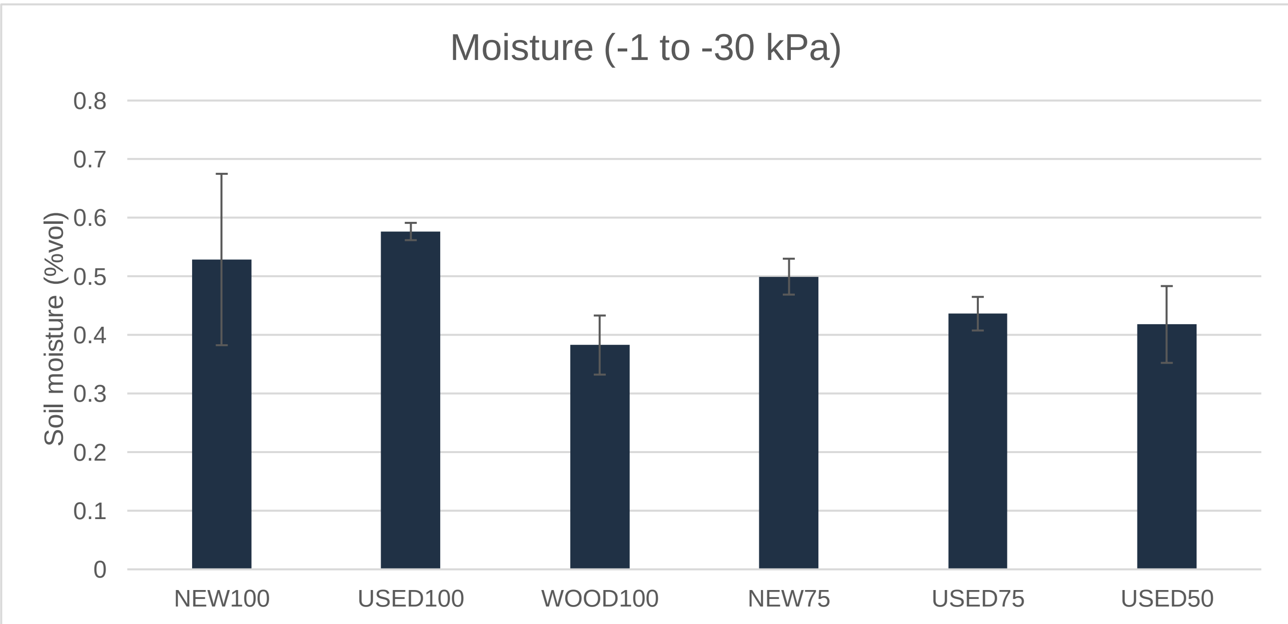

Figure A3-9: Water content (PAWC) between -1 and -30 kPa

Moisture content between -1 to -30 kPa is likely to be a more realistic measure of available moisture than PAWC for bagged coir, as moisture is almost certainly likely to be available to the plants at matric potential between -10 kPa and -1 kPa. Figure A3-9 indicates that the WOOD100 treatment had lower available moisture (-1 to -30 kPa) than the coir products, and that their appeared to be little difference between the new and used coir. Of note is that all the combined products appear have lower moisture availability than the 100% coir products.

Discussion

Discussion of moisture availability and drainage in coir and the wood fibres is limited by our poor understanding of the hydrology of these products. Whilst soil water retention data has been analyses using traditional concepts of drainable porosity, field capacity and plant available water, these concepts are almost certainly either invalid in bagged coir or exist at different matric potentials to that of in situ soil. For example, traditional soil theory contends that water held between 0 and -10 kPa, the drainable porosity, is unavailable to plants as it is thought to move through the soil profile too quickly to be used by plants. In the bagged coir initial drainage is likely to be extremely rapid due to the extremely high saturated hydraulic conductivity but being only 5 cm deep is likely to functionally cease between – 0.5 kPa and -1.0 kPa. Better understand the hydraulic behaviour of bagged coir and coir in trays is required in order that the retention function can be properly interpreted in relation to what constitutes plant available water in coir substrate.

The similarity in drainable porosity between -1 and -10 kPa indicates that the different products had similar levels of macro-porosity and thus gravitational drainage. This combined with the extremely high saturated hydraulic conductivity suggest that none of the products are likely to differ in their ability to rapidly drain from saturation or rapidly provide sufficient air capacity for root function.

The matric potential range between which plants / coir is usually kept is unknown, however the analysis of drainable porosity and soil moisture availability between -1 and -30 kPa suggests that with the exception of the WOOD100 treatment the different coir treatments had similar and considerable water availability.

Differences between the new and used coir were minimal. From a hydrological perspective it was difficult to discern any meaningful difference between the two products.

Mixing the coir with the wood fibre reduced the saturated water content such that the mixed coir products tended to have slightly lower PAWC than the 100% coir products, although it is noted that the drainable porosity of the mixed products didn't appear to differ from those of the 100% coir products.

Whilst the saturated hydraulic conductivity of all products was extremely high (270-3800 mm/hr), the unsaturated hydraulic conductivity at field capacity (-10 kPa) was very low at around 0.05 mm/hr for the coir and 0.001 mm/hr for the wood fibre, and flow had effectively ceased in all products at matric potentials dryer than -40 kPa. In all products, this indicates very rapid drainage through large accommodation macropores created between the coir / wood particles when the material is saturated, followed by very slow water movement through the coir/wood fibres after the gravitational drainage had ceased. Notably water movement in the 3 materials is almost entirely restricted to when the material is saturated or very close to saturation (<-5 kPa), such that even if the material still contained water, it would be unlikely that it could travel through the material to be taken up by roots.

Conclusion

Observed differences between plants grown in used and new coir do not appear to be a result of differences in their hydrological properties, as the PAWC, drainable porosity, density, saturated water content, unsaturated hydraulic conductivity and moisture content between -1 and -30 kPa were all similar between the two products (requires statistical analysis).

Overall differences between the mixed coir products and the 100% coir products were minimal. Mixing both NEW and USED coir with the wood fibre tended to slightly decrease PAWC, moisture between -1 and -30 kPa, volumetric saturated water content, whilst not affecting drainable porosity or bulk density.

Overall the wood product appeared to have poorer hydraulic properties compared to the coir. The WOOD100 treatment had, 1/3 less available moisture between -1 and -30 kPa, half the PAWC, lower unsaturated hydraulic conductivity, half the gravitational saturated moisture content and twice the density of the two 100% coir treatments.

Results demonstrated that the growers suggestion that differences in plants grown in new vs used coir may have resulted from reduced flow rate of water through the used coir or ‘pugging’ up of the old coir. Results show this to be unlikely as, the saturated hydraulic conductivity of the used coir was around double that of the new coir, and that no discernible differences existed between the unsaturated hydraulic conductivity of the new and used coir.

Further hydraulic analysis of coir or similar products requires further trials and monitoring of grower practice in order that existing soil water limits (field capacity, PAC, etc) can be remapped to appropriate matric potential ranges in order to be properly interpreted for coir. Furthermore, there is likely to be different hydraulic behaviour between bagged coir and coir in trays.

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Appendix 4: Sterilisation techniques – Overview SWOT analysis

Ozone	Hydrogen peroxide	Phosphorous Acid Derivatives	Microwaving	Steaming
Strengths (inherent)				
Safe to humans (minimises OHS risks) - unless at very high concentrations	Known as a strong disinfectant for potting mix and substrate mediums	Phosphoric acid already used on farms to clean out drip irrigation infrastructure	Estimate of $2/m cost, plus some labour, means it appears cost-effective (when compared to labour of removing and replacing coir currently)	Relatively simple, safe to use and effective sterilisation agent
Can be readily manufactured on site	Increases oxygen levels in hydroponics mediums	Relatively cheaply and freely available	Can be used in situ - with used coir in troughs on tables	Can potentially be done via portable truck going from farm-farm (previous conversation with Laurie)
Potent oxidising agent		Phosphorous Acid Derivatives are ideal for the Control of Pythium, Phytophthora, Fusarium and other Disease Causing Fungi in Hydroponics	1-4 hours per 100m length appear to be achievable - and likely to speed up in future as technology matures	
Potentially can be used in situ & fed through existing drip irrigation system				
Weaknesses (inherent)				
Too much ozone can be detrimental to plant health by inhibiting chlorophyll production	OHS and chemical disposal issues considerations	Unsure of effectiveness against bacteria and nematodes	Concerns over logistics of moving microwaving down rows - how close microwave needs to be to substrate - metal brackets are in the way every metre or so	Large labour requirement (removing plants, substrate, transporting substrate into piles) as it cannot be done in situ
Cost?	May damage plants if concentration slightly too high - risky	Limited information about its on substrates	Currently 1-4 hours per 100m length is relatively slow - need to determine time period between plants being removed from substrate and planting occurring again to ensure microwave can treat all substrate	Cost and space required for establishing infrastructure on-farm likely to be quite high (if setting up for each farm)
Uncertain whether it could occur in situ (with or without plants)		OHS and chemical disposal requirements		
Opportunities (external)				
New technologies to improve efficiency of ozone production on-site			Technology advancements - increasing speed and ease of use.	Development of steaming sterilising trucks - increased ease of access
Threats (external)				
	Tightened disposal and OHS requirements impeding economic use of product	Tightened disposal and OHS requirements impeding economic use of product	Increasing costs and competition for microwave products - potential for supply constraints, particularly during winter period when they will be in demand across berry industry?	

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