Assessing the benefits of sea urchin processing waste as an agricultural fertiliser and soil ameliorant

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20th December 2024

FRDC Project No **2019-128**

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2019-128

2024

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Acknowledgments

This work received funding from the Fisheries and Research Development Corporation (FRDC 2019-128) and the Tasmanian Governments Abalone Industry Reinvestment Fund (AIRF).

We would like to thank True South Seafoods for their contributions and cooperation throughout the project, including upgrades to the processing facility to generate an improved product, and access to the waste material itself.

We thank our agricultural industry partners, Craig Mundy from Two Buds Spur vineyard, Scott Price from R&R Smith, and Doug Clark and Ann-Maree Donoghue from TIA at the Tasmanian Vegetable Research Facility, for enabling us to run the commercial field trials.

We'd like to express our gratitude to Paolo Campus, the technical officer appointed to the project, for his work in taking measurements and collecting data for the trials. We thank Phil Andrews, the TIA Horticultural glasshouse manager, for helping to organise and maintain the pot trials. We are grateful to Yulia Lyovina (True South Seafoods) for her assistance in providing information for the economic analysis, and Namgay Dorji for his work in undertaking the economic analysis.

Abbreviations

CHA	Chardonnay
CL	Clay loam
EC	Electrical conductivity
ENV	Effective neutralising value
KB	Kingston Black
NPV	Net present value
SB	Sauvignon Blanc
SL	Sandy loam
SUW	Sea urchin waste
TA	Titratable acidity
TSS	Total soluble solids
YM	Yarlington Mill

Executive Summary

This project was a collaboration between researchers from the Tasmanian Institute of Agriculture (TIA) and the Institute for Marine and Antarctic Science (IMAS) to determine whether a marine problem could be transformed into a novel agricultural solution. The research teams from the University of Tasmania (UTAS), in collaboration with True South Seafoods, established a tailored sea urchin waste (SUW) processing facility in Electrona (Tasmania) in May 2021 to create and test several SUW products on soil health and crop productivity over a two-year period.

Over the last 50 years, populations of the invasive Longspined Sea Urchin (*Centrostephanus rodgersii)* have rapidly increased on the east coast of Tasmania, posing a major threat to kelp forests and marine biodiversity. Commercial fisheries have exploited booming urchin populations by harvesting the well-regarded roe and simultaneously assisting in population control. Yet sea urchin roe accounts for only ~10 % of urchin biomass, with the remaining urchin deemed as waste. In small production areas, such as Tasmania, this waste is destined for landfill at a substantial cost to industry. Strategies to address urchin waste in a manner that benefits industry and urchin control are yet to be explored. FRDC 2016-208 identified the potential of SUW utilisation in the agricultural industry; an industry that is seeking organic and effective alternatives to synthetic inputs to boost crop productivity. This led to the establishment of this project (FRDC 2019-128), encompassing the thorough examination of potential SUW products, the upscaling of crop trials, and an economic analysis to establish the commercial viability of SUW as a soil amendment.

Background

A gradual increase in water temperature in south-eastern Australia over the last 60 years (Banks et al., 2010; Banks et al., 2007) has facilitated the migration of Longspined Sea Urchin larvae from the east coast of New South Wales down to the east coast of Tasmania (Byrne & Andrew, 2013; Johnson et al., 2011). Scientists from IMAS estimate there are now approximately 20 million Longspined Sea Urchins off the coast of Tasmania (Ling & Keane, 2018). Urchin harvest supported by state government subsidies has been the primary control measure. Over the last eight years, this investment has allowed urchin fisheries to expand. However, strategies to assist the viability of the Tasmania urchin industry beyond harvest subsidies are necessary to continue to control urchin populations.

Aim and objectives

The overall aim of this project was to establish if SUW could be utilised as a commercially acceptable agricultural amendment to serve as an organic alternative for growers and farmers seeking more

sustainable inputs, and to provide an additional revenue for urchin fisheries. Five primary objectives were established:

1. To develop commercial scale processing equipment for sea urchin waste.
2. Determine the nutrient composition and plant bioavailability of nutrients from two high-throughput waste streams: liquid gut waste and dried powdered shell waste.
3. Evaluate the agronomic benefits of liquid gut waste as a frost retardant in perennial tree cropping (cherries).
4. Evaluate the agronomic benefits of powdered shell waste as a soil ameliorant in a wide range of annual and perennial cropping systems.
5. Undertake a cost-benefit analysis comparing fertiliser products (foliar sprays and/or soil conditioners) from this work to other products on the market to assess if the products are commercially viable.

Methodology

Objective 1 & 2

A modified food-waste processing facility was researched and obtained at project commencement, then revised by engineers to meet Australian standards, optimise operational efficiencies, and maximise throughput. Multiple test runs led to the obtainment of three suitable solid sea urchin waste (SUW) products which varied in processing times (14, 24, 48 hrs), resulting in end-products of different dryness and fineness, and one liquid SUW product. The physiochemical nature of both solid and liquid products were observed with additional analyses (organic contaminants, organic pesticides, microbiological) performed on potential commercial products (SWEP analytical laboratories, Keysborough, Victoria, Australia) to align with the Australian Standards for composts, soil conditioners and mulches (AS 4454-2012). The liquid product underwent sterilisation through autoclaving and fermentation yet was deemed unsuitable for agricultural use due to a high electrical conductivity (EC) and associated salt content, and relatively low nutrient content. Further testing of the liquid SUW and the commencement of Objective 3 ceased. Other liquid waste management strategies are currently being explored by the fishery.

Objective 4

Preliminary measures of the SUW product to assess its agronomic viability and commercial use included particle size analysis and crop-toxicity assessment. Particle size analysis was performed by sifting the solid SUW products (14, 24, 48 hrs) through different sized mesh to generate particle distribution curves and calculate product effective neutralising value (ENV) for liming product utility. The phytotoxicity trial was conducted on radish (*Raphanus sativus* L.) seeds using methods described by Wang et al. (2022) to calculate the germination rate, radicle length and germination index of seedlings exposed to up to 10% SUW.

A series of pot and field trials were conducted to explore the fertiliser potential (sunflower trial, apple orchard trial, potato trial) and liming potential (green bean trial, vineyard trial) of the SUW products. Different SUW products were applied to a variety of soil types at different rates (0–20 t ha^{-1}). Crop productivity and soil physiochemical status was measured throughout.

Objective 5

A net present value (NPV) analysis was performed in consultation with True South Seafoods and an external economic consultant. A cost-benefit analysis was redundant as any conversion of the waste on-site using the processing facility available was determined economically profitable. Three projects to produce the SUW-based agricultural product were considered. Post NPV computation, the project with the highest NPV was deemed most successful for implementation.

Results and key findings

SUW was converted into a successful soil amendment through a simple two-stage process of grinding and heating the solid waste, in which processing time impacted particle fineness and moisture content but did not meaningfully impact other product physiochemical properties for up to 48 hours. The resulting SUW product was high in several important plant nutrients and was largely characterised by a high calcium content (33%), resulting in its potential use as a liming material. This liming effect was demonstrated in a variety of trials across both annual (sunflowers, green beans, potatoes) and perennial (apples, grapevines) crops in sandy soils, loams and clay soils. The product's effective neutralising value was calculated and used to determine appropriate rates to increase the soil pH equivalent to or surpassing that of conventional liming products using typical liming formulas.

Fertiliser impacts from the SUW product were observed in low-nutrient pot trials but were not significant in commercial field trials. This suggests that the upper rate thresholds maintained based on the product's strong liming ability and the ideal soil pH parameters for crop production, prevented the observation of significant fertiliser effects from other nutrients present in the SUW products, at least in commercial field settings. However, the addition of other nutrients provided by the SUW is still beneficial and a fertiliser effect may be more readily observed in home gardens, such as shown in the sunflower pot trial.

The economic analysis determined that processing SUW was more profitable than waste disposal, regardless of whether the SUW product was sold. Further investment of $50,000 to upgrade the facility would reduce current annual production running costs and provide additional profit from the second year onwards.

The utility of SUW as a commercial 'liming plus' product shows promise, but growers are advised to proceed with caution due to the product's salt content. Commercial suppliers should provide growers with appropriate management techniques and recommended rates to reduce the likelihood of any salinity issues at first use and with prolonged use. Adding a freshwater wash step to SUW processing is likely to reduce salt-related land risks.

Implications

This project demonstrated that the cost of processing SUW using a simple grinder and heated processing facility is more financially beneficial than conversion to landfill, and that a valuable agricultural product can be made from the SUW that fisheries could profit from.

Recommendations

Further investigation into the long-term impact (3–5 years) of SUW and repeated SUW applications on soil health and crop production is advised due to the novelty of the product and potential salinity issues. From a sustainability perspective, a life-cycle analysis that explores the inputs and outputs of SUW production, particularly regarding energy, greenhouse gas emissions, and an additional freshwater washing step, would be beneficial.

Keywords

Longspined Sea Urchin, *Centrostephanus rodgersii,* sustainability, circular economy, waste management, waste utilisation, crop production, crop productivity, agriculture, fertiliser, liming material, soil pH

Introduction

In Tasmania, urchin harvesting is currently the primary urchin-control measure. Since the 2018/19 fishing season, subsidies of approximately $300,000 per year provided to the Tasmanian fishing industry has resulted in 2,455 tonnes (t) (491 t/year) of urchin being harvested. Of this, approximately 1,700 t was waste comprising shells, spines, guts (wet weight; Keane et al., 2021). Dumping costs are currently in excess of $200 per tonne, equating to over $340,000 being spent during this period. Eliminating dumping costs and turning these large volumes of waste into a saleable product is a clear way of increasing industry profitability and reducing the need for a subsidy.

Preliminary biochemical analyses and a pilot trial of urchin waste as an agricultural fertiliser proved highly successful (FRDC 2016-208). Urchin waste was shown to contain a variety of macro- and micronutrients essential for plant growth, including some that are highly deficient in Tasmanian soils, such as boron. A small-scale greenhouse trial with tomatoes showed plant growth utilising urchin waste fertiliser matched that of commercial grade fertilisers in several aspects, with the uptake of nutrients, particularly micronutrients, high (Campus et al., 2022). The pilot results indicated that a project to upsize to a moderate-scale commercial trial was warranted.

The primary aim of this project was to investigate the potential to use waste from the Longspined Sea Urchin fishery as an agricultural amendment to assist the industry to move away from subsidies. A large-scale sustainable fishery is seen as the most feasible and sustainable way to apply downward pressure on the rapidly expanding Longspined Sea Urchin population in Tasmania. Longspined Sea Urchin populations have grown to approximately 20 million individuals (5,500 t) and have resulted in 15% of reefs on the Tasmanian east coast becoming unproductive urchin barrens, up from 3% just 15 years ago (Ling & Keane, 2018). Subsidies for the Longspined Sea Urchin harvest commenced in 2016 and initiated significant investment in the industry to facilitate export market establishment which resulted in the 2019 harvest booming to over 550 t, making it Tasmania's third largest wild fishery by weight (Cresswell et al., 2019). However, the industry needs to move away from subsidies and waste utilisation is seen a viable option to turn a current financial cost (estimated at $77,000 in 2022/23 to dump ~383 t of waste generated) into an income stream.

FRDC project 2016-208 identified the potential of sea urchin waste utilisation in the agricultural industry and called for commercial upscaling of trials. This project was designed to meet that need. The Abalone Industry Reinvestment Fund (AIRF) provided $538,686 to kickstart the project and the

FRDC-funded work provided for multi-season agricultural trials on annual and perennial crops using the SUW products to obtain meaningful scientific and industry results.

In the push for sustainably produced food, agricultural industries are demanding organic products that improve soil health and alternative nutritional sources to synthetic fertilisers. Urchin waste is comprised of two major parts: a liquid waste, comprised of coelomic fluid and gut remnants, and a solid waste, encompassing the calcium-rich shell, spines and jaw. This project explored the utilisation of these waste products in an agricultural context.

Objectives

1. To develop commercial scale processing equipment for sea urchin waste.
2. Determine the nutrient composition and plant bioavailability of nutrients from two high throughput waste streams: liquid gut waste and dried powdered shell waste.
3. Evaluate the agronomic benefits of liquid gut waste as a frost retardant in perennial tree cropping (cherries)
4. Evaluate the agronomic benefits of powdered shell waste as a soil ameliorant in a wide range of annual and perennial cropping systems.
5. Undertake a cost-benefit analysis comparing fertiliser products (foliar sprays and/or soil conditioners) from this work to other products on the market to assess if the products are commercially viable.

Method

1. To develop commercial scale processing equipment of sea urchin waste

Appropriate waste-processing equipment was identified and researched by former key RTS PauaCo (now True South Seafoods) staff in the development of this project. After the funding was awarded, the former RTS PauaCo Business and Product Development Manager ordered a customised (modified) waste processing plant from China.

In September 2020, an engineering firm, Pitt & Sherry, was commissioned to assess the processing equipment and to provide technical support with installation. Pitt & Sherry undertook an initial assessment of the processor based on the documentation and information received prior to the processor's arrival. Overall, the machine was reported to be robust and functional, with a few repairable mechanical, electrical and safety issues, such as weld quality, wiring colour coding, stair safety and interlock presence to meet Australian standards. The machine was designed with higher-than-usual-capacity heating units to facilitate rapid drying and elevated temperatures to provide flexibility in experimental use. Engineering, logistical and safety requirements had to be met for the proper and safe installation of the processor at True South Seafoods (Electrona, Tasmania), including the appropriate location on site, footings, power, and drainage.

The processing plant arrived at True South Seafoods in mid-May 2021, where further assessment by Pitt & Sherry led to appropriate equipment modifications to meet Australian standards, such as electrical earthing (Fig 1).

Figure 1. Sea urchin waste processing facility installation at True South Seafoods (Electrona, Tasmania) in May 2021

Test runs were initiated in late May 2021 before further plant modifications were performed throughout June to optimise operational efficiencies and maximise throughput. Modifications included installing a hot-air recycling pipe from the top of the processor that fed the hot circulating air back into the processor to reduce heat loss and setting an appropriate grinding size to allow for maximum moisture extraction of the sea urchin waste (SUW). The modifications implemented during this time enabled 4 t of whole SUW to dry to ~10 % moisture content in 14 hours, and to have a negligible moisture content at 48 hours. It also enabled the facility to reach a sufficient temperature (>70°C) to eradicate potential pathogens.

The steps of SUW processing via the facility included pre-heating the chamber to 70 °C (maximum temperature) before feeding the processing waste directly into a shoot, where it was transported to the grinder. During this stage, the liquid was separated from the solid and drained out of the machine. As there was no liquid collection vessel included as part of the processor, the liquid needed to be collected in tubs. The solid waste was crushed as it was fed through the grinder, before it travelled through a shoot into a heated, enclosed chamber. Once in the chamber, the waste product was continuously turned by large paddles and was left for an allotted time. The longer the SUW was left to process, the drier and finer the end-product became (Fig 2).

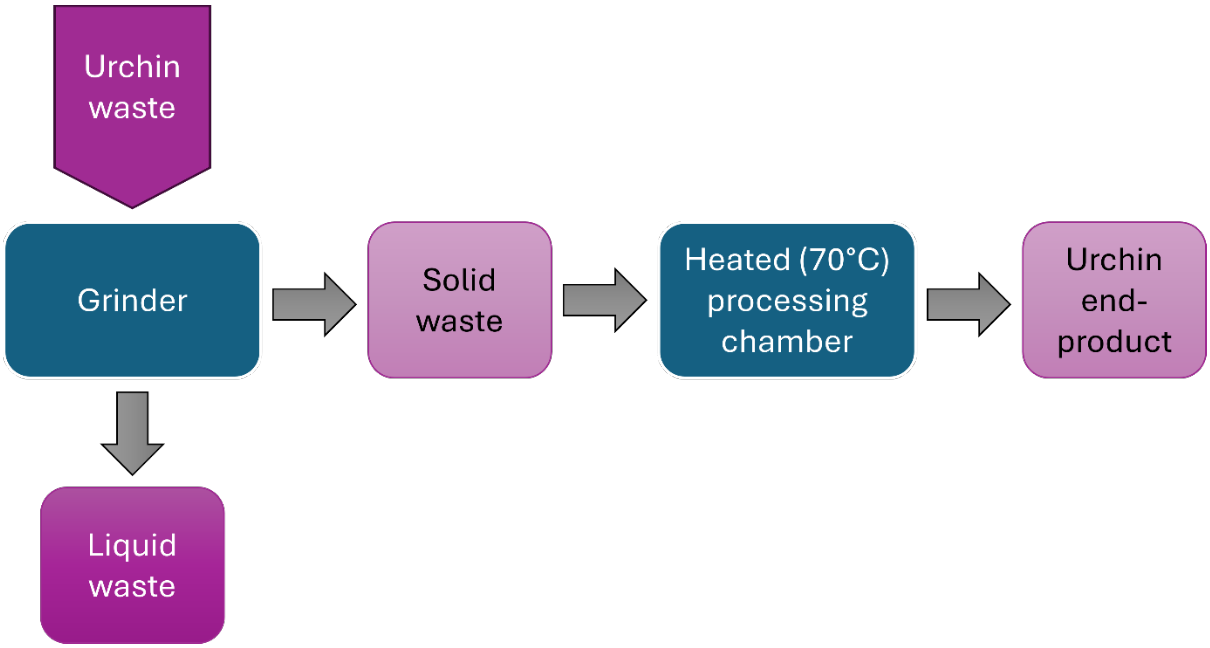

Figure 2. Simple flow chart of sea urchin waste processing steps using customised waste processing facility

2. Determine the nutrient composition and plant bioavailability of nutrients from two high throughput waste streams: liquid gut waste and dried powdered shell waste

The physiochemical and heavy metal analysis of solid and liquid SUW samples were undertaken by SWEP analytical laboratories (Keysborough, Victoria, Australia) and used the following methods. Total N was obtained though the Dumas method (Rayment & Lyons, 2011). Total P, K, S, Ca, Mg, Na, Fe, Mn, Zn, Cu, Co, B and Mo were obtained through acid digestion (solid SUW) or microwave digestion (liquid SUW) using inductively coupled plasma atomic emission spectrometry (ICP-AES) and Cd, Hg, Pb, As, Ni and Cr were measured using inductively coupled plasma mass spectrometry (ICP-MS). pH was measured in a 1:5 water suspension via Method 4A1 (Rayment & Lyons, 2011) and electrical conductivity (EC) was performed in a water extract through Method 3A1 (Rayment & Lyons, 2011). Moisture content of the solid SUW was measured gravimetrically.

Organic contaminant (OC) and organic pesticide (OP) residues were measured on a bulk SUW sample through solvent extraction, followed by liquid chromatography with tandem mass spectrometry and gas chromatography with tandem mass spectrometry (AMAL Analytical Pty Ltd, Huntingdale, Victoria, Australia).

Microbiological analysis was performed by SWEP analytical laboratories and included the detection of faecal coliforms following the method outlined by Kumar et al. (2010) and salmonella detection using the Australian Standards Method AS1766.2.3-1992.

The physiochemical analyses that were performed were in alignment with the Australian Standards for composts, soil conditioners and mulches (AS 4454-2012). AS 4454-2012 was used as a guiding document to ensure the SUW products met basic requirements, but the end-use of the final product (e.g., liming material, soil conditioner) will define the final product specifications to be met for commercial sale.

2.1 Liquid product

2.1.1 Initial product analysis

The liquid product was collected from the processing facility via solid and liquid separation at the initial processing stage. Two liquid samples were collected for physiochemical analysis (SWEP analytical laboratories). One of these samples was kept in its raw form, and the other was sterilised via autoclaving at 121°C for 20 minutes.

2.1.2 Sterilisation and product analysis

The fermentation of the liquid product was explored as a means of sterilisation (Hammoumi et al., 1998; Kim, 2011; Ramesh et al., 2020) as large-scale sterilisation was unlikely to be economically feasible, but was deemed necessary if the liquid waste was to be used for food production or in an agricultural setting.

Four 60 L barrels were filled to 50 L using a 1.5 (dextrose) : 1 (SUW) : 5 (distilled water) ratio to reach the necessary dilution to reduce the salt content of the liquid product for agricultural use and to allow for successful fermentation, which aligned closely with other studies that fermented marine waste (Ramesh et al., 2020). The liquid SUW barrels were fermented in a dark, temperature-controlled room set at 20°C (Fig 3 a,b).

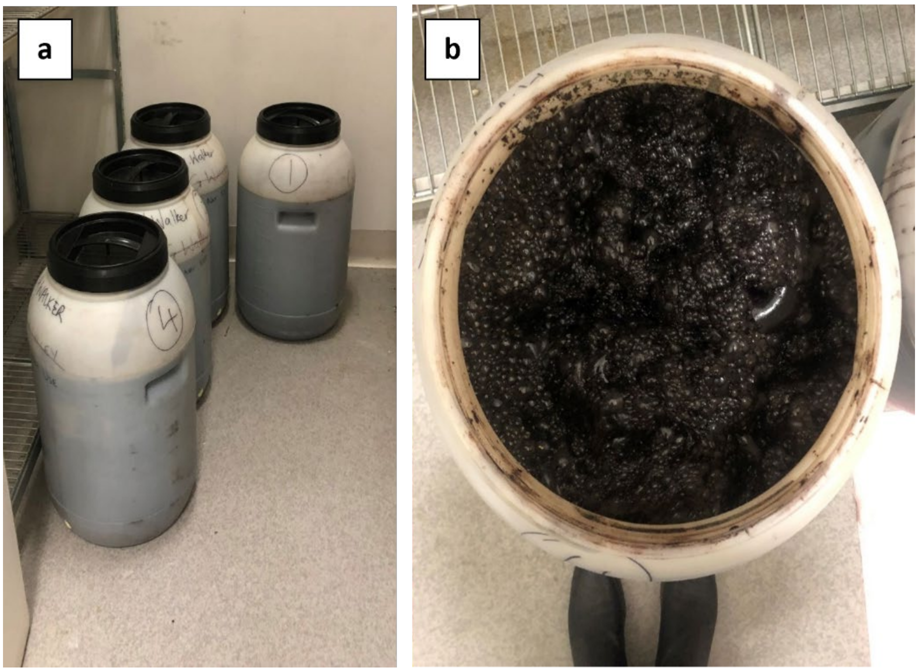

Figure 3. Liquid Sea Urchin waste (SUW) in barrels a) prepared for fermentation, b) SUW visibly fermenting

Fermentation was monitored using a pH meter, in which a decline in pH signified ongoing fermentation. A target of pH 4 was used to determine the end point to ensure the product was stable and the pathogen load was reduced. The sugar content was not used as a fermentation measure as the high salt levels in the SUW would interfere with the accuracy of refractometer measurements typically used to calculate sugar content. The target pH was reached in approximately seven weeks and fermented SUW subsamples (n = 4) were sent for physiochemical analysis (SWEP analytical laboratories).

2.1.3 Liquid sludge analysis

The “sludge” was a part of the liquid waste, which was formed from the natural separation of the SUW liquid water-based component from the viscous sludge-based component when the liquid was allowed to settle. The sludge waste was sent to SWEP analytical laboratories for physiochemical, microbiological, heavy metal, organic contaminant, and organic pesticide analysis.

2.2 Solid product

2.2.1 Initial product analysis

Initial product analysis took place in early June, shortly after the processor was installed. The SUW samples were collected after 48 and 96 hours of processing. At this point, modifications to the processor had not yet been undertaken to speed up the drying time, and the product was too wet at previous sampling times to warrant testing.

As the solid SUW product was non-homogenous, both the 48 and 96 hr products were separated into size categories (>2 mm, 1–2 mm, 0.5–1 mm, <0.25 mm) to establish whether there were physiochemical differences between particle sizes which may influence product development. The physiochemical composition of the SUW samples (n = 8) were measured through SWEP analytical laboratories.

2.2.2 Updated product analysis

Processor modifications in June and July sped up the product drying time, and further analysis was necessary to establish SUW composition with the improved facility. Three processing times were chosen for SUW collection (14, 24 and 48 hrs) based on visual composition markers (moisture content, particle size) and processing logistics.

Physiochemical, microbiological, heavy metal, organic contaminant, and organic pesticide analysis of the samples (14, 24 and 48 hrs) were undertaken by SWEP analytical laboratories.

2.2.2.1 Particle size analysis

Particle size analysis was undertaken to accurately determine product fineness in alignment with the procedure to determine the effective neutralising value (ENV) of liming products as a potential product end-use. To generate particle size distribution curves, approximately 250 g of SUW from each of the three products (14, 24 and 48 hours) were sifted through a series of 13 meshes (5.60 mm, 4.00 mm, 2.80 mm, 2.00 mm, 1.40 mm, 1.00 mm, 710 µm, 500 µm, 355 µm, 250 µm, 180 µm, 63 µm, 45 µm) (Fig 4).

Figure 4. Separation of particle sizes from Sea Urchin waste product sample via particle size analysis

Particle separation was performed with a Vibratory Sieve Shaker (ANALYSETTE 3 – Fritsch), set at a five second range/timing interval for a total of three minutes shaking time at an amplitude of 0.3 mm. At each mesh size, the mass of particles retained, the percentage of particles retained relative to the total initial weight, the cumulative percentage of particles retained, and the percentage of particles passing through the meshes were recorded. The particle size distribution curve of the three products was generated based on the percentage of particles passing through the meshes using grain size identification points that allowed the passing of 60, 30 and 10% of the particles indicated as D60, D30, D10.

3. Evaluate the agronomic benefits of liquid gut waste as a frost retardant in perennial tree cropping (cherries)

This project objective was contingent on the liquid waste being a suitable product for agronomic means. As established in objective 2 (see discussion), this was not the case, and therefore no further experimentation of the liquid waste was undertaken. This project objective was thus discontinued and research was more heavily invested in the bulk dried products.

4. Evaluate the agronomic benefits of powdered shell waste as a soil ameliorant in a wide range of annual and perennial cropping systems

The physiochemical properties of the SUW suggested that it could be used as a) a liming product due to its high calcium content, b) a fertiliser due to its high micronutrient profile and relatively high nitrogen content compared to other marine agricultural products or, c) a soil conditioner due to its structural properties and nutrient profile. Several agronomic trials were established to test these end uses using differing SUW rates and product types. Field sites were chosen according to the aim of the individual experiments and to create variety amongst crops, cropping systems, soil types and climates, in order to investigate the result of SUW application under different agricultural conditions.

Unless otherwise stated, soil physiochemical and plant tissue analyses were performed by Agvita Analytical (Devonport, Tasmania, Australia) using Australasian Soil and Plant Analysis Council (ASPAC) certified methods. Plant tissue analysis was performed via dry ash methods. Soil Total Nitrogen (N) and Total Carbon (C) were obtained through a furnace method of complete combustion (analogous to the Dumas method). Available soil phosphorous (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) were obtained through Mehlich-3 extraction (Mehlich, 1984). Available soil nitrate ($N\text{-}NO_3$) measurements were obtained through a K-Cl extraction solution (Method 7C2a), and available soil chloride (Cl) via a 1:5 water suspension (Method 5A2b). Soil pH was measured in a 1:5 water suspension via Method 4A1 (Rayment & Lyons, 2011) and electrical conductivity (EC) was performed in a water extract through Method 3A1 (Rayment & Lyons, 2011).

4.1 Phytotoxicity trial

The phytotoxicity trial was conducted on radish (*Raphanus sativus* L.) seeds to establish whether there were toxicity effects of the SUW product on seed germination and growth, as this would limit its use for annual cropping.

The phytotoxicity assay was performed as described by Wang et al. (2022). Briefly, 100 ml of deionised water was mixed with SUW (14 hr product) to create 0.5%, 1%, 3%, 5%, 8% and 10%

dilutions inside Falcon tubes. The tubes were placed on a mechanical mixer and were continuously shaken for one hour and filtered through Whatman filter paper. Five ml of supernatant was pipetted into petri dishes lined with filter paper containing ten radish seeds and replicated four times across each dilution against a 100 % deionised water control. The petri dishes were incubated for 48 hours at 25°C in the dark (Fig 5).

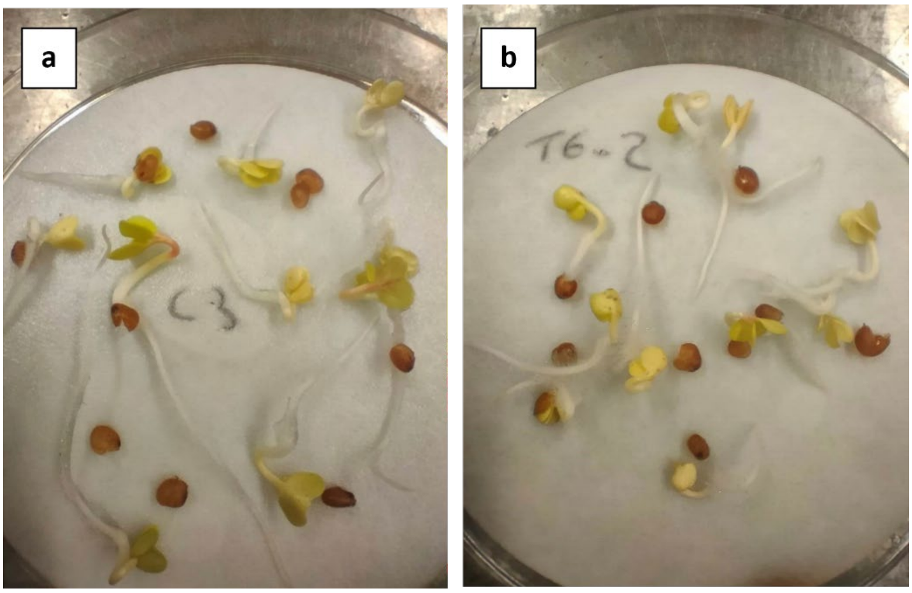

Figure 5. Germinated radish seeds in petri dishes after the 48 hour incubation period, a) control and b) 10 % SUW dilution rate

Germination rate (GR), radicle length (RL) and germination index (GI) were calculated using the following equations:

GR (%) = number of germinated seeds in SUW extract/number of germinated seeds in control * 100

RL (%) = radicle length of all seeds in SUW extract (mm)/radicle length of all seeds in control (mm) * 100

GI (%) = GR*RL/100

4.2 Pot trials

4.2.1 Sunflower trial

The sunflower pot trial was established to determine the impact of the different SUW products (14, 24 and 48 hr) at varied rates on a model crop's (sunflower) health and productivity, and soil physiochemical parameters.

Five rates (1%, 2%, 4%, 8% and 10% SUW w/w) of the three SUW products (14, 24 and 48 hr) were mixed thoroughly with a low nutrient potting mix (80% composted pine bark, 20% coarse sand v/v) in 1.9 kg batches, together with a 0% SUW (100% potting mix) control, for a total of sixteen treatments with five replicates of each treatment across eighty treatment pots (160 mm diameter x 170 mm depth). This resulted in SUW applications of 19 g (1%), 38 g (2%), 76 g (4%), 152 g (8%) and 190 g (10%).

The pots were left on a glasshouse bench (University of Tasmania, Sandy Bay campus, Hobart, Australia) at approximately 20 ± 5°C under natural daylight conditions. A dripper system was installed to deliver irrigation for three minutes, four times a day, for a total rate of 320 ml pot day^{-1}. The pots were left to equilibrate for one week before a 10 g soil sample was taken from each replicate pot to measure soil pH and EC (TPS WP-81, Queensland, Australia) using the 1:5 method (Rayment & Lyons, 2011). pH and EC soil measurements were repeated mid-way through the experiment (22nd November 2021) using the same method.

Sunflower (*Helianthus annuus* L., 'Dwarf Sunsation'*)* seeds were hand sown into seedling trays containing vermiculite on the 30th of August 2021 and left to germinate under the same glasshouse conditions as the treatment pots. After approximately three weeks (24th September 2021), the strongest seedlings were transferred into the eighty treatment pots (one seedling per pot) in alignment with the end of the one-week soil equilibration period.

100 ml of a standard Hoagland solution was applied to the control treatment pots (0 % SUW, 100 % potting mix) three times a week from the start of the trial period (24th September) until the start of senescence (24th December), equating to a total of 3.37 ml of $Ca(NO_3)^2$ and KNO_3, 1.35 ml of $MgSO_4$, 0.67 ml of KH_2PO_4 and Iron Chelate $C_{10}H_{16}FeN_2NaO_8$ and the following micronutrients H_3BO_3 (0.2%), $MnCl_2$ (0.3%), $ZnSO_4$ (0.02%), $CuSO_4$ (0.008%), Na_2MoO_4 (0.002%).

Plant growth and health was measured weekly through plant height measurements, node counts, stem thickness, leaf chlorophyll content (SPAD-502, Konica Minolta, Europe), flowering dates, and symptom monitoring. Harvest was determined when the majority of plants were senescing (18th

January 2022), which was characterised by petal shrivelling and loss, a darkened calyx, and leaf chlorosis. The sunflowers were gently removed from the pots and separated into roots, shoots and leaves, flower heads and seeds. Attached soil particles were carefully removed from the roots through water and gentle agitation and left on paper towel until the external moisture had evaporated. All sunflower components were weighed before drying at 60 °C (Unitherm Drier, Birmingham & Blackburn Construction Co. LTD. England) until constant weight and the dry weight was obtained. The number of seeds from each pot were counted and separated by colour where appropriate into mostly black (mature) and mostly white (immature) seeds.

The dried sunflower seeds of the control, 8% and 10% SUW treatments were ground (< 1 mm) using a Mixer Mill MM 200 (Retsch, Haan, Germany) at an oscillation frequency of 25 Hz for 2 minutes and the total lipid content was determined gravimetrically using a modification of the Bligh and Dyer (1959) method.

The above-ground vegetative mass of the sunflowers (excluding sunflower heads and seeds) were sent for plant tissue analysis (Agvita Analytical, Devonport, Tasmania) and a subsample from the remaining soil in each pot were sent for soil physiochemical analysis (Agvita Analytical, Devonport, Tasmania).

All data were analysed using IBM SPSS Statistics V27. The data were subjected to normality tests prior to analysis using Product and Rate as fixed variables. Data that did not meet normality assumptions were examined through non-parametric independent sample tests, where Kruskal-wallis was used to determine significant differences among sample means at $\alpha = 0.05$. Analysis of variance (ANOVA) was used to test for significant differences between treatments with normal distribution, and Tukey's post-hoc test was used to determine significant differences among sample means at $\alpha = 0.05$. Due to the nature of the data, product x rate interactions were unable to be statistically observed.

4.2.2 Green bean pot trial

The aim of the green bean pot trial was to explore the liming ability of the SUW, as this was arguably the most significant result gathered from the sunflower pot trial. In general, liming mixtures with finer particle sizes are more effective at ameliorating soil acidity, as the finer particles have a larger surface area to react with the acid in the soil. The impact of SUW particle size in a sandy loam (SL) soil (pH adjusted to 5.8) and a clay loam (CL) soil (pH adjusted to 5.4) was examined to assess the SUW's liming potential in alignment with commercial liming products. The trial was also set up to observe any potential salinity effects that may have been missed in the sunflower trial due to the free-draining nature of the potting mix by reducing salt loss from the system and using a salt-sensitive crop.

The results from the particle size analysis and the calcium content of the SUW were used to determine the effective neutralising value (ENV) of the SUW product at three particle size groupings: < 710 µm > 250 µm (T1), < 250 µm > 63 µm (T2), and < 63 µm (T3). The SUW treatments (T1, T2, T3) were created by sifting the 48 hr SUW product into the appropriate size categories. The ENV was used to determine the predicted rate of SUW required across each treatment to raise the soil pH by 1.0 unit, equal to a target pH of 6.8 in the SL and 6.4 in the CL, compared to a conventional liming product (Dolomite; DL) applied at a rate to also raise the soil pH by 1.0 unit, and a non-treated control (C) (Table 1). Dolomite was chosen as the control liming product due to its widespread use, affordability, and overall effectiveness.

Table 1. Rate of Sea Urchin waste product (T1, T2, T3), conventional liming product (DL), and non-treated control (C) applied to green bean (*Phaseolus vulgaris* L., 'Dwarf Snap Bean') pots filled with a sandy loam or clay loam soil

Treatments	**Particle size (µm)**	**ENV (%)**	**Rate (Sandy loam)**			**Rate (Clay loam)**		
			t ha^{-1}	**g pot^{-1}**	**% pot^{-1}**	**t ha^{-1}**	**g pot^{-1}**	**% pot^{-1}**
T1	250–710	69.96	5.72	10.72	0.54	12.86	20.10	1.01
T2	63–249	80.45	4.97	9.32	0.47	11.19	17.48	0.87
T3	0–62	85.26	4.69	8.80	0.44	10.56	16.49	0.82
DL	-	98	4.08	7.65	0.38	9.18	14.35	0.72
C	-	0	0	-	-	0	-	-

The established treatment rates were mixed into the soil of 24 x sandy loam and 24 x clay loam filled pots, with five replicates of the liming treatments and four of the control administered across each soil type, for a total of 48 treatment pots (3 L capacity). Three green bean (*Phaseolus vulgaris* L., 'Dwarf Snap Bean') seeds were sown directly into the soil, and emergence was monitored. After 10 days, the seedlings were thinned to one per pot. Stakes were inserted into the pots to train the bean plant upwards.

All treatments received fertiliser (standard Hoagland solution) twice weekly through hand-watering. To observe potential salinity effects, water was restricted to the Hoagland addition with only small weekly top-ups for a total water addition of 2.05 L pot^{-1} over the entire trial period. Any water that drained through the pots into the pot lids was reapplied at the soil surface to reduce salt loss.

Weekly measurements of treatment pots included plant height (cm), shoot width (mm), leaf chlorophyll content (SPAD-502, Konica Minolta, Europe), node counts, and observing any visual symptoms. The plants were subject to thrips 4 weeks post-sowing and were sprayed with Rogor® insecticide to prevent further plant damage.

The plants were harvested after approximately 10 weeks. At harvest, measurements included plant height (cm), shoot width (mm), leaf chlorophyll content (SPAD-502, Konica Minolta, Europe), node counts, biomass for above-ground (stem and leaves) and below-ground (root) growth. Yield analysis was conducted by measuring the wet and dry weights of the pods (total weight), pods (no beans), beans, and counting the number of pods per plant and the total number of beans per plant.

Soil pH and EC (TPS WP-81, Queensland, Australia) were measured throughout the trial using the 1:5 method (Rayment & Lyons, 2011), at one-week post-mixing (Week 2), five weeks post-sowing (Week 5), and at harvest (Week 10).

All data were analysed using IBM SPSS Statistics V27. The data were subjected to normality tests prior to analysis. Analysis of variance (ANOVA) was used to test for significant differences of the dependent variables due to the fixed effects of soil type and the liming product treatments. The data was split by soil type as no significant interactions between soil type and liming product were observed across the measured variables, yet significant soil type effects were. Tukey's post-hoc test was used to determine significant differences among sample means at $\alpha = 0.05$.

4.3 Field trials

4.3.1 Vineyard trial

The trial was set up at a commercial vineyard (Two Bud Spur vineyard, Gardners Bay, Tasmania) on vines that had experienced stunting and poor shoot growth and yields in the last few years due to suggested soil acidity issues (Fig 6).

Figure 6. Two Buds Spur vineyard (Gardners Bay, Tasmania), a) aerial view of vineyard (Google Maps), b) in-field photo of vineyard

Preliminary measurements of several soil samples collected in September 2021 at 5–10 cm, 15–20 cm, and 35–40 cm depths from two rows running downslope verified an acidic soil (pH <5.5) and thus the experimental site was selected for a liming trial. The aim of the trial was to build on the knowledge gained from the green bean pot trial, by assessing how coarse SUW (14 hr processing time) and fine SUW (48 hr processing time) impacted soil pH over time, and its relative impact on other soil physiochemical parameters, vine health and vine productivity, compared to a conventional liming product (Ozcal) and a non-treated control. In this trial, Ozcal was used as the conventional (control) liming product to reflect what the grower typically applies.

The trial was established across two grapevine (*Vitis vinifera* L.) varieties, Chardonnay (CHA) and Sauvignon Blanc (SB). At the time of project commencement, the vines were 26 years old, on their own rootstock, with an NNW row orientation. The CHA vines were vertically shoot-positioned and unilaterally cane-pruned, had a vine spacing of 1.1 m and a row spacing of 2.5 m, and were comprised of 8127 and 8129 clones. The SB vines were vertically shoot-positioned and bilaterally cane-pruned, had a vine spacing of 1.4 m, row spacing of 2.5 m, with 2413 and 2414 clones. The soil was characterised as a heavy clay.

The trial was set up as a randomised block design across both varieties. Three replicates of the four treatments (Coarse SUW, Fine SUW, Ozcal, Control) were randomly designated across three blocks, which were used to reduce the variability in the downward slope of the site, where the gradient goes from block 3 (top of the hill) to block 1 (bottom of the hill) (Fig 7).

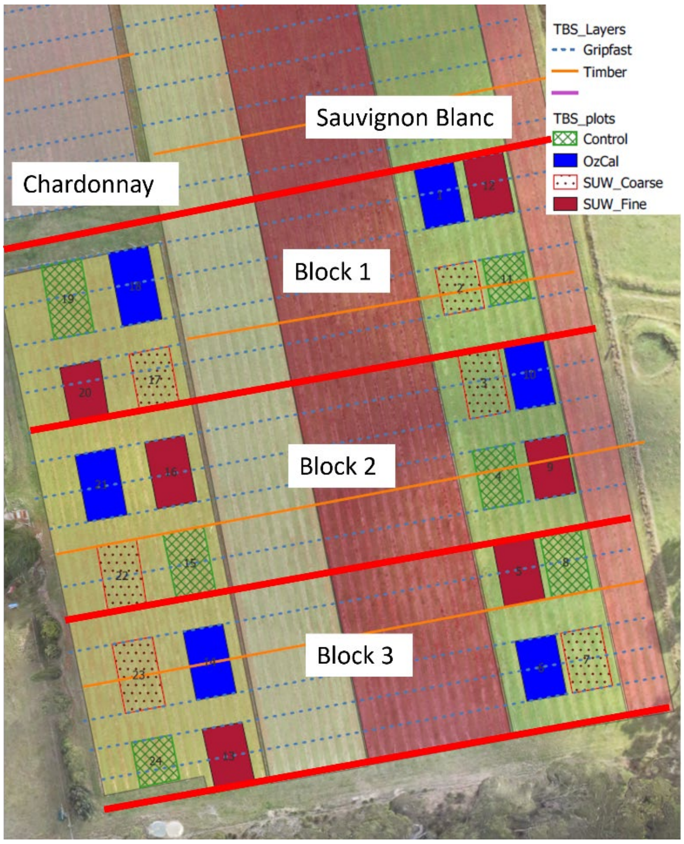

Figure 7. Vineyard trial experimental design at Two Buds Spur vineyard (Gardners Bay, Tasmania)

The experimental replicate plots were two rows in width, and two row panels in length, encompassing a total of approximately 24 vines. Replicate blocks were separated by a buffer panel. For each row panel within a replicate plot, a monitor vine was randomly selected (n = 4) to account for further variability and to take measurements from, where the results were averaged to generate one measurement value per replicate plot (n = 3).

Pre-treatment soil tests were undertaken on the 28th September 2021 by taking a soil core at 10 cm depth from each row panel at random within a treatment replicate plot, before the samples were pooled to create one sample per replicate (n = 24). The soil samples were sent for physiochemical analysis (Agvita Analytical, Devonport, Australia) to obtain baseline measurements.

Treatments were applied directly to the soil surface on the 1st December 2021. The application rates for each treatment were determined by the rate needed to reach a desirable pH (6.5–7) based on each product's ENV and the average soil pH obtained from the pre-treatment soil testing (Table 2). Despite the acidity indicated in preliminary soil tests, the correction required was only for a 0.5 pH increase.

Table 2. Rate (t ha^{-1}, kg $plot^{-1}$) of treatments (SUW coarse, SUW fine, Ozcal, Control) applied based on calculations to increase the soil pH by 0.5 units at Two Buds Spur vineyard (Gardners Bay, Tasmania) across *Vitis vinifera* L. var. Chardonnay and var. Sauvignon Blanc treatment blocks

Treatment	Rate (t ha^{-1})	Rate (kg replicate $plot^{-1}$)
SUW Coarse (14 hr)	20	120
SUW Fine (48 hr)	10	60
Ozcal	5	30
Control	0	0

Soil testing

The soil pH and other physiochemical parameters were monitored using the same process as with the pre-treatment measurements in April 2022 (veraison), January 2023 (post-flowering) and August 2023 (dormancy).

Leaf nutrient analysis

At veraison (E-L 35) in the 2021/22 and 2022/23 growing seasons, 30 leaves were randomly collected across each replicate plot and sent for tissue analysis (Agvita Analytical, Devonport, Tasmania) to assess vine nutrient status.

Yield analysis

Grapes were hand-harvested in each growing season at target commercial ripeness. Before picking, the total number of bunches and shoots on each tagged monitor vine were counted, and five bunches per monitor vine were harvested for each replicate plot, kept cool, and frozen later that day for analysis.

Four random bunches from each replicate plot were sampled to obtain bunch weight (g), bunch density (OIV, 2009), the number of berries per bunch (g), and berry weight (g). The data obtained in the 2021/22 growing season was used for background information only, as the vines had not been pruned to a consistent bud number during dormancy (June 2021, preceding trial set-up), confounding potential treatment effects.

Grape analysis

At harvest 2023, a 20 g sample of berries from each treatment replicate was collected for mineral nutrient analysis (B, Ca, Fe, Mg, P, K, Na, S, Zn, Cu, Mn, Mo) and sent to Analytical Services Tasmania (New Town, Tasmania) for measurement using ICP-AES.

Juice analysis

At harvest 2023, the remaining bunches were basket-pressed (1.3 L, Ferrari) to extract 100 mL of juice, which was collected and frozen for chemical analysis (total soluble solids (TSS), pH, titratable acidity (TA)).

The juice samples were defrosted before analysis, and centrifuged (Hettich Universal 320R, Tuttlingen, Germany) at 4000 rpm for 10 min to clarify. TSS was measured using a hand-held digital refractometer (Pocket Refractometer Pal-1, Atago, Tokyo, Japan) and pH and TA were measured using an auto-titrator (Mettler Toledo G20 Compact Titrator, Greifensee, Switzerland) where the TA results were measured in g L^{-1} of malic acid and converted to g L^{-1} of tartaric acid using a conversion factor of 1.12.

Vine vigour

During dormancy in 2022, the CHA vines were hand cane-pruned to 10 buds, with two 2-bud spurs, and the SB vines were hand cane-pruned to 20 buds, with two 2-bud spurs to allow for uniformity amongst treatments within varieties. In dormancy 2023, the prunings from each monitor vine were weighed using a set of digital hanging scales (model WS603, Wedderburn).

Statistical analysis

All data were analysed using IBM SPSS Statistics V27. The data were subjected to normality tests prior to analysis. Analysis of variance (ANOVA) was used to test for significant differences of the dependent variables due to the fixed effects of the treatments and random block effects. Tukey's post-hoc test was used to determine significant differences among sample means at $\alpha = 0.05$.

4.3.3 Apple orchard trial

A newly established block in a commercial organic apple orchard (R&R Smith, Ranelagh, Tasmania) was utilised as a trial site to examine the fertiliser impact of SUW on young apple trees. As a new block, the soil was considered to be relatively low in nutrients, with the young trees requiring a high demand of nutrients due to active growth (Fig 8). The soil was characterised as a sandy loam. Treatments were hand- applied to the tree line on the 8th November 2022.

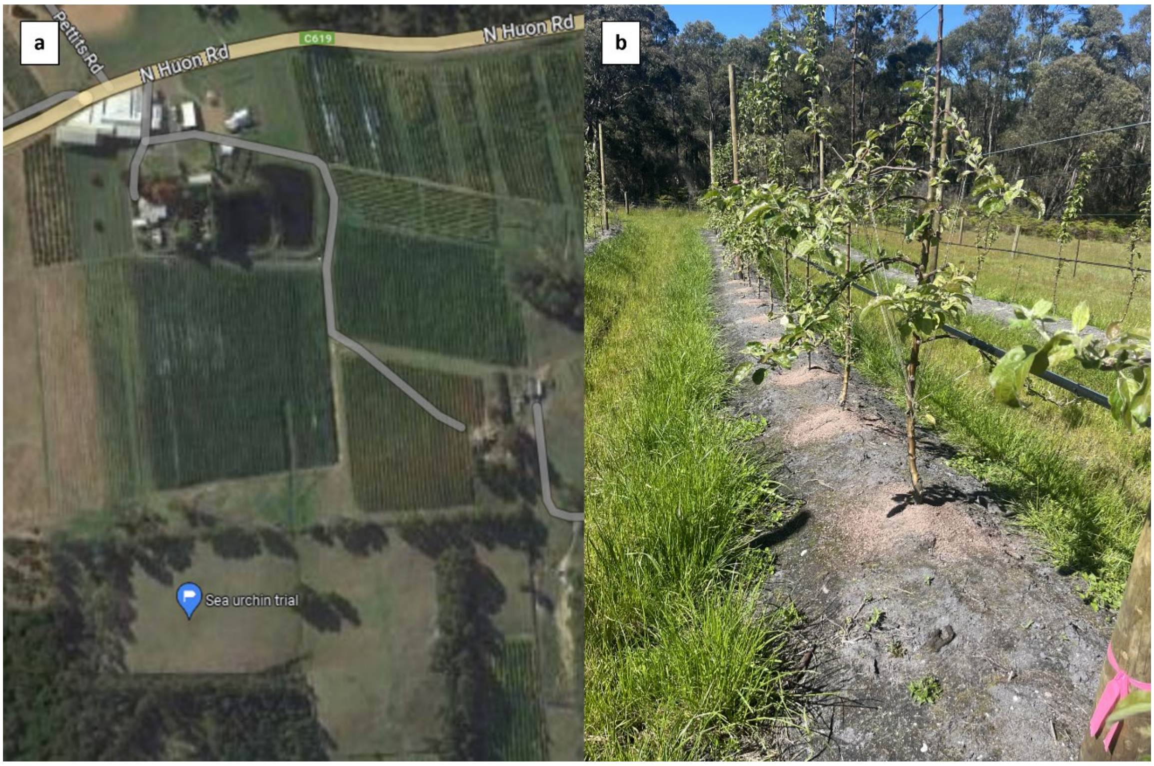

Figure 8. Apple orchard field trial site (Ranelagh, Tasmania), a) aerial image of apple orchard with marked location of trial block (Google Maps; satellite image taken previous to planting), and b) in-field photo of trial block with SUW applied on tree line

The trial was set up across two apple cider varieties, Yarlington Mill (YM) and Kingston Black (KB). Both varieties were grown on M111 rootstock, with a north-south row orientation with 3.5 m row spacing and 1.2 m tree spacing. The YM site consisted of four rows set up in a randomised block design, with four blocks designated down the length of the rows, separated by buffer regions. Four treatments were randomly allocated to treatment plots within a block, resulting in a total of four treatment replicates. Each treatment plot consisted of 16–18 trees, in which three trees were randomly selected as monitor trees from which to obtain measurements. These measurements were then averaged to obtain one measurement per replicate block (n = 4). The treatments applied were a low (4 t ha^{-1}), medium (8 t ha^{-1}), and high (12 t ha^{-1}) SUW rate and a control plot (0 t ha^{-1}) (Fig 9a).

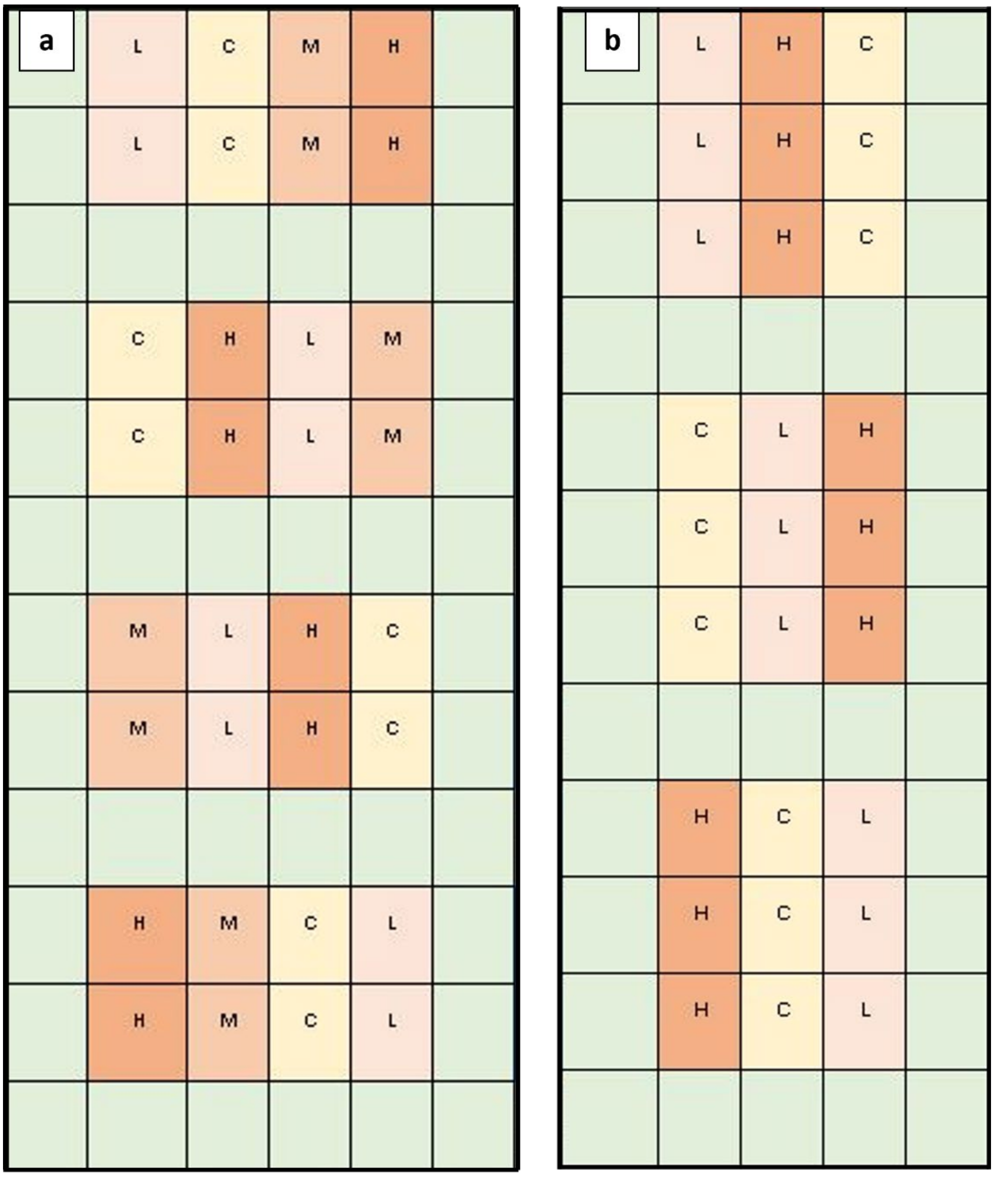

Figure 9. Experimental design of a) Yarlington Mill and b) Kingston Black trial sites at R&R Smith apple orchard (Ranelagh, Tasmania). C = control, L = low SUW rate, M = medium SUW rate, H = high SUW rate.

The KB site had fewer rows which were shorter than the YM site, and therefore was limited to three treatments, low SUW (4 t ha^{-1}), high SUW (12 t ha^{-1}) and control plot (0 t ha^{-1}), set up in a randomised block design, with three blocks organised down the length of each row, separated by buffer regions. The three treatments were randomly allocated to treatment plots within a block, resulting in a total of three treatment replicates. Each treatment plot contained 24–27 trees, and three trees were randomly selected as monitor trees to obtain measurements from (Fig 9b).

Soil analysis

Prior to treatment application, soil tests were undertaken by collecting five soil cores at 10 cm depth within a treatment replicate plot, before the samples were pooled to create one sample per replicate (YM n = 16; KB n = 9). The soil samples were sent for physiochemical analysis (CSBP Soil and Plant Analysis Laboratory, Bibra Lake, WA) to obtain baseline measurements.

Approximately 10 months post-treatment application, this procedure was repeated to collect soil samples before they were sent for physiochemical analysis (Agvita Analytical, Devonport, Tasmania).

Plant tissue analysis

In February 2023, 30 leaves were randomly collected across each replicate plot and sent for tissue analysis to assess tree nutrient status (Agvita Analytical, Devonport, Tasmania).

Tree vigour

The trunk diameter of the monitor trees were measured at treatment application (November 2022) and at tree dormancy (August 2023) using a digital calliper at 30cm above ground level.

Statistical analysis

All data were analysed using IBM SPSS Statistics V27. The data were subjected to normality tests prior to analysis. Analysis of variance (ANOVA) was used to test for significant differences of the dependent variables due to the fixed effects of the treatments and random block effects. Tukey's post-hoc test was used to determine significant differences among sample means at $\alpha = 0.05$.

4.3.4 Potato trial

The Tasmanian vegetable research facility (Forth, Tasmania) was utilised for the annual cropping trial to determine the impact of SUW rate in a continuous cropping scenario. This trial differed from the other field trials in that the farm was an intensive production system relative to that of the perennial crop field trials, where several crops are typically grown on the same parcel of land within a year. The soil type was characterised as a Ferrosol (Fig 10).

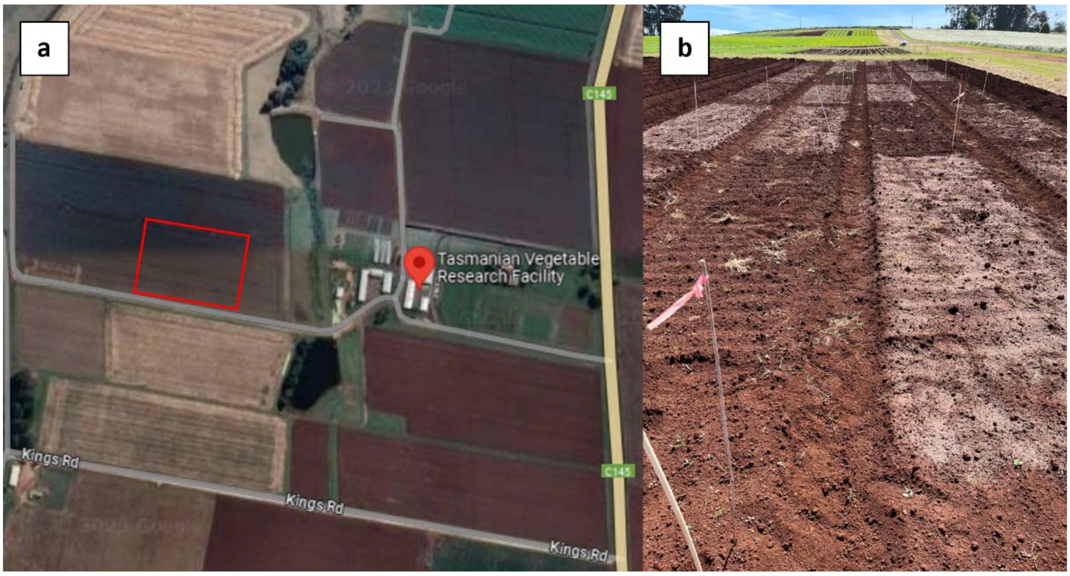

Figure 10. Tasmanian vegetable research facility (Forth, Tasmania), a) aerial photo with trial site highlighted in red box, b) in-field photo of trial site

The experiment was set up across four vegetable beds. Four treatments were randomly designated across 24 replicate plots (10 m^2) for a total of six treatment replicates. The treatments included a low (4 t ha^{-1}), medium (8 t ha^{-1}), and high (12 t ha^{-1}) SUW rate and a control plot (0 t ha^{-1}).

Wet spring conditions resulted in a 3-month delay in planting due to the inability of machinery to get on to the field. As conditions improved and the soil dried out sufficiently to allow for cultivation, potatoes were chosen as the vegetable crop of choice to fit in with the planting date and experimental timeframe.

Pre-treatment soil sampling, treatment application, and potato seed sowing commenced on the 2nd December 2022. Soil samples were obtained by collecting five soil cores at 30 cm depth from each replicate plot, which were then pooled to create one sample per replicate plot before sending off for analysis (Agvita Analytical, Devonport, Tasmania). The same soil sampling procedure was repeated at harvest.

Harvest was determined by the farm manager and considered tuber maturity and weather conditions. Potatoes were harvested on May 5th 2023. Yield analysis involved sampling 10 plants per replicate plot. The total number of tubers and total tuber weight were recorded, before the tubers were separated into three size categories (<50 g, 50–400 g, > 400 g), in which the number of tubers and total tuber weight were also recorded across the respective size categories. The number of waste tubers and total waste weight was recorded, where waste was considered tubers that were unacceptable for commercial sale, largely due to pest damage or greenness. Hollow heart and brown spot were measured by cutting 5 tubers at random in the 50–400 g size category for each treatment replicate.

Statistical analysis

All data were analysed using IBM SPSS Statistics V27. The data were subjected to normality tests prior to analysis. Analysis of variance (ANOVA) was used to test for significant differences of the dependent variables due to the fixed effects of the treatments. Tukey's post-hoc test was used to determine significant differences among sample means at $\alpha = 0.05$.

5. Undertake a cost benefit analysis comparing fertiliser products (foliar sprays and/or soil conditioners) from this work to other products on the market to assess if the products are commercially viable

A net present value (NPV) analysis was performed in consultation with True South Seafoods and an external economic consultant. After communication between both parties, a cost-benefit analysis was deemed unnecessary as with current waste disposal costs, any conversion of the waste on-site using the processing facility available would be economically profitable, regardless of whether the product was sold. For example, the product could be given away at no cost and the company would still be more profitable than if the waste was being disposed of through the methods previously employed.

True South Seafoods considered three projects for the production of the SUW-based agricultural product. Project 1 involved no capital investment due to already securing the waste processor, but incurred an annual production cost and provided an annual revenue of $78,975 and $131,625, respectively, from Year 1 to Year 5. Project 2 was characterised by a one-off capital investment of $50,000 for facility modifications in Year 0, incurred no annual production cost, and returned an annual revenue of $131,625 from Year 1 to Year 5. In Project 3, a one-off capital investment of $100,000 for facility modifications in Year 0 was followed by an annual revenue of $105,300 from Year 1 to Year 5, with no production cost incurred in any year after the initial capital investment.

The NPV of the three alternative projects were computed in order to identify the most profitable one to implement. The aggregate present values (APV) of the future costs and revenues of each project were computed using the following formula,

$$\text{Aggregate Present Value (APV)} = \sum_{t=0}^{5} \frac{X_t}{(1+r)^t}$$

where X_t represents the cost or revenue at time t and r the discount rate to be applied to the future values of the cost or revenue to convert it to the present value. For each period, the cost was the sum of the capital investment, if made, and the annual production cost, if incurred. Regarding r, True South Seafoods determined its value to be 10 %. Once the APVs of both the costs and revenues were computed, the NPV of the project was computed as follows:

NPV = APV of revenues – APV of costs

Post NPV computation, the project with the highest NPV was deemed most successful for implementation.

Results

1. To develop commercial scale processing equipment of sea urchin waste

The processing facility was adequate for the processing of the SUW once modified, yet several further modifications could be made to further improve operation and safety, particularly to reduce the amount of labour required to run the facility. This includes the potential to separate the facility into two isolated components on site, where the grinding mechanism is moved closer to the factory so that the SUW can be fed directly to the machine via a conveyor belt to reduce excess handling. The paddles inside the chamber could also be made longer to ensure that all the SUW is removed from the facility, as labour was required at the final emptying stages to retrieve the remaining product and to clean out the chamber sufficiently (Fig 11).

Figure 11. Sea Urchin waste from initial trial run fed out of the processor's chamber by the paddles and into a storage tub

The main barriers to continual use of the processing facility as operated by True South Seafoods are the labour requirements and the management of the final product.

2. Determine the nutrient composition and plant bioavailability of nutrients from two high throughput waste streams: liquid gut waste and dried powdered shell waste

Liquid product

The physiochemical properties of the liquid SUW products are shown in Table 3. The raw SUW provided a baseline product physiochemical composition and the sterilised SUW results reflect the requirement for product sterilisation for use in an agricultural setting. Note that the sterilisation method used in this instance would be difficult to do on a large-scale and would take significant investment but was used for initial comparative purposes.

Table 3. Physiochemical properties of liquid Sea Urchin waste (SUW) products (raw, sterilised, raw diluted (predicted), fermented, gunk) and comparative commercial marine agricultural products

Physiochemical property		Raw SUW	Sterilised SUW	Raw SUW diluted 1:5 (predicted)	Raw fermented SUW	Gunk SUW	Competitive product A[1]	Competitive product B[1]
N	%	0.373	0.265	0.075	0.071	0.565	0.100	0.040
P	%	0.024	0.046	0.005	0.003	0.127	0.010	0.002
K	%	0.214	0.279	0.043	0.021	0.135	1.500	0.700
S	%	0.247	0.233	0.049	0.029	0.229	0.100	0.029
Ca	%	0.066	0.055	0.013	0.510	10.2	0.043	0.021
Mg	%	0.125	0.122	0.025	0.031	0.553	0.034	0.008
Na	%	0.920	0.960	0.184	0.124	0.584	0.320	0.110
Fe	ppm	8.97	10.5	1.794	47.90	307	65	220
Mn	ppm	0.135	76.7	0.027	0.078	5.53	3	2
Zn	ppm	2.62	50	0.524	1.05	19.3	7	8
Cu	ppm	0.755	9.19	0.151	0.535	2.15	1	1.5
Co	ppm	0.015	0.585	0.003	<0.001	0.095	<0.5	0.5
B	ppm	7.66	14.4	1.532	1.67	22.2	8	2
Mo	ppm	0.215	0.975	0.043	0.023	0.200	<0.5	<0.5
pH		6.07	7.02	4	3.96	7	10.5 – 11.4	10.5 – 11.4
EC	dS m[1]	18.7	18.9	3.74	10.90	25.7		
OC	%	1.47	0.952	0.294	3.11	5.94		

[1] Data obtained from product analysis via competitor product websites

The nitrogen (N) concentration of the raw SUW (0.37%) was lower than predicted, yet it was 0.27% higher than the comparative liquid marine products. The sterilised SUW was 0.12% lower in N than the raw SUW, but higher in the concentration of other nutrients compared to the raw SUW, including manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), boron (B) and molybdenum (Mo). Both the raw and the sterilised SUW had a high electrical conductivity (EC; 18.7–18.9 dS m^{-1}), signifying a high salt content, which indicated poor suitability as a direct spray to buds and foliage as initially intended.

Diluting the raw SUW product to reduce the salt content and associated EC, and sterilising the product through fermentation was explored as an alternative, with predicted diluted nutrient levels calculated in the raw SUW diluted 1:5 (predicted) column. The physiochemical nature of the raw fermented product was similar to that of the predicted values in most cases, apart from the iron (Fe) content, which was higher in the raw fermented SUW (47.9 ppm) than in the predicted SUW (1.79 ppm) and raw SUW (8.97 ppm) concentrations. The salt content of the raw fermented SUW (10.9 dS m^{-1}) was also higher than the raw SUW diluted 1:5 predicted value (3.74 dS m^{-1}). A pH of <4 was achieved for the raw fermented SUW product, which was 2.11 pH units lower than the raw SUW product and 3.06 pH units lower than the sterilised SUW. The raw fermented SUW met the heavy metal (Cd, Hg, Pb, As, Ni, Cr) and microbiological requirements (salmonella, faecal coliforms) of the AS 4454-2003 (data not shown).

The physiochemical properties of the gunk SUW were measured as a potentially higher source of nutrients, which could be diluted with water further to lower the EC and still retain a sufficient nutrient concentration to be considered a fertiliser. The gunk SUW had the highest N content (0.57 %) of all SUW products tested, and a higher concentration of all nutrients compared to the raw SUW apart from potassium (K), sodium (Na) and Mo. The gunk SUW also had the highest salt content (25.7 dS m^{-1}). The gunk SUW met AS 4454-2003 heavy metal and microbiological standards.

Solid product

Physiochemical analysis

The physiochemical properties of solid SUW products were relatively similar across Product Trial 1 (original processing) and Product Trial 2 (modified processing) (Table 4).

Table 4. Physiochemical properties of solid sea urchin waste (SUW) products from Product Trial 1 (48 hr, 96 hr), Product Trial 2 (14 hr, 24 hr, 48 hr), and comparison products (Product 1 and 2)

		Product trial 1		Product trial 2			Competitor products[1]	
Physiochemical property		**48 hrs**	**96 hrs**	**14 hrs**	**24 hrs**	**48 hrs**	**Product 1**	**Product 2**
N	%	0.99	0.94	1.00	0.99	0.83	1.50	0.66
P	%	0.06	0.05	0.05	0.05	0.04	0.20	0.38
K	%	0.35	0.33	0.28	0.30	0.26	1.40	0.19
S	%	0.51	0.48	0.46	0.46	0.42	0.04	0.14
Ca	%	32.23	32.45	33.50	33.20	33.60	0.04	2.63
Mg	%	1.43	1.48	1.47	1.45	1.42	0.00	0.48
Na	%	1.09	1.00	1.05	1.05	0.93	0.11	0.19
Fe	ppm	768.00	686.25	215.00	236.00	293.00	60.00	11000.00
Mn	ppm	6.63	6.25	2.36	2.83	2.76	1.00	200.00
Zn	ppm	10.00	9.59	28.20	10.40	10.10	2.00	100.00
Cu	ppm	2.35	2.23	1.75	1.91	2.82	<0.5	LOW
Co	ppm	0.26	0.30	0.08	0.09	0.07	<0.5	LOW
B	ppm	42.37	46.98	38.90	39.50	36.80	2.00	100.00
Mo	ppm	1.03	1.34	0.18	0.20	0.16	<0.5	Trace
pH		8.01	8.23	7.94	7.86	7.99	10.5 – 11.4	7.11
EC	dS m^{-1}	5.85	5.31	5.27	5.16	5.29		
OC	%	8.85	8.53	9.97	11.10	13.40		
Moisture content	%	13.90	0.24	9.46	3.16	2.69		

[1] Data obtained from product analysis listed in respective competitor product websites

The iron (Fe), Mn and cobalt (Co) concentrations from Product Trial 1 were higher than in Product Trial 2, whereas the remaining nutrient concentrations were similar or less than those measured in Product Trial 2.

Within the product trials, the moisture content was consistently lower with increased processing time. The 48 hr processing time in Product Trial 2 generated a product with a lower N concentration (0.83%) than that of the products generated from 14 hr (1.00%) and 24 hr (0.99%) processing times. Fe and Organic Carbon (OC) concentrations were higher with increased processing time, whereas other nutrients remained similar. Zinc (Zn) was higher in the 14 hr product compared to the 24 and 48 hr products.

In comparison to competitor product 1, the SUW products were generally lower in N, P and K, but higher in all other tested nutrients, with a lower pH. Compared to competitor product 2, the SUW products were higher in N, K, S, Ca, Mg, Na and lower in P, Fe, Mn, Zn, with a higher pH.

Particle size analysis

An increase in processing time from 14, 24 and 48 hours resulted in progressively smaller particle sizes within the SUW products as observed by particle size distribution curves (Fig. 12 a,b,c)

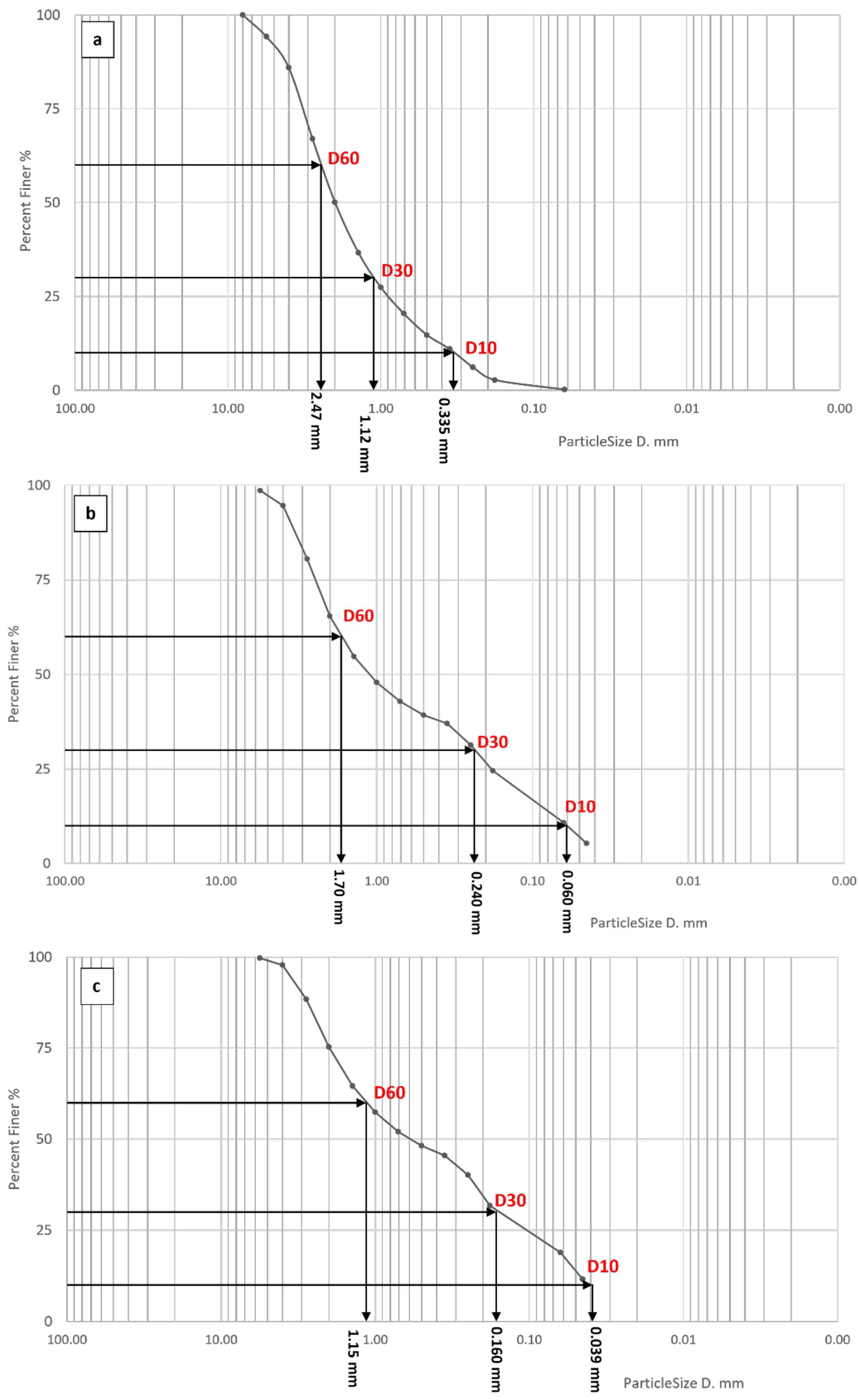

Figure 12. Particle size distribution curves of the Sea Urchin waste product after a) 48 hours, b) 24 hours, and c) 14 hours. D60, D30 and D10 represent the fineness of particles (mm) at 60 %, 30 % and 10 % of the product's weight.

3. **Evaluate the agronomic benefits of liquid gut waste as a frost retardant in perennial tree cropping (cherries)**

This project objective was contingent on the liquid waste being a suitable product for agronomic means. As established in objective 2 (see discussion), this was not the case, and therefore no further experimentation of the liquid waste was undertaken. This project objective was thus discontinued.

4. **Evaluate the agronomic benefits of powdered shell waste as a soil ameliorant in a wide range of annual and perennial cropping systems**

Phytotoxicity trial

There were no differences in the number of germinated seeds across the SUW extracts (0.5, 1, 3, 5, 8, 10%) and the control as illustrated by the germination rate (Fig 13a), yet differences were observed in the radicle length of the germinated seedlings (data not shown), leading to differences in the germination index, whereby there was a progressive decline in GI with increasing SUW rate (Fig 13b).

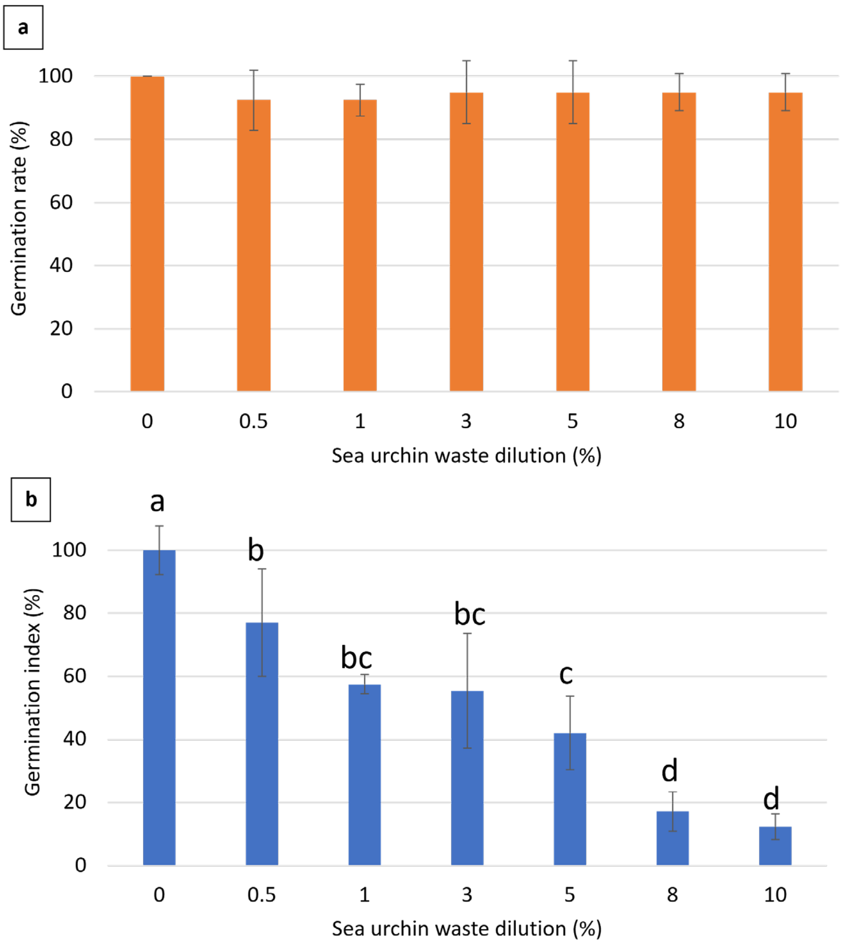

Figure 13. a) Germination rate (%), and b) Germination index (%) of radish seeds (*Raphanus sativus* L.) across different Sea Urchin waste dilutions (0, 0.5, 1, 3, 5, 8, 10 % SUW). Error bars represent ± 2 x SEM. Different letters indicate significant differences ($p < 0.05$) between treatments

Pot trials

Sunflower trial

Soil physiochemical analysis

Treatment rate had a significant effect on most of the other soil physiochemical parameters measured at harvest (Table 5).

Table 5. Mean available soil nutrient concentration (P, K, Ca, Mg, S, Na, Cl, Fe, B, Zn, Cu Mn, Al; mg kg^{-1}), cation exchange capacity (CEC; meq $100g^{-1}$), P solubility (M3-PSR), total nitrogen (TN; %), total carbon (TC; %), organic matter (OM; %), and electrical conductivity (EC; dS m^{-1}) in sunflowers (*Helianthus annuus* L., 'Dwarf Sunsation') amended with different sea urchin waste (SUW) rates (control (standard fertiliser, 0 % SUW), 1, 2, 4, 8 and 10 % SUW) and SUW products (14hr, 24hr, 48hr processing times) as measured at harvest. Different letters indicate significant differences ($p < 0.05$) between treatments.

	Nutrients (mg kg^{-1})																	
Treatment	P	K	Ca	Mg	S	Na	Cl	Fe	B	Zn	Cu	Mn	Al	CECe (meq $100g^{-1}$)	P solubility (M3-PSR)	TN (%)	TC (%)	OM (%)
SUW rate																		
1 %	11.23 ab	159.46 a	2902.12 de	315.27 c	13.24 d	70.31 de	53.15 cd	174.31 b	0.60 d	5.91 a	2.53 a	23.47 abc	118.53 b	18.33 de	0.05 c	0.28	8.03	12.37
2 %	10.10 bc	132.56 ab	3674.23 d	327.84 c	20.15 d	81.74 d	60.90 bcd	154.47 c	0.73 d	5.41 ab	2.50 a	23.23 b	80.14 c	21.73 d	0.06 c	0.38	8.18	12.60
4 %	9.53 bc	114.46 bc	5797.62 c	395.96 c	39.25 c	131.72 c	88.55 abc	122.21 d	0.94 c	4.67 b	2.17 ab	19.43 c	42.30 d	33.06 c	0.08 b	0.50	7.61	11.73
8 %	9.52 bc	81.04 cd	9207.94 b	522.11 b	61.46 b	184.43 b	98.32 ab	85.66 e	1.24 b	4.56 b	1.84 b	16.37 d	37.05 d	51.25 b	0.11 ab	0.91	7.47	11.51
10 %	9.07 c	68.74 cd	14240.91 a	745.92 a	88.64 a	272.39 a	120.95 a	79.01 e	1.69 a	4.48 b	1.48 bc	15.03 d	16.91 e	78.55 a	0.14 a	0.67	8.82	13.59
Control	12.13 a	80.11 d	1093.10 e	189.03 d	13.24 d	32.45 e	31.45 d	194.77 a	0.32 e	4.64 b	2.16 ab	15.06 d	205.92 a	10.34 e	0.03 c	0.19	6.98	10.78
SUW product																		
14 hr	11.11 a	115.42	6987.23	480.57	47.31	151.58	90.43	124.05	1.02	5.24	2.04	19.66	60.63	40.07	0.10	0.30 b	8.44	13.00
24 hr	9.40 b	108.76	7236.99	453.46	45.95	152.99	87.67	117.46	1.03	4.77	2.08	18.48	56.83	40.78	0.09	1.09 a	7.78	12.00
48 hr	9.17 b	109.57	7269.48	450.23	40.40	139.78	75.02	127.89	1.07	5.01	2.19	20.38	59.51	40.90	0.08	0.25 c	7.85	12.08

Increased SUW application rates corresponded to higher soil available Ca, Mg, S, Na, Cl, B, and CEC and PSR. Alternatively, increased SUW rates were associated with lower soil available P, K, Fe, Zn, Cu, Mn and Al. The control treatment had higher concentrations of soil available Fe and Al and lower soil available concentrations of K, Mg and B than the SUW treatments, otherwise the control was statistically similar to at least one of the SUW rates across the measured nutrients (Table 5).

Alternatively, minimal differences in the soil physiochemical properties between SUW products were observed at harvest (Table 5). Soil TN was highest in the 24 hr treatment (1.09 ± 0.38) at 3.6 x the concentration of the 14 hr (0.30 ± 0.03) and 48 hr treatments (0.25 ± 0.02). Soil P was 1.7 – 1.9 % higher in the 14 hr treatment compared to the other SUW treatments, whilst P availability was similar across the SUW products, averaging 0.09 PSR. The EC was lower with increased SUW processing time, where the 14 hr product had the highest EC (0.30 ± 0.03) and the 48 hr product had the lowest (0.25 ± 0.02).

The average baseline pH measured in the soil medium prior to experiment commencement was 6.16. As measured at one-week post-mixing (Week 2), half-way through the experiment (Week 9), and at harvest (Week 18), the mean soil pH was progressively higher with increasing SUW treatment rates (Fig 14).

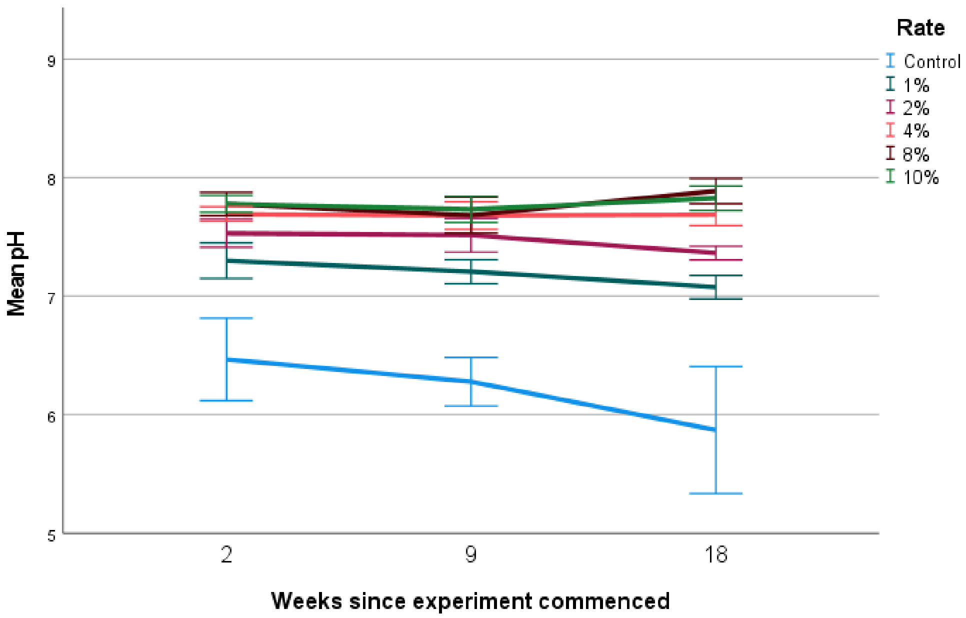

Figure 14. Mean soil pH at one-week post-mixing (Week 2), half-way through the experiment (Week 9), and at harvest (Week 18) for sunflower pots amended with different sea urchin waste (SUW) rates (control (standard fertiliser, 0% SUW), 1, 2, 4, 8 and 10% SUW). Error bars represent ± 2 x SEM.

The highest soil pH for the 1% (μ = 7.3 ± 0.14) and 2% (μ = 7.5 ± 0.11) SUW rates was observed one-week post-mixing, whereas the soil pH was higher in the 8% (μ = 7.9 ± 0.10) and 10% (μ = 7.8 ± 0.10) rates at harvest. The 4% rate had a steady pH of 7.69 throughout the trial period, whereas the control pH was highest at one-week post-mixing (μ = 6.5 ± 0.25) and continually decreased, with an average decline of 0.6 pH units between Week 2 and harvest (μ = 5.9 ± 0.36).

In Week 2 and Week 9 measurements, the SUW products (14 hr, 24 hr, 48 hr) had a higher soil pH than the control, yet no differences in soil pH were observed between the SUW product types (Fig 15). At Week 18, the lowest soil pH was observed in the control followed by the 14 hr product, which had a statistically lower pH than both the 24 and 48 hr product as a result of an average decrease in the 14 hr soil pH, and an average increase in the 24 and 48 hr product soil pH (Fig 15).

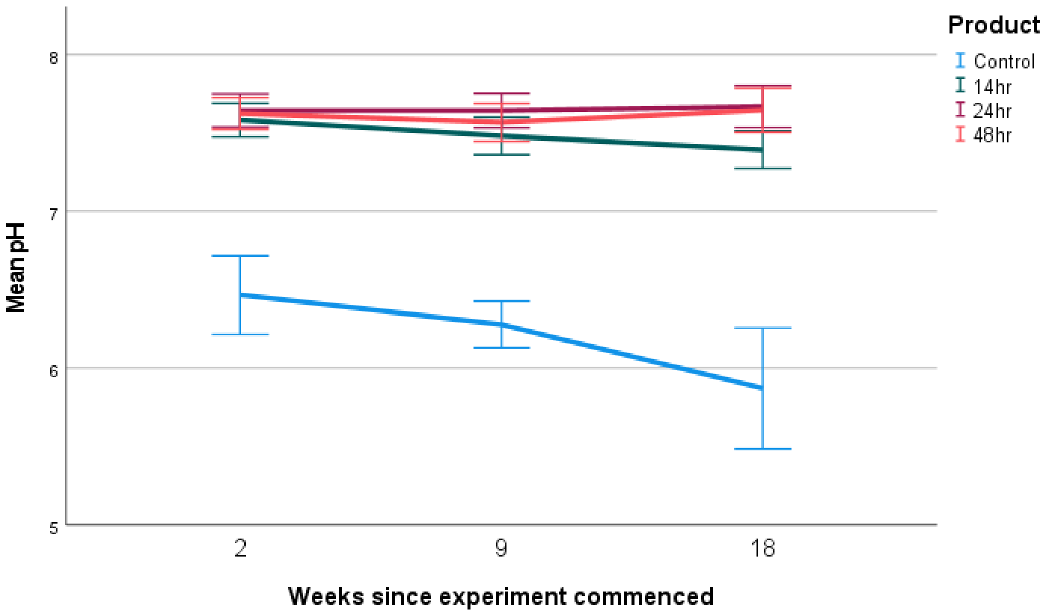

Figure 15. Mean soil pH at one-week post-mixing (Week 2), half-way through the experiment (Week 9), and at harvest (Week 18) for sunflower pots amended with different sea urchin waste (SUW) products (control (standard fertiliser) 14 hr, 24 hr and 28 hr SUW). Error bars represent ± 2 x SEM.

Soil EC values were progressively higher with increased SUW rates across the sampling periods, with a general decline in SUW EC values and an increase in control EC values observed over time (Fig 16). No differences in the soil EC between SUW product types were observed, but the EC was higher in the SUW products compared to the control group across all sampling periods (data not shown).

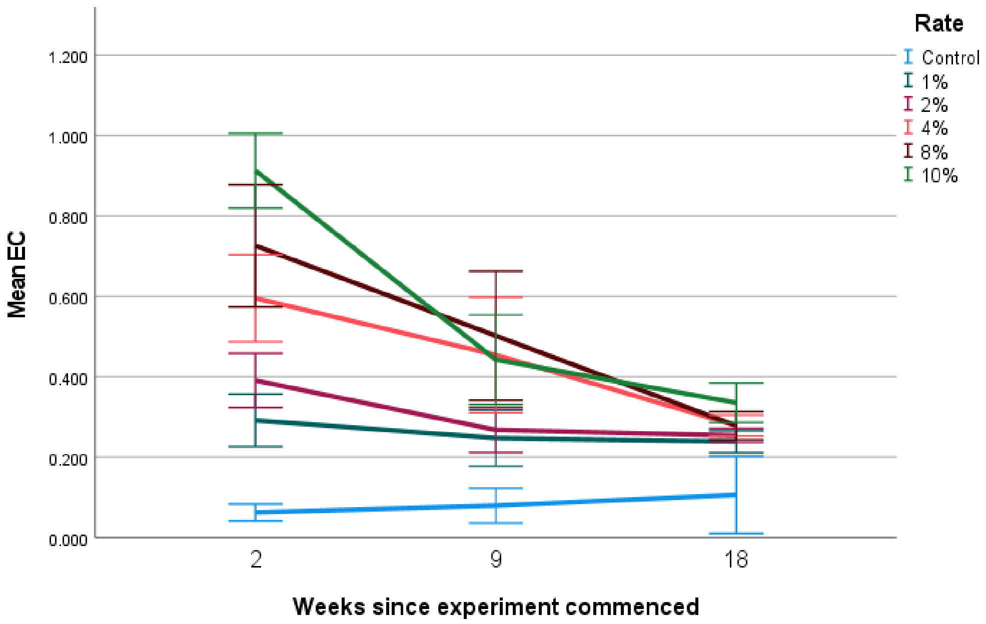

Figure 16. Mean soil EC at one-week post-mixing (Week 2), half-way through the experiment (Week 9), and at harvest (Week 18) for sunflower pots amended with different sea urchin waste (SUW) rates (control (standard fertiliser, 0% SUW), 1, 2, 4, 8 and 10% SUW). Error bars represent ± 2 x SEM.

Plant tissue analysis

The sunflower tissue nutrient concentrations, derived from the shoots and leaves, did not show similar patterns to that of available soil nutrients (Table 6).

Table 6. Mean plant tissue nutrient concentration (P, K, Ca, Mg, S, Na, Cl; %) (Fe, B, Zn, Mn, Al, N-NO3; mg kg-1) of sunflowers (Helianthus annuus L., 'Dwarf Sunsation') at harvest amended with different sea urchin waste (SUW) rates (control (standard fertiliser, 0% SUW), 1, 2, 4, 8 and 10% SUW) and SUW products (control (no SUW), 14hr, 24hr, 48hr SUW processing times). Different letters indicate significant differences ($p < 0.05$) between treatments.

	Nutrients (%)								Nutrients (mg kg^{-1})						
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Na**	**Cl**	**Fe**	**B**	**Zn**	**Cu**	**Mn**	**Al**	**N-NO_3**
SUW rate															
1%	0.35 d	0.17	2.12	2.72 b	0.55 b	0.17	0.04 a	0.31 b	105.91 a	67.39 b	63.66	5.99 a	88.63 b	73.30 a	7.73 b
2%	0.40 cd	0.18	2.18	2.71 b	0.48 bc	0.17	0.02 ab	0.33 b	84.15 ab	65.27 b	42.49	3.85 ab	48.96 c	52.10 a	7.71 b
4%	0.42 cd	0.16	2.10	2.88 b	0.43 c	0.14	0.03 a	0.51 a	62.90 bc	51.70 c	34.33	2.87 b	39.11 c	40.24 ab	5.85 b
8%	0.50 bc	0.19	2.11	3.57 a	0.53 b	0.16	0.04 a	0.58 a	53.69 c	58.29 bc	47.46	2.95 b	48.11 c	33.95 ab	7.15 b
10%	0.57 ab	0.16	2.13	3.59 a	0.55 b	0.15	0.04 a	0.58 a	49.77 c	49.64 c	38.90	2.85 b	46.02 c	27.82 b	7.39 b

Control	0.64 a	0.17	1.86	2.67 b	0.81 a	0.15	0.01 b	0.22 b	54.77 c	80.72 a	98.35	5.56 a	340.83 a	42.79 ab	55.90 a
SUW product															
14 hr	0.49	0.18	2.21	2.94	0.51	0.15	0.03	0.53	69.78	59.18	45.87	3.53	70.58	46.95	7.12
24 hr	0.45	0.18	2.15	3.17	0.52	0.16	0.04	0.48	70.40	60.28	47.93	4.20	49.48	44.23	6.48
48 hr	0.41	0.16	2.02	3.17	0.49	0.15	0.04	0.45	73.67	55.92	42.32	3.37	42.43	45.27	7.55

In general, greater SUW application rates were associated with higher N, Ca, and Cl plant tissue concentrations, and lower Fe, B, Zn, Cu, Mn and Al concentrations. The control plants had higher tissue Mg, N-NO_3, B, Zn and Mn concentrations and lower Na concentrations than all SUW-amended treatments. Tissue P, K, and S were unaffected by treatment application.

Tissue Mn tended to decrease with increased SUW processing time, where the 48 hr treatment had lower tissue Mn (42.43 ± 5.14) than the 14 hr (70.58 ± 16.86) treatment. No other differences in plant tissue nutrient concentrations were observed across the different SUW products.

Plant growth and health

A progressive increase in plant growth and health measurements (plant height, stem width, node number and leaf chlorophyll content (SPAD)) were observed with increasing SUW rates (Table 7). The 10% SUW rate often displayed an equivalent plant response to that of the control (standard fertiliser) as observed in weekly measurements throughout the experiment (data not shown) and for the majority of measurements at experiment completion. No SUW product effects were observed (data not shown).

Table 7. Mean plant growth (height, node count, shoot width), flower growth (flower diameter, calyx diameter) and health (SPAD) markers in sunflowers (Helianthus annuus L., ‘Dwarf Sunsation’) at harvest amended with different sea urchin waste (SUW) rates (control (standard fertiliser, 0 % SUW), 1, 2, 4, 8 and 10% SUW). Different letters indicate significant differences ($p < 0.05$) between treatments.

SUW rate	Plant height (cm)	Node count	Shoot width (mm)	Flower diameter (cm)	Calyx diameter (cm)	SPAD
1%	15.33 a	6.73 a	3.59 a	5.12 a	0.90 a	11.95 a
2%	16.17 a	7.47 ab	4.28 ab	6.14 a	1.29 a	14.68 ab
4%	24.87 b	9.47 bc	5.19 b	8.64 b	2.67 b	18.38 b

8%	30.57 bc	10.13 c	6.95 c	10.49 c	3.62 c	22.40 c
10%	36.10 c	12.47 d	8.86 d	13.75 d	5.08 d	26.27 d
Control	44.20 d	13.40 d	9.04 d	14.40 d	5.82 d	28.04 d

At harvest, sunflower biomass measurements were impacted by SUW treatment rates, displaying a similar stepwise increase in mass measurements with increased SUW rate across plant components (Table 8).

Table 8. Mean harvest wet and dry weights of sunflower (*Helianthus annuus* L., 'Dwarf Sunsation') components (shoot, roots, flower, seeds) and overall biomass according to different sea urchin waste (SUW) rates (control (standard fertiliser, 0% SUW), 1, 2, 4, 8 and 10% SUW). Different letters indicate significant differences ($p < 0.05$) between treatments.

SUW rate	Wet weight (g)					Dry weight (g)				
	Shoot	Roots	Flower	Seeds	Plant biomass	Shoot	Roots	Flower	Seeds	Plant biomass
1%	2.18 a	2.14 a	1.66 a	0.14 a	5.76 a	0.49 a	0.30 a	0.22 a	0.03 a	0.88 a
2%	3.28 a	3.22 ab	2.16 a	0.20 a	8.67 a	0.74 a	0.51 a	0.29 a	0.04 a	1.42 a
4%	5.66 a	5.27 ab	5.39 a	0.56 ab	15.96 ab	1.60 a	0.80 a	0.79 ab	0.22 a	3.19 a
8%	14.93 ab	15.58 bc	14.20 b	1.81 b	43.76 bc	3.98 b	2.37 ab	2.11 b	0.74 a	8.47 b
10%	24.12 b	24.89 cd	25.72 c	3.76 c	73.02 cd	6.05 bc	3.92 bc	4.35 c	1.83 b	14.32 c
Control	27.10 b	33.29 d	36.44 d	4.51 c	96.82 d	6.61 c	4.82 c	5.68 c	2.27 b	17.10 c

Similar to plant growth markers, the control treatment (standard fertiliser) displayed the highest mass across plant components, however showed no statistical difference to that of the 10% SUW mass measurements, apart from the flower wet weight. No significant differences between SUW products were observed (data not shown).

Seed oil analysis

Sunflower seed oil analysis was performed on the 8% SUW, 10% SUW, and control treatments. Overall, total seed oil content was low. No significant differences between the SUW product type (data not shown) or treatments (Fig 17) were found, however seeds from the SUW treatments, particularly at the 8% rate, tended to have a higher oil content than the unamended control.

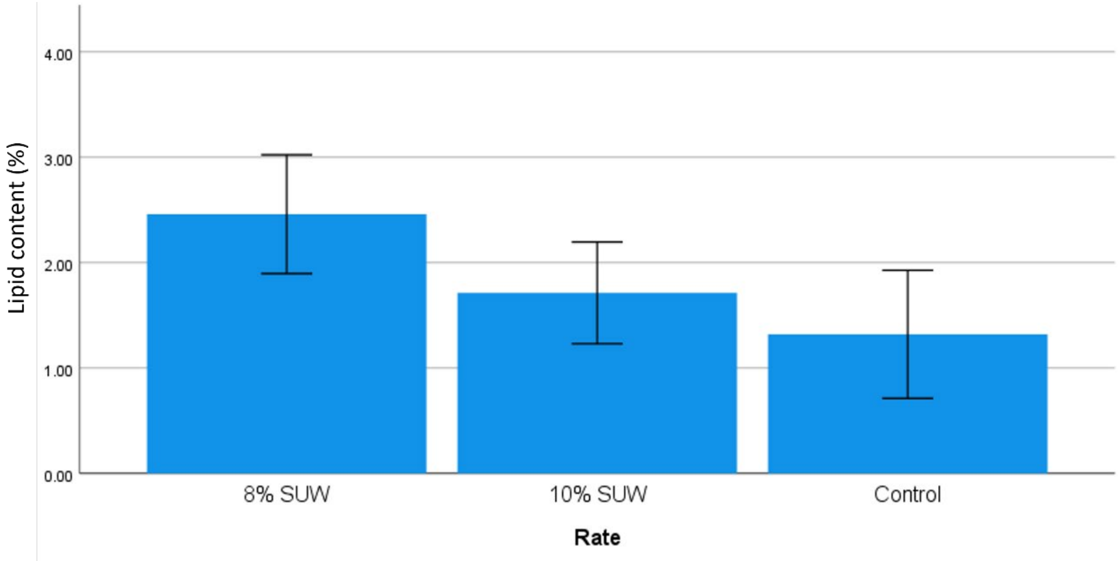

Figure 17. Lipid content (%) of sunflower seeds obtained from pots amended with 8 % and 10 % sea urchin waste (SUW) rates compared to a control (standard fertiliser, 0 % SUW). Error bars represent ± 2 x SEM.

Green bean pot trial

Soil pH and EC

The soil pH was significantly impacted by the liming treatments across all sampling dates in both soil types. In the sandy loam (SL) soil, the SUW-amended treatments (0–62 μm, 63–249 μm, 250–710 μm) had a higher mean soil pH than the unamended control and the conventional liming product (Dolomite) across all sampling periods (start (one-week post-mixing), midway, end (harvest)), in which the finer particle size SUW treatment (0–62 μm) exhibited a higher soil pH at the start ($\mu = 7.17$) and midway ($\mu = 7.46$) sampling points compared to the other treatments, with the greatest soil pH achieved midway, which was 1.92 pH units higher than the control ($\mu = 5.54$) and 0.9 pH units higher than Dolomite ($\mu = 6.56$) (Fig 18a).

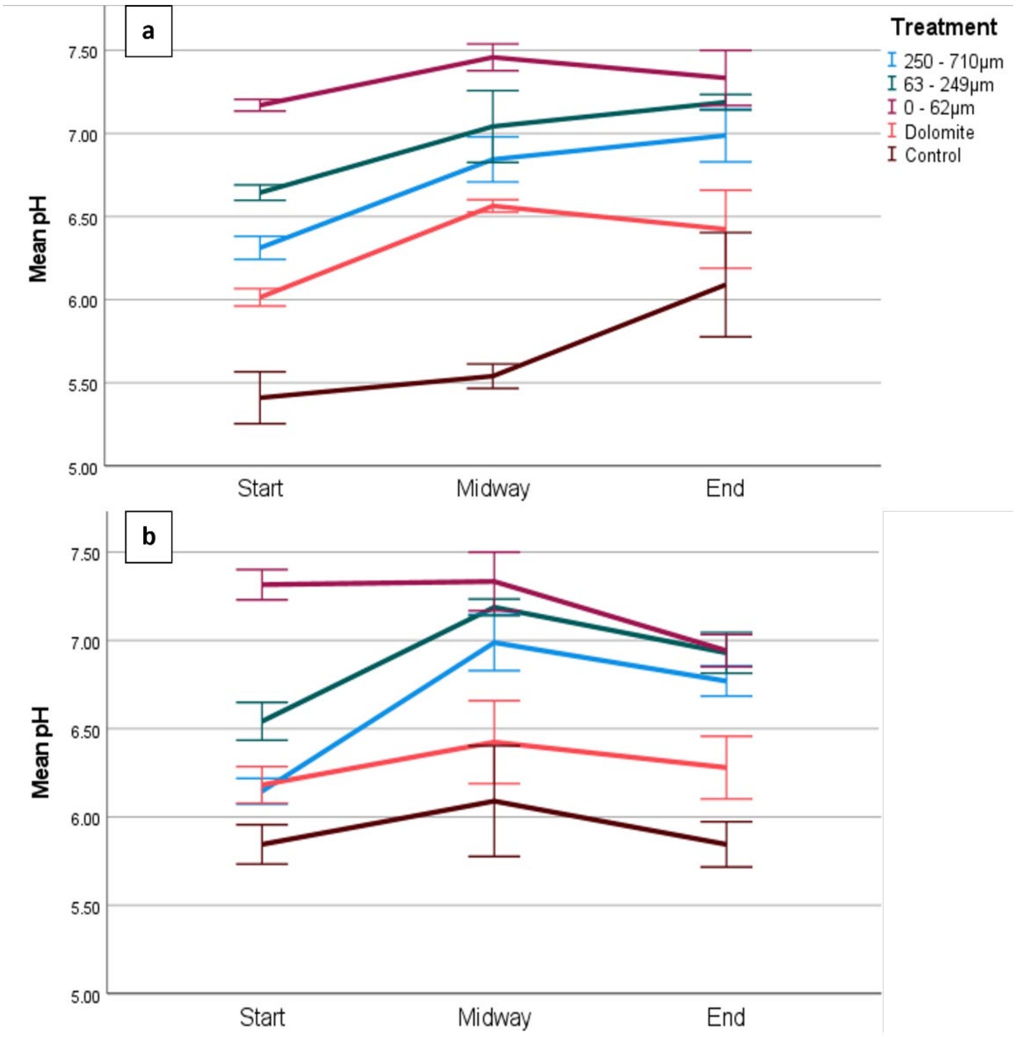

Figure 18. Mean soil pH of green bean (*Phaseolus vulgaris* L., 'Dwarf Snap Bean') pots filled with a) a sandy loam and b) clay loam soil amended with different sea urchin waste products (0 – 62 µm, 63 – 249 µm, 250 – 710 µm), a conventional liming product (Dolomite) and an unamended control at the start (Week 2), midway (Week 5) and end (Week 10; harvest) of the experiment. Error bars represent ± 2 x SEM. Different letters indicate significant differences ($p < 0.05$) between treatments.

The middle particle size SUW treatment (63–249 µm) had the next highest soil pH at the start of the experiment (µ = 6.64) yet was statistically similar to the larger particle size SUW treatment (250 – 710 µm) by midway through the experiment. Both the middle (µ = 7.19) and large (µ = 6.99) particle sized SUW treatments had the highest pH recorded at the end of the experiment, in which they were similar to the finer particle size SUW treatment (µ = 7.33), which had slightly dropped. Dolomite showed a higher soil pH than the control at the start (µ = 6.01) and midway (µ = 6.56) points of the experiment but was statistically similar (µ = 6.42) to the control (µ = 6.09) by the end of the experiment due to the control soil pH increasing and the Dolomite soil pH slightly decreasing. The unamended control treatment consistently had the lowest soil pH throughout the experiment, starting at 5.41 and gradually rising 0.68 pH units by the end of the experiment.

In the clay loam (CL) soil, a similar pattern in soil pH measurements between treatments were observed, although differences between the SUW particle sizes were less distinct (Fig 18b). The control treatment consistently had the lowest pH at the start (μ = 5.85), middle (μ = 6.09) and end (μ = 5.85) sampling dates yet did not exhibit the same increase over time as observed in the SL control. Similar to the SL, the finer particle size SUW treatment had the highest soil pH, which spiked at the start of the experiment to 7.32 and remained relatively steady at the midway point (μ = 7.33), before decreasing slightly to 6.94 at harvest. Despite the soil pH being higher in the 0 – 62 μm treatment at the start, it was statistically similar to the other SUW treatments at both the midway and end sampling dates, which were recorded at 7.19 and 6.93 for the 63 – 249 μm treatment and 6.99 and 6.77 for the 250 – 710 μm treatment, respectively. At the first sampling time, the Dolomite treatment had a soil pH greater (μ = 6.18) than the control and similar (μ = 6.15) to the larger particle size SUW treatment. Similar to the other treatments in CL, the Dolomite soil pH reached its peak midway (μ = 6.42) through the experiment, before decreasing slightly at the end (μ = 6.28). Dolomite was comparable to the control treatment at the midway point as the control had risen 0.25 pH units, yet by the end of the experiment, the Dolomite soil pH was statistically greater than the control, with a 0.43 pH unit increase. The Dolomite soil pH was lower than that of the SUW treatments at the end of the experiment, being 0.6 pH units on average less than the SUW treatments combined.

In the SL, the soil EC was significantly different between treatments at the start of the experiment (Week 2), with a higher EC with finer SUW particle sizes, resulting in the 0–62 μm and 63–249 μm treatments displaying moderate salinity, whereas low salinity was observed in the 250–710 μm treatment and in Dolomite, and the control treatment was classed as non-saline (Table 9).

Table 9. Mean soil EC (dS m^{-1}) and associated salinity class of green bean (*Phaseolus vulgaris* L., 'Dwarf Snap Bean') pots filled with a clay loam and sandy loam soil amended with different sea urchin waste products (0–62 μm, 63–249 μm, 250–710 μm), a conventional liming product (Dolomite) and an unamended control at the start (Week 2), midway (Week 5) and end (Week 10; harvest) of the experiment. Different letters indicate significant differences ($p < 0.05$) between treatments.

	Start (Week 2)		Midway (Week 5)		End (Week 10)	
Treatments	**EC (dS m^{-1})**	**Salinity class[1]**	**EC (dS m^{-1})**	**Salinity class**	**EC (dS m^{-1})**	**Salinity class**
Clay Loam						
0–62 μm	0.30 a	Low	0.26	Low	0.35	Low
63–249 μm	0.24 b	Low	0.19	Non-saline	0.30	Low
250–710 μm	0.17 c	Non-saline	0.25	Non-saline	0.28	Low
Dolomite	0.13 c	Non-saline	0.14	Non-saline	0.25	Non-saline

Control	0.13 c	Non-saline	0.19	Non-saline	0.25	Non-saline
Sandy Loam						
0–62 µm	0.57 a	Moderate	0.79 a	High	0.26	Low
63–249 µm	0.40 b	Moderate	0.49 ab	Moderate	0.19	Low
250–710 µm	0.31 c	Low	0.43 ab	Moderate	0.25	Low
Dolomite	0.19 d	Low	0.28 b	Low	0.14	Non-saline
Control	0.16 e	Non-saline	0.39 b	Moderate	0.19	Low

[1]Salinity class determined from Hardie and Doyle (2012)

By midway through the experiment (Week 5), there was a general increase in EC across all treatments compared to the Week 2 measurements, lifting the 0–62 µm treatment to salinity class high, and both 250–710 µm and Control to moderate. By harvest (Week 10), all SUW treatments showed a decrease in EC equivalent to a low salinity class, which corresponded to the control treatment, whereas the Dolomite treatment was classed as non-saline. All treatments displayed statistically similar soil EC at harvest.

In the CL, a similar trend in higher soil EC with finer SUW particle size was observed across sampling dates, although all soil ECs were classed as low salinity or non-saline. The 63–249 µm treatment had a higher EC than the 250–710 µm, Dolomite and Control treatments, and the 0–62 µm was higher than all other treatments at the start of the experiment. However, these differences were not apparent across the other sampling dates. At harvest, the SUW treatments had low salinity classes, and the Dolomite and Control treatments were non-saline.

Plant growth, plant biomass and yield measurements

Plant heights increased over time as expected, with heights stabilising around Week 6 in the CL and Week 7 in the SL, with no statistical differences across weekly height measurements between treatments observed (data not shown). At harvest, plant height, stem width and SPAD values were statistically similar between treatments (Table 10).

Table 10. Plant height (cm), stem width (mm) and SPAD values from green bean (*Phaseolus vulgaris* L., ‘Dwarf Snap Bean’) plants in a clay loam and sandy loam soil amended with different sea urchin waste products (0–62 µm, 63–249 µm, 250–710 µm), a conventional liming product (Dolomite) and an unamended control at harvest. Different letters indicate significant differences ($p < 0.05$) between treatments.

	Height (cm)	**Stem width (mm)**	**SPAD**
Clay Loam			
0–62 µm	31.40	4.20	47.44
63–249 µm	30.40	4.07	50.34

250–710 µm	31.20	3.98	50.26
Dolomite	33.33	4.57	49.70
Control	33.00	4.40	51.10
Sandy Loam			
0 –62 µm	28.60	5.11	44.72
63–249 µm	29.00	4.76	43.50
250–710 µm	25.60	5.16	39.76
Dolomite	27.40	5.38	44.72
Control	30.75	5.38	44.65

Differences in plant biomass and yield parameters between treatments were minimal across both soil types (Table 11).

Table 11. Wet and dry weights of green bean (*Phaseolus vulgaris* L., 'Dwarf Snap Bean') organs (shoot, roots, pods, beans), the root to shoot ratio, average pod number and total pod weight (g) from plants in a clay loam and sandy loam soil amended with different Sea Urchin Waste products (0–62 µm, 63–249 µm, 250–710 µm), a conventional liming product (Dolomite) and an unamended control at harvest. Different letters indicate significant differences (p < 0.05) between treatments.

	Wet weight (g)				**Dry weight (g)**						
	Shoot	**Roots**	**Pods (no beans)**	**Beans**	**Shoot**	**Roots**	**Pods (no beans)**	**Beans**	**Root to shoot ratio**	**Average pod number**	**Total pod weight (g)**
Clay Loam											
0–62 µm	20.73	6.28	14.55	14.23	3.84	3.23	2.42	5.34	0.14	9.60	28.82
63–249 µm	21.60	3.56	16.88	11.56	4.21	2.80	2.56	5.09	0.13	8.80	28.47
250–710 µm	19.94	4.46	10.57	11.05	4.01	3.37	1.90	5.20	0.16	6.40	21.59
Dolomite	23.23	3.49	14.86	12.20	4.44	2.99	2.51	5.89	0.13	8.00	27.08
Control	21.66	6.37	18.26	10.88	4.16	4.78	2.72	4.93	0.22	7.25	29.14
Sandy Loam											
0–62 µm	33.91	5.48 ab	24.37	6.01	5.42	4.82 b	2.55	2.42	0.14 c	6.40	29.63
63–249 µm	29.66	4.12 b	27.95	8.25	4.23	2.88 b	2.71	2.92	0.10 bc	8.00	36.05
250–710 µm	30.29	6.87 ab	28.98	6.60	4.76	5.95 ab	2.94	2.06	0.20 abc	6.60	34.85
Dolomite	24.58	7.15 ab	17.35	7.96	4.62	5.45 ab	1.83	3.06	0.23 ab	5.80	23.66
Control	30.26	9.96 a	28.58	7.71	5.53	8.49 a	3.29	2.81	0.28 a	7.00	41.13

In the SL, root weight (wet and dry weight) was highest in the control treatment although not significantly different from the other treatments except for the 63–250 µm root wet weight, and the 0–62 µm and 63–249 µm treatment root dry weights, which in both cases were lower than that of the other treatments. This had a follow-on effect to the root to shoot ratio, which progressively decreased with finer particle SUW size, with the 0–62 µm and 63–249 µm treatments having a significantly lower root to shoot ratio than the control.

On average, plants grown in the SL were more vigorous than in the CL as represented by higher shoot, shoot, pod, and bean weights, however plants from the SL showed higher average pod numbers.

Field trials

Vineyard trial

Soil physiochemical analyses

The impact of the liming treatments across soil physiochemical traits were inconsistent across varieties and sampling times with the impact of block, related to the slope of the vineyard site, often having a greater impact on the soil physiochemical profile than the treatments imposed. In general, the soil at the bottom of the slope (block 1) was more nutrient rich than that of the middle (block 2) and top (block 3) of the slope. However, no treatment x block interactions were apparent. In SB, the treatments had an impact on soil K, Na, Cl, and EC, albeit inconsistently over the trial period (Table 12).

Table 12. Soil nutrient concentration (K, Na, Cl; mg kg^{-1}) and Electrical Conductivity (EC; dS m^{-1}) across treatment plots (Control, Ozcal, Fine sea urchin waste (SUW), Coarse SUW) in *Vitis vinifera* L. var. Sauvignon Blanc blocks (Two Buds Spur vineyard, Gardners Bay, Tasmania) across selected sampling dates (September 2021, April 2022, January 2023, August 2023). Different letters indicate significant differences ($p < 0.05$) between treatments.

	Nutrients (mg kg^{-1})			**EC (dS m^{-1})**
	K	**Na**	**Cl**	
September 2021 (pre-treatment)				
Control	355.13	59.60	24.79	0.11
Ozcal	273.14	60.64	23.65	0.10
Fine SUW	338.29	58.00	22.67	0.10
Coarse SUW	254.22	57.77	24.82	0.10
April 2022 (veraison)				
Control	492.87	65.92 b	63.21 b	0.17
Ozcal	390.03	66.06 b	66.49 b	0.33
Fine SUW	450.46	104.87 ab	96.51 ab	0.28
Coarse SUW	364.09	152.19 a	141.33 a	0.36
January 2023 (post-flowering)				
Control	290.90 a	62.88	29.81	0.14
Ozcal	193.24 bc	58.10	26.56	0.16

Fine SUW	234.43 ab	54.46	22.59	0.17
Coarse SUW	164.43 c	65.35	23.89	0.21
August 2023 (dormancy)				
Control	291.51	56.19	32.89	0.17 a
Ozcal	201.89	55.28	43.12	0.16 a
Fine SUW	232.69	53.63	38.82	0.16 a
Coarse SUW	185.69	69.58	53.44	0.27 b

In April 2022, soil Na and Cl showed a similar pattern, in which the concentrations were increased in the coarse SUW treatment blocks compared to the control and Ozcal treatments, however in the next two sampling dates, no differences between treatments were apparent. In January 2023, the control treatment had a higher soil K concentration than the Ozcal and coarse SUW treatments, which showed lower soil K. This same pattern was evident in August 2023, however differences between treatments were not statistically significant. In August 2023, the coarse SUW showed a higher EC than the other treatments, corresponding to a low salinity class at 0.27 dS m^{-1}.

In CHA, soil Na, Cl and EC concentrations were similarly impacted by the imposed treatments (Table 13), together with soil S and B concentrations.

Table 13. Soil nutrient concentration (S, B, Na, Cl; mg kg^{-1}) and Electrical Conductivity (EC; dS m^{-1}) across treatment plots (Control, Ozcal, Fine sea urchin waste (SUW), Coarse SUW) in *Vitis vinifera* L. var. Chardonnay blocks (Two Buds Spur vineyard, Gardners Bay, Tasmania) across selected sampling dates (September 2021, April 2022, January 2023, August 2023). Different letters indicate significant differences ($p < 0.05$) between treatments.

	Nutrients (mg kg^{-1})				**EC (dS m^{-1})**
	S	**B**	**Na**	**Cl**	
September 2021 (pre-treatment)					
Control	15.28	1.38	57.73	24.00	0.10
Ozcal	15.45	1.43	54.56	26.68	0.11
Fine SUW	16.42	1.43	53.57	22.01	0.10
Coarse SUW	15.04	1.46	62.76	20.86	0.10
April 2022 (veraison)					
Control	18.41 b	1.40	67.98 b	70.51 b	0.15 b
Ozcal	49.42 a	1.48	52.63 b	55.19 b	0.24 ab
Fine SUW	37.57 a	1.51	136.75 a	123.01 a	0.33 a
Coarse SUW	39.44 a	1.50	137.64 a	127.23 a	0.33 a
January 2023 (post-flowering)					
Control	13.54 b	1.09 a	52.33	26.70 ab	0.12 b
Ozcal	14.87 ab	1.19 a	47.34	29.86 a	0.14 ab
Fine SUW	18.95 ab	1.38 ab	62.06	30.25 a	0.19 ab
Coarse SUW	21.67 a	1.55 b	69.25	16.44 b	0.23 a
August 2023 (dormancy)					

Control	16.27	1.11	53.58	33.42	0.14
Ozcal	17.43	1.18	51.93	32.46	0.16
Fine SUW	20.13	1.14	66.31	43.00	0.21
Coarse SUW	25.48	1.35	73.72	32.79	0.25

In April 2022, soil S concentrations were higher in the liming treatments than in the control, but in January 2023, S concentrations were only higher in the coarse SUW than the control, whereas the Ozcal and fine SUW treatments were statistically similar to both. By August 2023, a similar pattern in the data was present, yet no statistical differences between treatments were apparent.

In April 2022, both Na and Cl were higher in the fine and coarse SUW treatments compared to the control and Ozcal treatments, which resulted in a similar pattern in soil EC, which was higher in the SUW treatments. In January 2023, both Na and Cl concentrations decreased across all treatments, particularly in the SUW treatment plots. Soil Cl concentrations in the coarse SUW was significantly lower than in the Ozcal and fine SUW treatments, yet the coarse SUW EC was higher than in the control.

In both SB and CHA, the liming treatments had a significant impact on soil pH across the different sampling times (Fig 19a,b). In SB, the soil pH was consistent across treatment plots before treatment application in September 2021, exhibiting an average soil pH of 6.07 (Fig 19a). Five months post-treatment application (April 2022), the soil pH of all liming treatments were significantly higher than the non-treated control, increasing by an average of 0.8 pH units. Thereafter, the soil pH of the Ozcal treatment dropped progressively over the trial period, becoming statistically similar to the control at the next two sampling dates, and lowering to 6.15 by the end of the trial period (0.73 unit decrease from April 22–August 23). The fine SUW showed a gradual decrease in pH from April 2022 to August 2023, dropping 0.37 pH units by August 2023, yet the pH remained higher than the control treatment across the post-treatment sampling dates. The coarse SUW remained relatively steady across the trial period, showing a slight increase in January 2023 to 7.04, before decreasing to 6.96 at trial completion, which was 1.09 pH units higher than the control. In both January and August 2023, the soil pH was higher in the coarse SUW treatment than in the other treatments.

In CHA (Fig. 19b)., the soil pH between treatment plots was also statistically similar before treatment application in September 2021, with a slightly higher average soil pH than SB of 6.18. Similar to SB, all liming treatments had higher soil pH in April 2022, increasing 0.62 pH units on average. In January 2023, the soil pH in the coarse SUW treatment continued to climb to 7.09, before dropping back to 6.71 in August 2023, which was 0.90 pH units higher than the control pH measured at that time. At both time periods, the coarse SUW soil pH was higher than both the Ozcal and control treatments. The fine SUW treatment showed a gradual decline over the remaining trial period yet continued to show a higher pH than the control plot, with a final pH of 6.36 at trial completion. The Ozcal treatment also showed a gradual decrease in soil pH, remaining higher than the control treatment in January 2023 at 6.59, before dropping to 6.03 in August 2023, in which the soil pH became statistically similar to the control.

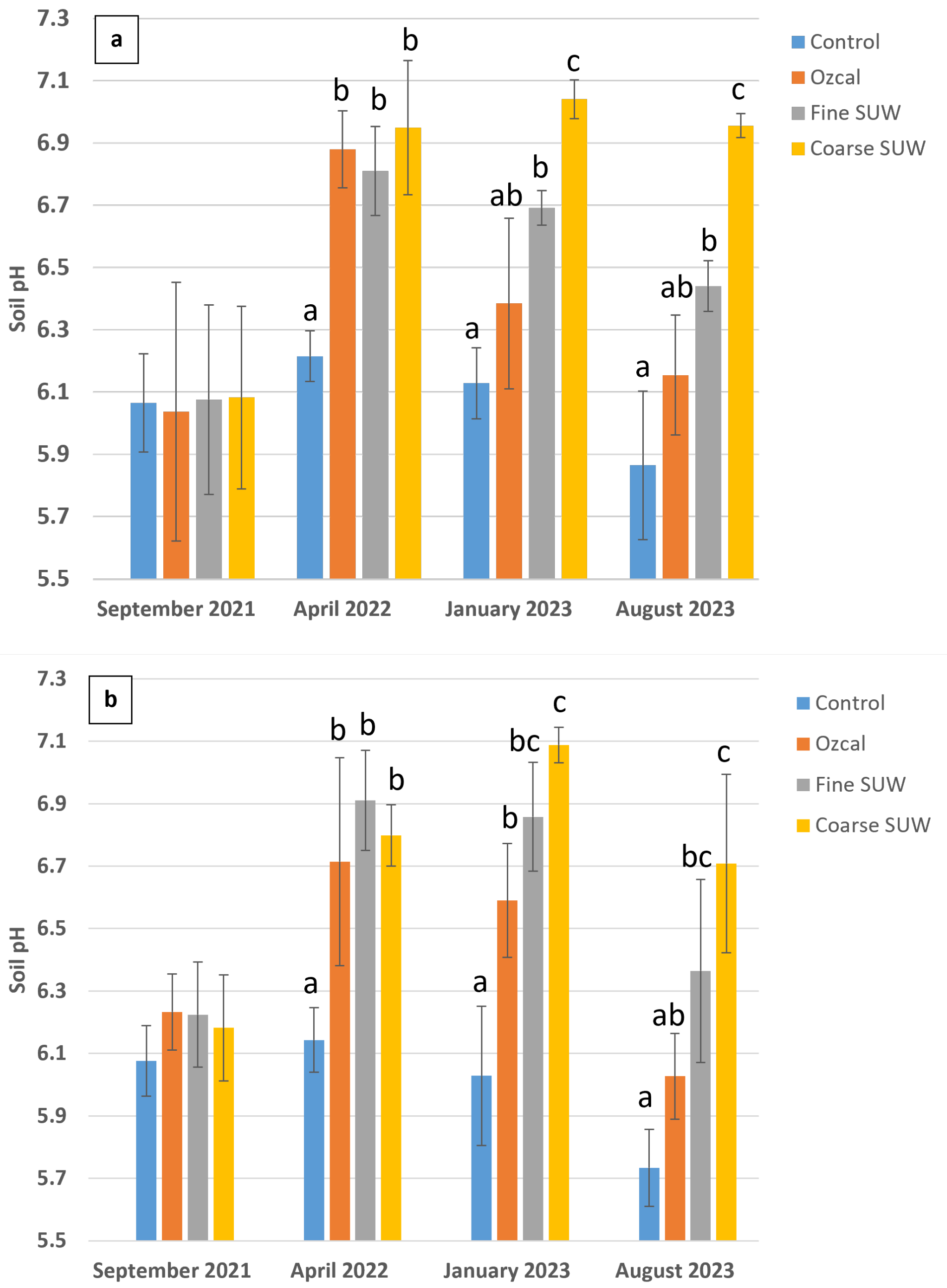

Figure 19. Mean soil pH of treatments (control, Ozcal, fine sea urchin waste (SUW), coarse SUW) applied at Two Buds Spur vineyard (Gardners Bay, Tasmania) in *Vitis vinifera* L. var. a) Sauvignon Blanc and b) Chardonnay across selected sampling dates (September 2021, April 2022, January 2023, August 2023). Different letters indicate significant differences ($p < 0.05$) between treatments.

Leaf tissue analysis

The imposed treatments had no effect on the leaf nutrient status of SB and very minimal impact on that of CHA across both sampling dates (veraison 2022 and veraison 2023) (data not shown). At veraison in 2022, the Ozcal treatment had a higher leaf iron concentration (92.06 ± 9.59 mg kg^{-1}), than the control (56.85 ± 11.04 mg kg^{-1}), fine SUW (52.81 ± 5.76 mg kg^{-1}) and coarse SUW (52.88 ± 2.62 mg kg^{-1}) treatments in CHA, yet no significant differences were apparent between treatments the following season (veraison 2023).

There were several block effects on leaf nutrient composition, where N, P, K, Mg tended to be higher in block 1 (bottom of site) and Ca, Cu and Fe tended to be highest in block 3 (top of site), however these trends were not always significant or consistent across sampling dates (data not shown).

Vine vigour

No treatment effects were present in SB, although a significant block effect was, where block 3 (top of site) had lower pruning weights than the other blocks (data not shown). In CHA, no main treatment or block effects were observed, however a significant treatment x block interaction was found (Fig 20), in which no differences between the pruning weights of treatments were observed in block 1, but some differences were observed in block 2 and 3. In block 2, the control pruning weight was the lowest and was significantly lower than the Ozcal treatment, whereas in block 3, the Ozcal pruning weight was the lowest and appeared significantly lower than the fine SUW treatment.

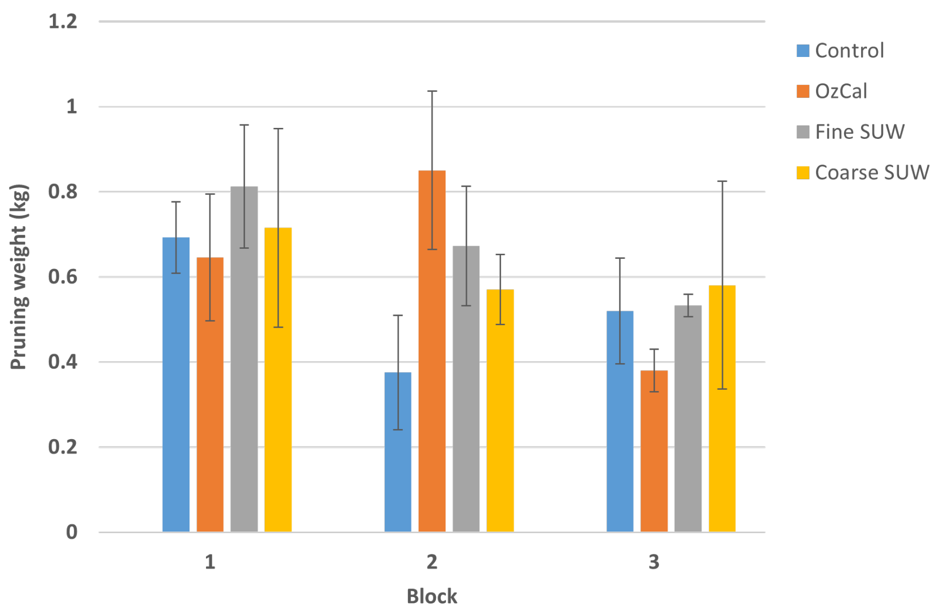

Figure 20. Pruning weight (kg) of *Vitis vinifera* L. var. Chardonnay at dormancy 2023 according to soil treatments (control, Ozcal, fine sea urchin waste (SUW), coarse SUW) and experimental trial blocks (Two Buds Spur vineyard (Gardners Bay, Tasmania)

Yield components

The yield in 2022 provided a site baseline but does not represent accurate treatment effects due to the commercial pruning of individual vines to different bud numbers prior to trial commencement (data not shown). The average yield in SB was 0.68 kg vine^{-1} and 0.32 kg vine^{-1} in CHA which was 3.8 times lower than what was harvested in 2023 in the SB and 2.3 times lower than that of CHA.

In 2023, the yield from SB was approximately three times greater than that of CHA, driven mostly by a much higher bunch number due to leaving more shoots per vine at pruning. No significant differences in yield and yield parameters between treatments were apparent across either variety (Table 14).

Table 14. Yield components (shoots/vine, bunches/ vine, average bunch count, average bunch weight (g), average yield (kg vine^{-1}), average bunch density, average berry number, average total berry weight (g) and average single berry weight (g) of treatments applied (Control, Ozcal, Fine sea urchin waste (SUW), Coarse SUW) in *Vitis vinifera* L. var. Sauvignon Blanc and Chardonnay (Two Buds Spur vineyard, Gardners Bay, Tasmania) at commercial harvest (April 2023)

	Shoots/ vine	Bunches/ vine	Average bunch count	Average bunch weight (g)	Average yield (kg vine^{-1})	Average bunch density	Average berry number	Average total berry weight (g)	Average single berry weight (g)
Sauvignon Blanc									
Control	24.08	29.00	29.00	95.67	2.78	9.00	89.17	93.39	1.04
Ozcal	23.25	25.25	25.25	89.89	2.42	8.67	92.92	87.56	0.96

Fine SUW	23.67	26.67	26.67	108.28	2.89	8.67	93.67	105.30	1.14
Coarse SUW	25.25	25.75	25.75	90.23	2.33	9.00	79.42	87.86	1.12
Chardonnay									
Control	12.42	11.08	11.08	57.17	0.62	5.33	64.00	54.61	0.87
Ozcal	12.92	11.42	11.42	64.16	0.77	5.50	65.58	61.52	0.94
Fine SUW	13.75	11.67	11.67	69.61	0.84	6.00	71.92	66.42	0.92
Coarse SUW	13.42	11.58	11.58	61.15	0.70	5.33	63.58	58.61	0.93

Juice and grape nutrient composition

No differences in juice nutrient composition or grape nutrient composition were apparent across both varieties (Table 15), however the SB juice pH was higher in block 1 (bottom of site) than in the other blocks (data not shown). No other block effects were observed.

Table 15. Juice composition (Brix (%), pH, titratable acidity (TA; g L^{-1})) and grape nutrient concentration (B, Ca, Cu, Fe, K, Mg, Mn, P, Zn; mg kg^{-1}) of treatments applied (Control, Ozcal, Fine sea urchin waste (SUW), Coarse SUW) in *Vitis vinifera* L. var. Sauvignon Blanc and Chardonnay (Two Buds Spur vineyard, Gardners Bay, Tasmania) at commercial harvest (April 2023)

	Juice composition			**Grape nutrients (mg kg^{-1})**								
	Brix (%)	pH	TA (g L^{-1})	B	Ca	Cu	Fe	K	Mg	Mn	P	Zn
Sauvignon Blanc												
Control	19.0	3.0	10.8	22.9	948.3	4.1	9.3	10763.3	478.3	3.4	1363.3	3.2
OzCal	17.9	3.0	10.6	24.4	1090.3	4.3	10.2	10900.0	530.0	4.0	1600.0	3.8
Fine SUW	18.7	3.0	10.8	23.5	1034.7	4.0	9.6	10273.3	491.3	3.4	1413.3	3.8
Coarse SUW	19.0	3.0	11.9	22.6	913.3	3.9	9.9	10333.3	478.7	3.4	1363.3	4.1
Chardonnay												
Control	19.3	3.0	11.6	19.7	1390.0	4.9	12.9	10933.3	594.3	5.0	1536.7	7.5
OzCal	19.0	3.1	12.3	20.4	1480.0	5.0	13.8	11133.3	608.0	4.8	1610.0	9.0
Fine SUW	18.5	3.1	11.9	19.9	1486.7	5.4	14.2	11000.0	619.0	5.5	1570.0	8.3
Coarse SUW	16.8	3.1	10.2	19.4	1316.7	5.1	14.3	11066.7	583.7	5.0	1516.7	9.8

Apple orchard trial

Soil physiochemical analyses

No differences in the measured soil physicochemical parameters between treatment plots were observed in the preliminary (pre-treatment application) soil tests, indicating a uniform baseline (data not shown). The absence of significant differences in soil physiochemistry was observed again 10-

months post-treatment application (Table 16), however there was a general trend for higher nutrient concentrations in SUW-amended plots compared to the control.

A consistent block effect was observed both pre- and post-treatment application in both varieties for a number of physiochemical parameters, where Block 1 was more nutrient rich, had a higher EC and a lower pH than the other blocks (data not shown).

Table 16. Soil nutrient concentration (P, K, Ca, Mg, S, Na, Zn, B, Cu, Fe, Mn, Al, Cl, NO_3^-, NH_4^+ ; mg kg^{-1}), Total Nitrogen (TN; %), Total Carbon (TC; %), Organic matter (OM; %), soil pH ($CaCl_2$), and Electrical Conductivity (EC; dS m^{-1}) across sea urchin waste (SUW) treatment plots (control (zero), low, medium, high SUW rate) 10-months post-treatment application (August 2023) in Kingston Black and Yarlington Mill trials

	Nutrients (mg kg^{-1})															**Nutrients (%)**			**EC (dS m^{1})**	**pH**
	P	K	Ca	Mg	S	Na	Zn	B	Cu	Fe	Mn	Al	Cl	NO_3	NH_4	TN	TC	OM		
Kingston Black																				
Control	7.07	46.86	2405.72	391.85	1.67	13.68	4.72	0.38	1.14	55.92	4.51	54.38	12.97	3.50	4.54	0.15	3.08	4.75	0.06	6.42
Low	9.29	78.42	2165.15	450.94	2.19	18.88	4.12	0.36	0.94	87.85	5.11	116.21	15.25	3.80	7.26	0.17	3.66	5.63	0.07	5.90
High	9.83	115.02	2186.12	482.17	2.24	27.42	4.34	0.41	1.20	91.37	5.45	112.60	11.87	4.43	8.83	0.17	3.97	6.10	0.07	5.72
Yarlington Mill																				
Control	24.91	90.73	2259.15	465.92	3.05	18.85	6.16	0.47	2.95	81.94	5.44	128.84	12.12	5.17	10.69	0.21	4.10	6.32	0.07	6.15
Low	49.49	181.82	2355.28	537.27	4.57	22.55	7.23	0.54	3.50	88.93	5.78	161.13	11.33	6.80	10.89	0.23	4.36	6.70	0.09	6.29
Medium	44.67	104.42	2415.96	421.24	3.91	15.62	6.72	0.61	5.48	86.70	6.33	162.03	8.13	5.15	8.33	0.20	3.67	5.65	0.08	6.40
High	33.65	143.09	2484.92	453.88	4.29	25.59	6.90	0.57	3.93	79.23	5.88	136.29	11.69	5.75	11.18	0.20	3.95	6.08	0.09	6.19

Leaf tissue analysis

In YM, the leaf sodium (Na) concentration (%) was higher in the high SUW treatment (μ = 0.43 ± 0.004) compared to the low SUW treatment (μ = 0.35 ± 0.002), yet not statistical differences were apparent amongst other treatment groups, including the control (p>0.05).

There were no significant differences (p>0.05) between treatments in leaf nutrient concentrations across other measured nutrients in either variety (data not shown). There were also no significant block effects or block x treatment interactions.

Tree vigour

The change in trunk diameter (mm) from prior to pre-treatment application in 2022 to dormancy in 2023 between treatment plots were not significantly different (p>0.05) from each other in either variety. There were also no significant block effects or treatment x block interactions.

In both varieties, there was a trend for the low (4 t ha^{-1}) SUW treatment to have the biggest increase in trunk circumference (KB: μ = 6.74 mm ± 0.75; YM: μ = 5.78 mm ± 0.86), followed by the medium (8 t ha^{-1}) SUW treatment (YM: μ = 5.24 mm ± 0.85), and for the high (12 t ha^{-1}) SUW treatment (KB: μ = 5.46 mm ± 0.81; YM: μ = 4.27 mm ± 0.49) and control (KB: μ = 5.10 mm ± 1.05; YM: μ = 4.32 mm ± 0.31) treatments to have similar means within varietal blocks.

Annual crop trial

Soil physiochemical analyses

There were no significant differences (p>0.05) in the physiochemical attributes (nutrient concentrations, pH, EC) of the initial soil samples (pre-treatment application) of treatment plots (data not shown), indicating a uniform baseline. At potato harvest, there were differences in the concentration of several nutrients across treatments as indicated in Table 17.

Table 17. Soil nutrient concentration (Ca, Mg, Ca: Mg, S, Na, Mn; meq 100 g^{-1}), soil pH ($CaCl_2$), soil pH change, and electrical conductivity (EC; dS m^{-1}) across sea urchin waste (SUW) treatment plots (control (zero), low, medium, high SUW rate) derived at potato harvest (May, 2023)

SUW Treatment	**Ca**	**Mg**	**Ca: Mg**	**S**	**Na**	**Mn**	**pH**	**pH change**	**EC**
				meq 100 g^{-1}					dS m^{-1}
Control (0 t ha^{-1})	12.35 ± 0.47 a	2.92 ± 0.09 a	4.23 ± 0.11 a	24.18 ± 6.16 a	0.30 ± 0.02 a	87.57 ± 1.70 b	5.34 ± 0.05 a	-0.28 ± 0.05 a	0.07 ± 0.01 a
Low (4 t ha^{-1})	16.30 ± 1.22 b	3.20 ± 0.11 ab	5.09 ± 0.27 b	28.90 ± 4.00 ab	0.45 ± 0.03 b	65.72 ± 8.93 a	6.09 ± 0.19 b	+0.46 ± 0.21 b	0.14 ± 0.03 b
Medium (8 t ha^{-1})	16.65 ± 0.97 b	3.21 ± 0.13 ab	5.19 ± 0.16 b	34.12 ± 3.30 ab	0.49 ± 0.04 b	71.64 ± 4.46 a	6.16 ± 0.18 b	+0.50 ± 0.15 b	0.16 ± 0.03 b
High (12 t ha^{-1})	17.90 ± 2.92 b	3.29 ± 0.24 b	5.41± 0.55 b	40.05 ± 8.52 b	0.52 ± 0.09 b	72.72 ± 4.91 a	6.28 ± 0.33 b	+0.64 ± 0.35 b	0.18 ± 0.04 b

Calcium (Ca), sodium (Na), pH, pH change, and electrical conductivity (EC) were higher across all the SUW treatments compared to the control. Across these measurements, there was a trend for higher concentrations with increased SUW rate, however the differences between SUW treatments were not significant. Magnesium (Mg) and sulfur (S) showed a similar trend, with the high SUW treatment having significantly higher concentrations than the control (zero SUW) treatment. Alternatively, manganese was higher in the control treatment than in the SUW treatments.

There were no significant differences between treatments in the other measured soil nutrients ($p>0.05$).

Yield parameters

No differences between treatments ($p>0.05$) were apparent across the yield parameters measured, including the total number of tubers, total tuber weight, total yield, number of tubers and tuber weight within three size categories (<50g, 50–400g, >400g), the number of waste tubers, total waste weight, and hollow heart and brown spot measurements (data not shown).

5. **Undertake a cost benefit analysis comparing fertiliser products (foliar sprays and/or soil conditioners) from this work to other products on the market to assess if the products are commercially viable**

True South Seafoods computed the Net Present Values (NPV) of the three projects, which, following a review by an independent consultant, are reported in Table 18. The NPVs for all the projects are positive, indicating that all the projects are financially profitable. Among the projects, Project 2 is most profitable as it has the highest NPV.

True South Seafood's analysis suggests that implementing either Project 2 or Project 3 will not only eliminate the recurring production cost of $78,975 associated with Project 1 but will also substantially contribute to the company's cash inflow. Considering it's higher NPV, Project 2 appears to be the best project to pursue.

Table 18. Net present value analysis of three different projects determined by True South Seafoods financial team to produce Sea Urchin waste-based agricultural product

Project	Cost ($)		Benefit ($)	Net Present Value ($)
	One-off Capital Investment	Recurring Production Cost	Recurring Revenue	
1	0	78975	131625	199585
2	50000	0	131625	448962
3	100000	0	105300	299169

Discussion

This project investigated the conversion of sea urchin waste (SUW) into a successful agricultural product through several trials to address commercial viability from both a fisheries and agricultural lens.

In alignment with objective 1, the development of commercial-scale processing equipment for SUW was successful. The processing facility was able to grind and heat the SUW to decrease the particle size, sterilise the product effectively to meet agricultural production safety standards (AS 4454-2012), and homogenise the SUW to different extents based on processing time to create a consistent product. The processor was modified in-house to meet Australian safety standards and to speed up waste processing time to meet commercial needs. For example, in peak season approximately 4 t of sea urchins were processed at the factory per day, and 4 t of SUW could fit into the processor and be left for 14 hours to generate an acceptable product before the next SUW batch arrives. In principle, this should allow for a smooth operation and management of resources. However, this was not always realised due to the unforeseen labour required to run the processor which was not always possible during busy periods. Key modifications to streamline SUW processing highlighted by True South Seafoods, including grinder and chamber separation and interior paddle modification for improved SUW removal, were set as different scenarios (projects) in the net profit value (NPV) analysis (objective 5). By investing $50,000 (project 2), recurring annual production costs, set on top of baseline costs, could be eliminated, resulting in a higher profit than the current operating scenario (project 1) after just one year. Alternatively, spending an additional $100,000 (project 3) also resulted in higher profits over a five-year period compared to current operations, yet did not meet the same profit margins as project 2 over a five-year timeframe. The economic scenario work undertaken for objective 5 established that after the initial cost of processing facility procurement, which in this case was supported by the project, the running of the facility and the production of the waste end-product was more profitable than the current waste disposal costs, regardless of whether the SUW product was sold. Therefore, any income generated from selling the product would add to the company’s profit margins. Commercialisation of the product for smaller markets, including smaller bagging, would require additional facilities or third-party involvement. Given that SUW production relies on the fishery’s core business of sea urchin fishing for premium roe, waste generation may be too seasonally inconsistent to sell using only one fishery’s waste and may not be worth the additional expenses of the company investing in the facilities required for smaller market product commercialisation. Therefore, industry may benefit more from selling the SUW product in bulk or selling it to a third party for commercialisation.

The second project objective was to determine the physiochemical composition of the solid and liquid SUW to establish usability as an agricultural amendment. The original aim of the liquid SUW was to use it as a direct foliar spray on buds as a frost protectant. The liquid SUW in its initial (raw) form had a high salt content, as indicated by the EC and Na concentration, and a lower N content than expected, which was crucial to its potential in offering frost protection. The planned end-use of the product was therefore deemed not practicable and objective 3 (evaluate the agronomic benefits of liquid gut waste as a frost retardant in perennial tree cropping (cherries)) was no longer achievable. As an alternative, the potential for a soil-applied liquid fertiliser spray was investigated as the liquid SUW contained important plant nutrients of which some, such as N, P and S, were in higher concentrations than comparative liquid marine fertiliser products. However, the liquid SUW salt content was still of concern. Diluting the product reduced the Na content, but the EC did not drop as much as expected and its recommended rate to meet guidelines (AS 4454-2012) was relatively small, meaning that the nutrients delivered from the diluted SUW product would be low, thereby reducing the products overall effectiveness. Desalinisation to reduce the salt content of the liquid product was deemed unsuitable as although there are many successful desalinisation technologies, they require adequate scale to make them economically feasible (Al-Karaghouli & Kazmerski, 2013), which was not an option for the comparatively small amount of liquid collected in the waste process or for company investment in desalinisation technologies. The additional cost of sterilisation to ensure the product met agricultural guidelines added to the complexity of producing an effective product from the liquid SUW that would be commercially viable and profitable. Alternative options for the liquid SUW outside of the agricultural industry continue to be explored by True South Seafoods, such as its use in seaweed growing systems where salt is of no concern.

The solid SUW product had a lower EC than the liquid SUW and had a similar or higher concentration of several nutrients essential for plant growth, including a high calcium content (33%), which could be used to increase soil pH. The Na content of the product was still of concern, yet it was approximately 0.35% lower than the SUW product used by Campus et al. (2022) who reported positive results on tomato growth, and 0.23 % higher than that of Garau et al. (2012) who observed some positive effects on bean growth. The phytotoxicity trial showed that the SUW product had a progressively negative impact on seed germination with increased rates due to a reduction in seed radicle (root) length. A reduction in root cell division is a common response to salt stress (Jung & McCouch, 2013). Nonetheless, the seeds used in the phytotoxicity trial were exposed to highly available salt (NaCl) due to the SUW being applied in a liquid medium in a soil-less petri dish, making it more analogous to a hydroponic system and likely a more extreme version of what would occur in the soil. Indeed, no negative impacts on plant growth were observed in sunflowers from SUW addition (objective 4), despite observed increases in soil Na and Cl with increased SUW application rates at harvest and increased soil EC concentrations, particularly at the start of the trial, reaching close to 1.0 dS m^{-1} (high salinity) (Hardie & Doyle, 2012). It is likely that the free-draining nature of the potting mix increased salt loss from the system, resulting in a drop in EC throughout the trial and no negative impacts on the plant itself. In fact, a progressive increase in plant growth (height, shoot, flowerhead), health (chlorophyll content (SPAD)) and biomass was observed with increased SUW rate, likely related to the additional nutrients that the SUW provided as reflected in some of the soil and plant nutrient analyses. In addition, the SUW showed a strong liming ability, with the 10% SUW rate increasing the soil pH by 2.0 units compared to the control treatment by the end of the experiment. The green bean trial explored the SUW products' liming ability and potential salinity issues further. The established liming ability of the SUW products and the data gathered from the sunflower trial were used to determine appropriate rates. Seeds were planted directly into SUW-amended soils, water was restricted, and a salt-sensitive crop was used for salinity impact observations. The soil EC was increased by SUW amendments, particularly in the sandy loam soil, yet this did not appear to have an impact on bean growth or yield. However, a reduction in the root biomass compared to the control was observed, again suggesting a potential salt stress response. Alternatively, the potato field trial used similar maximum rates (up to 12 t ha^{-1}) to that of the clay loam soil in the bean trial and showed no impact on yield parameters, despite seeds also being sown directly into SUW-amended soil. However, it should be noted that in the potato trial, the soil EC at harvest only measured 0.18 dS m^{-1}, signifying that the soil was non-saline compared to the varied salinity (low to high) experienced throughout the green bean trial. This is likely due to the wet conditions experienced at Forth, where the majority of the salt may have washed away or penetrated into deeper soil layers. This may explain the potatoes' success, although higher soil Na concentrations were observed in the SUW-amended plots compared to the unamended control. Soil Ca and S concentrations were also higher in the SUW potato plots. S and Ca applications have been linked to increased tuber yields under specific rates and times of plant development (Gumede, 2017; Pavlista, 2005) and reduced tuber defects (Palta, 1996; Pavlista, 2005), however the increase in soil Ca and S in this study did not translate to improved yield or quality parameters. In the vineyard trial, soil Na and Cl concentrations were also higher in the SUW-amended plots compared to the control and the control liming treatment at five months post-application, however this effect dissipated thereafter. In contrast,, there was no change to soil Na, Cl or EC concentrations in the apple trial. Overall, it is evident that the SUW does result in increased salt (NaCl) in soils, and that even if crop yield and quality parameters are unimpacted in the first couple of seasons, repeated additions of the SUW are likely to cause salt build up in the soil, which may cause long-term problems. SUW-amended soils should be monitored over a longer period and recommended rates and management practices should take product salt content and soil types into account. A pre-washing step of the SUW with freshwater could be implemented to reduce salt content and generate a more advantageous soil amendment which could be applied at higher recommended rates. However, it is noted that this would require additional resources and reduce the initial environmental and economic benefits of SUW conversion.

The greatest impact of the SUW overall was its ability to increase soil pH across a variety of soils. Tasmanian soils tend to be naturally acidic (Hamlet, 2002). In these soils, some essential nutrients become unavailable for plant uptake at a low pH, while others, such as aluminium, become more available and can result in plant toxicity. Soils naturally weather over time and crop production and agricultural management practices, such as nitrogen fertiliser use, gradually lower soil pH (Hamlet, 2002). Current strategies to raise soil pH include a consistent liming application of materials that are high in calcium, such as limestone or gypsum. However, these materials are sourced and produced under energy intensive processes. Therefore, the ability to supplement or replace these traditional liming materials with a calcium-rich waste material, such as SUW, could be advantageous, particularly with the benefit of additional nutrients. Similar to commercial liming materials, SUW particle size influenced the liming strength of the end-product. We successfully grouped solid SUW into five products ranging in particle sizes with effective neutralising values ranging from 22–85%. When applied at appropriate rates to raise the soil pH by a predicted amount, the SUW products were either comparable or exceeded expectations to that of commercial liming products. In the vineyard trial, the coarser 14-hr product collected directly from the processor reached an equivalent soil pH to that of the finer 48 hr product and commercial product (Ozcal) five months post-application, yet resulted in a longer-term liming effect, suggesting that it may be a valuable alternative. Modifying the fineness of the SUW product further, such as in the green bean trial, had the benefit of reducing required rates by approximately 50% for a similar soil pH change. Commercially, this may not be favourable due to extra processing steps and the lower volumes of SUW required for soil pH conversion, but it would reduce associated salt additions.

As demonstrated in the sunflower trial, increased SUW rates resulted in higher soil nutrient concentrations, increased plant nutrient uptake from the soil, and subsequent improvements in plant growth and yield. However, in field trials, where soils were comparatively more nutrient-rich and maintained to ensure commercial crop productivity, this fertiliser effect was largely unobserved. This suggests that the upper limit SUW rates applied based on the products' strong liming ability and the ideal soil pH parameters for crop production, prevented the observation of significant fertiliser effects from other nutrients present in the SUW products in commercial field settings. For example, the high rate (12 t ha^{-1}) of SUW applied in the potato trial was less than 10% that of the recommended rate of nitrogen to apply for a 40 t ha^{-1} potato crop (national average) (AUSVEG, 2018), yet applying a higher amount of SUW to meet nitrogen targets would push the soil pH too alkaline, reducing plant nutrient availability and crop yields. For this reason, the SUW product is likely to be more successful as a "liming plus" product, where the other nutrients supplied are an added benefit, rather than it existing as a primary fertiliser product. It is however possible that in environments with lesser inputs, such as in home gardens, a fertiliser effect may be more readily observed, such as shown in the sunflower pot trial.

The NPV analysis undertaken through objective 5, and the general financial analysis leading up to it, accounted for the economic benefits of converting SUW into an agricultural product as discussed earlier. However, part of the appeal of the SUW product is the notion of recycling waste into a new product in alignment with circular economy principles of sustainable development, which also acknowledges environmental and social sustainability (Korhonen et al., 2018). From a sustainability perspective, a life-cycle analysis that explores the inputs and outputs of the SUW production, particularly regarding energy and greenhouse gas emissions, and including a freshwater washing step, would be beneficial, particularly as a comparison to commercial waste disposal practices. This has the potential to improve the social license of the fishery as a whole.

Conclusion

Sea urchin waste (SUW) can be converted into a soil amendment through grinding and heating the solid material to create a safe and spreadable product. The longer the waste is left to process, the finer, the drier, and the more homogenous the SUW product becomes. The resulting material was high in several important plant nutrients, such as boron, and its physiochemical composition was not largely impacted by processing time up to 48 hours. The SUW product can be characterised by a high calcium content (33%), resulting in its potential use as a liming material to increase soil pH. This liming effect was demonstrated in a variety of trials across both annual (sunflowers, beans, potatoes) and perennial (apples, grapevines) crops in sandy soils, loams and clay soils. When the effective neutralising value of the SUW was calculated, it could be applied to determine appropriate rates to increase the soil pH equivalent to or surpassing that of conventional liming products using typical liming formulas, where a coarser particle size SUW product resulted in a longer-term effect than the finer SUW, likely due to a slower calcium release over time. Fertiliser impacts from the SUW product were observed in low-nutrient pot trials but were not significant in field trials.

The economic analysis determined that processing SUW using the facility procured was more profitable than waste disposal, regardless of whether the SUW product was sold, meaning that any income generated from selling the product would add to the company's profit margins. Further investment of $50,000 to upgrade the facility would reduce current annual production running costs and provide additional profit from the second year onwards.

The utility of SUW as a commercial liming product shows promise, but growers are advised to proceed with caution due to the product's salt content. Commercial suppliers should provide growers with appropriate management techniques and recommended rates to reduce the likelihood of any salinity issues. Adding a freshwater wash step to SUW processing is likely to reduce salt-related land risks.

Implications

This project demonstrated that the cost of processing SUW using a simple grinder and heated processing facility is more economically advantageous than conversion to landfill, and that a beneficial agricultural product can be made from the SUW that could be profited from. For the fishing industry, this provides a financially beneficial and environmentally conscious waste management solution. For the agricultural industry, this offers an alternative or supplement to the use of energy-intensive liming materials and synthetic fertilisers.

Recommendations

It is recommended that the results of this project will be shared directly with project partners, with the interpretation of results and support in understanding provided by the team to ensure sufficient knowledge transfer before further investment and/or commercialisation. It is also recommended that the final results be shared with the fishing industry at large for awareness and to encourage others to investigate advantageous waste management solutions, and in parallel, to the agricultural industry through field days and fact sheets. The results are also recommended to be shared to scientific audiences through peer-reviewed journal papers.

Further development

Further investigation into the long-term impact (3–5 years) of SUW on soil health and crop production is advised due to the novelty of the product and potential salinity issues.

Extension and Adoption

This project was extended and communicated to researchers, industry, the education sector, and potential product consumers via personal communications, presentations, radio and television segments, conferences, field days, and fact sheets. The project has been viewed positively by local agricultural industry; some of the product has been bought from True South Seafoods or it has been given in smaller quantities to interested parties to try.

Project coverage

2021

AgFEST (TAS)—sea urchin project exhibit

ABC radio (TAS)—radio interview at AgFEST

Beaker Street sci-art crawl (TAS)—table at urchin exhibit

ABC news (Australia)—news story: From ocean menace to possible garden saviour. Is this the pest you want in your garden?

ABC radio (Hobart)—radio interview

IMAS news—article

2022

agriCULTURED (TAS)—guest presentation (scientific and community audience)

Forthside Field Day (TAS)—presentation to agricultural industry

Wine Tasmania Field Day (TAS)—presentation to wine industry

Friends School (TAS)—in-school presentation to year 11/12 students

Newstead College (TAS)—in-school presentation to year 11/12 students

2023

National Centrostephanus Workshop (TAS)—guest presenter and panellist

Friends School (TAS)—in-school presentation to year 11/12 students

Hobart College (TAS)—in-school presentation to year 11/12 students

FRDC news—article

Agvision (NSW)—display and presentation

Project materials developed

- “From trash to treasure: can sea urchin waste be beneficial for crops?”—project fact sheet (Appendix B)
- “Sea urchin soil amendment/fertiliser”—commercial product fact sheet (created for industry) (Appendix C)

Appendices

Appendix A: References

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Appendix B

From trash to treasure:
Can sea urchin waste be beneficial for crops?

utas.edu.au/tia

Authors: Harriet Walker (TIA), Nigel Swarts (TIA), John Keane (IMAS)

Promoting a circular economy through waste utilisation

Background

The long-spined sea urchin *Centrostephanus rodgersii*, is a major threat to the kelp forests and biodiversity of Tasmania's east coast. Since the late 1970's, urchin populations have migrated from mainland Australia following the warming ocean current down the east coast of Tasmania.

Urchins graze extensively on kelp beds producing lifeless barrens displacing around 150 marine species, including abalone.

Scientists from the Institute of Marine and Antarctic Science (IMAS) estimate there are now around 18 million long-spined sea urchins off the coast of Tasmania, a 75% increase in population density from 2002 to 2017.

Control measures

In 2016, the Tasmanian Abalone Council introduced a harvest subsidy to help reduce urchin numbers in Tasmanian waters.

This initiative has seen the expansion of urchin processing facilities in Tasmania to remove and package the delicate roe for high end restaurants and export markets, particularly Japan.

Urchin populations have since declined - a positive sign for the environment and the abalone industry in Tasmania.

However, further work is needed to assist the viability of this fledgling industry beyond harvest subsidies.

Kelp bed

Urchin barren

Photos from East coast waters of Tasmania, courtesy of IMAS

An agricultural solution?

TIA and IMAS researchers are joining forces to address waste management within the sea urchin industry, which may increase industry profitably and provide agricultural benefit.

Long Spined Sea Urchin
Centrostephanus rodgersii

- **Found:** from Byron Bay (NSW) to Tasmania
- **Lifespan:** >40 years
- **Colour:** black/purple – underwater shows iridescent turquoise/ purple around spines
- **Shell size:** Up to 13.5 cm in diameter
- **Spines:** Hollow and up to 10 cm long
- **Spawn:** Late winter
- **Larval period:** 3 months

Turning sea urchin waste (SUW) into fertiliser

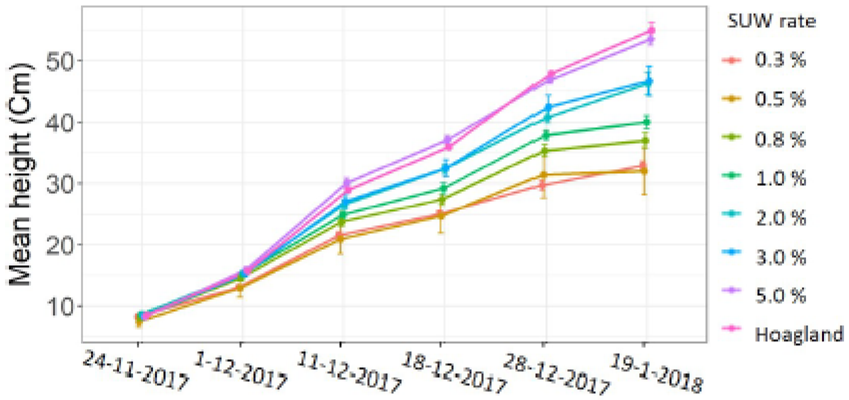
Sea urchins are harvested for their roe, which makeup only ~10% of their total biomass, with the remaining urchin destined for landfill. TIA and IMAS researchers saw the opportunity of turning this waste into a useful product.

The dried and ground sea urchin waste (SUW) had a positive impact on tomato growth and production in preliminary research trials conducted by TIA/IMAS. The more SUW applied, the bigger the tomato plants grew (see below). The researchers found that plants actively take up the nutrients from SUW particularly calcium and boron.

TIA Researcher Harriet Walker (left) with IMAS researcher Dr. John Keane (right) at the project partners sea urchin processing facility (True South, Electrona, Tasmania)

What's next?

- **A new processing facility:** The Fisheries Research & Development Council and Abalone Industry have invested in a SUW processing facility, currently being set up at True South Seafood (Electrona, Tasmania)
- **Optimising the product:** Researchers are trialling different fertiliser particle sizes and processing techniques to optimise SUW products
- **Optimising rates for different crops:** The SUW fertiliser will be tested on a large amount of crops, in both pot and field trials, at a variety of rates to determine SUW recommendations
- **Frost Protection:** The liquid component of the SUW (gut waste) will be trialled as a frost protectant spray, due to it's high nitrogen content, which plays an important role in plant cell hardening



Graph caption: Tomato plant height (cm) measured during the trial period for increasing sea urchin waste (SUW) fertiliser rates (0.3 % - 5.0 %), and standard fertiliser (Hoagland solution)

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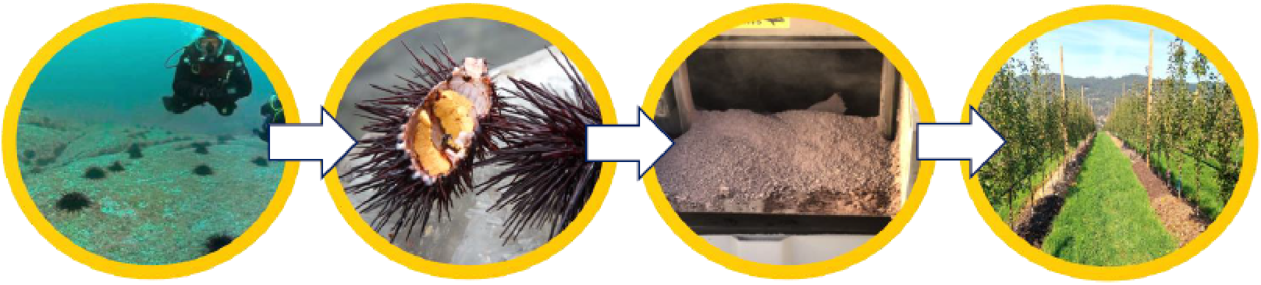
We are thankful to AIRF, FRDC and True South Seafoods for their support of this project

Appendix C

Sea urchin soil amendment / fertiliser



The story

Background

The long-spined sea urchin *Centrostephanus rodgersii*, is a **major threat** to kelp forests and the marine biodiversity of Tasmania's east coast. Since the late 1970's, urchin populations have migrated from mainland Australia down the east coast of Tasmania, due **to increases in water temperatures and warming ocean currents.**

Urchins graze extensively on kelp beds **producing lifeless sea beds**, otherwise known as "barrens", **displacing ~150 marine species.** Other parts of Australia, and the world, are facing similar urchin problems.

Urchin control & utilisation

There are now approximately **18 million** long-spined sea urchins off the coast of Tasmania, **a 75% increase in population density** from 2002 to 2017.

Commercially harvesting sea urchins for their **roe** has helped to **control urchin populations** in Tasmania. Yet, the roe only accounts for **~10% of the urchin biomass,** and in small production areas like Tasmania, this waste is **destined for landfill.**

Providing a commercial market for this **nutrient-rich waste stream** through processing it into an **organic soil amendment** promotes a **circular economy** through repurposing, recycling and value-adding, whilst tackling broader issues, such as **environmental and economic sustainability.**

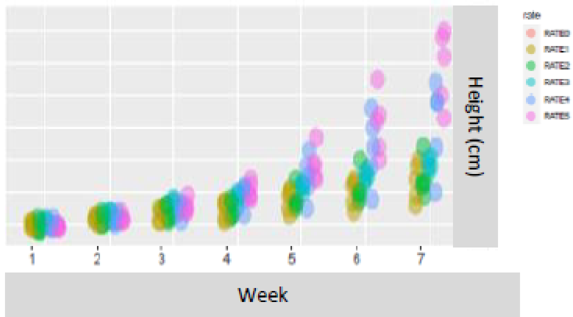
Processing technique

The research related to the sea urchin product and the product specifications outlined in this factsheet are from sea urchin waste processed via a facility that grinds the material, before turning it in an enclosed, heated (70°C) chamber for at least 14 hours.

Research

Fertiliser

A preliminary pot trial using the sea urchin (SU) product on potted sunflowers at five different rates (1, 2, 4, 8, 10% SU) showed that the more SU that was applied, the bigger the sunflowers became. The 10% SU rate promoted equal productivity to that of a conventional fertiliser.



The fertiliser abilities of SU continues to be explored at different rates on different soils in other crops, such as potatoes, lettuce, grapevines & apples.

Liming-plus product

SU has shown a great liming potential in trials to date. With the processing technique used, the greater the processing time, the greater the product break-down and the smaller the particle size, resulting in a greater liming potential. For example, in a heavy clay soil, ~20 t/ha of 14hr (coarser) SU and ~10 t/ha of 48hr (finer) SU was shown to elicit a ~1.0 soil pH increase 4 months after top-dressing. This pH change was equivocal to the change induced by a conventional liming product applied at the recommended rate (5 t/ha).

Table 1. Comparison of the sea urchin products nutrient composition against similar commercial marine by-product soil amendments

Nutrient	Unit	Sea urchin	Seasol liquid concentrate	Seasol super soil wetter and conditioner	Seasol advanced	Ocean 2 earth fish compost
N	%	1.00	0.1	0.04	1.5	0.66
P	%	0.05	0.01	0.002	0.2	0.38
K	%	0.28	1.5	0.7	1.4	0.19
S	%	0.46	0.1	0.029	0.039	0.14
Ca	%	33.5	0.043	0.021	0.039	2.63
Mg	%	1.47	0.034	0.008	0.004	0.48
Na	%	1.05	0.32	0.11	0.105	0.19
Fe	ppm	215	65	220	60	1.1
Mn	ppm	2.36	3	2	1	160
Zn	ppm	28.2	7	8	2	50
Cu	ppm	1.75	1	1.5	<0.5	10
Co	ppm	0.08	<0.5	<0.5	<0.5	4
B	ppm	38.9	8	2	2	60
Mo	ppm	0.18	<0.5	<0.5	<0.5	Trace
pH	1:5 method	7.94	10.5 – 11.4	10.5 – 11.4	10.5 – 11.4	7.11

PRODUCT HIGHLIGHTS

- Higher in nitrogen (N) than similar commercial marine by-product soil amendments/fertilisers on the market – *Nitrogen is the most limiting nutrient for plant growth, and it can be difficult to find in large quantities in organic soil amendments*
- High in calcium (Ca) – *Calcium is the main component of liming products, which are used to de-acidify soils to promote optimal growing conditions. Conventional liming products are obtained through the mining of natural resources and/or the high energy processing of rocks*
- High in key micronutrients, such as boron (B), iron (Fe) and zinc (Zn) – *important for plant health, growth and flowering*
- Meets Australian Standards for composts, soil conditioners and mulches (AS4454-2003) - *meets organic contaminant and pesticide concentrations, pathogen (Salmonella spp., Faecal coliforms) and heavy metal thresholds, and basic physiochemical requirements*

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