PFR SPTS No. 24215

Experimental future vineyard prototype planter pots

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June 2023

Confidential report for:

Marlborough Research Centre Trust
Project 3

CONFIDENTIALITY

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PUBLICATION DATA

Martin D, Theobald J. June 2023. Experimental future vineyard prototype planter pots. A Plant & Food Research report prepared for: Marlborough Research Centre Trust. Milestone No. 95994. Contract No. 40821. Job code: P/413003/15. PFR SPTS No. 24215.

KEYWORDS: Grapevine, lysimeter, soil, root, design.

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June 2023

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1 Introduction

A key element of Plant & Food Research (PFR) Marlborough's research strategy is the development of a world-leading viticulture research facility that will be the vineyard equivalent of the Bragato Research Institute (BRI) Research Winery. The PFR Senior Leadership team have committed to the creation of the Experimental Future Vineyard (EFV), which will become a world focal point for the integrated above- and below-ground study of vineyard production systems. The EFV will integrate the parallel development of a revolutionary vineyard production system with sensing, deep learning, modelling and robotics technologies. Further, the EFV will be a facility to prepare the New Zealand wine industry for the digital future as a hub for collaborative co-innovation, a learning resource for vocational education, and as a demonstration and evaluation facility for technology developers in the Viti/Ag-Tech space. The facility will also support multi-sector research, aligning with Marlborough Research Centre (MRC)'s mandate to fund research for the benefit of other Marlborough industries and/or the environment and community at large.

As part of the existing collaborative work to develop the EFV, we received funding from the Marlborough Research Centre Trust (MRCT) to design and prototype build large-volume (cubic metres) cylindrical, modular planter pots. These pots, technically referred to as lysimeters, will be a critical component of the EFV experimental platform. The primary purpose of a lysimeter is to quantify and understand the water balance and related processes within a specific soil system. It provides valuable data for various applications, such as water management, irrigation optimization, groundwater modelling, and environmental impact assessment. By measuring water movement through the soil profile, researchers can evaluate plant-water relationships, nutrient dynamics, agrichemical transport, and the overall hydrological behaviour of the system. Researchers in Marlborough will be able to test water infiltration, evapotranspiration, nutrient leaching, and contaminant transport across a range of local soil types and textures. Amongst the major science questions that the lysimeter system will help us answer are:

- What are the limiting factors to grapevine photosynthetic output? Leaf removal and shading studies indicate that there is 20–30% of untapped capacity under normal vineyard conditions. Why are grapevines not operating at 100%?
- What is the ideal grape growing system to meet future production targets within future constraints? Are these systems different for different soil types in Marlborough? How might they change under a warmer climate?
- How do we better understand and manage below-ground ecosystem function? How do we build more soil carbon? How do tailored soil microbiomes and arbuscular mycorrhizal fungi (AMF) function to provide more resilient systems (e.g. water, nutrient cycling and uptake, disease tolerance)? Full above- and below-ground partitioning experiments, monitored through below ground gas exchange, would establish annual carbon budgets and identify the carbon cost of investment in overwintering/perennial biology.
- What are vineyard nutrient fluxes and pesticide/herbicide fate under different soil types, canopy and groundcover scenarios?

Highly controlled experiments will help us more quickly develop response curves and provide validation data for the Vineyard and Orchard Digital Twin programme of work within PFR. Work will also directly provide a platform and validation loop for the Instrumented Orchard programme.

2 Methods

2.1 Lysimeter design

Lysimeters come in different designs, but a common approach is the use of a cylindrical or rectangular container with precise dimensions and a controlled drainage system. The container should be made of non-reactive, impermeable materials to ensure that water movement is limited to the soil within the lysimeter. The dimensions of the lysimeter should be representative of the study area, to ensure accurate measurements (Simunek et al. 2003). From a practical perspective, and particularly within an EFV facility, we would expect planter modules containing vines to be periodically ‘portable’ using an overhead gantry crane system, and that for ease of portability and access, they would sit within semi-permanent in-ground sleeves. To that end, design and development of independent trellis and vine support systems are also necessary, as well as proof-testing of planter system structural integrity.

2.1.1 Material selection

The selection of materials for building a lysimeter is critical to avoid interference with the water and soil chemistry. The container can be made of stainless steel, PVC, or fibreglass, which are non-reactive and durable. The bottom of the lysimeter should have an impermeable layer, such as a rubber membrane or a plastic liner, to prevent water loss through the base.

2.1.2 Installation

Lysimeters are typically installed in the ground, representing the natural soil profile as closely as possible. The installation process involves digging a hole that matches the dimensions of the lysimeter and carefully placing it into the ground. The lysimeter should be installed in a location representative of the study area, away from trees or other vegetation that could affect water balance.

2.1.3 Data collection

Lysimeters are equipped with sensors and instruments to collect data on water content, water pressure, temperature, and possibly other parameters depending on the research objectives (Wang et al. 2017). Our fully equipped planters will be fitted with below-ground soil and root, and above-ground vine and environmental monitoring technologies. Development work will also include soil reconstitution and address the feasibility of transplanting mature field vines with in situ soil and root systems largely intact, into the planters. The collected data can be used to calculate water fluxes, evapotranspiration rates, nutrient concentrations, and pollutant transport. Various techniques such as weighing lysimeters, time domain reflectometry (TDR), tensiometers, and soil moisture sensors can be employed to measure these parameters (Vereecken et al. 2008). The project will cover sensor choice (type and brand), placement and installation criteria within the planter modules. PFR already has a large programme of work (Digital Horticulture Systems (DHS) – The Instrumented Orchard) which is tasked with identifying sensor types and placement for apple orchard monitoring. PFR has also extensively used instrumented lysimeters in arable and pastoral systems. The latest lysimeter was built by PFR (with joint funding) in Southland for dairy research activity. Our programme will springboard off that knowledge to tailor methods for vineyard monitoring and extend the suite of instruments to enable detailed study of soil and plant root function at multiple depths.

3 Results

3.1 Lysimeters from PFR Lincoln

As part of the process of investigating what technologies and hardware is/was used within PFR for lysimeter development, we became aware of an experimental system that was established at PFR Lincoln in the early 2010s by soil and plant modeller Hamish Brown. The 24 lysimeters that were developed were for measuring the effects of stone content on root function and water extraction in shallower-rooted pasture and arable crop stands, and as such have modest cylindrical dimensions of 500 mm diameter, 700 mm deep and a wet filled weight of 250 kg (Figure 1). They were filled with reconstituted silty/stony soils of types very comparable to those found in the Rapaura Road area of Marlborough, and equipped with multiple soil moisture sensors in each lysimeter. This experimental platform and the data previously generated from it were a valuable resource on which our larger EFV lysimeter/planter development could expand. Further, as these ‘mini-lysimeters’ were no longer being used at PFR Lincoln, we have been able to secure long-term access and have relocated them to PFR Marlborough where they will act as an additional valuable platform to feed into the EFV. Not least, young vines of Sauvignon blanc and Pinot noir already established in the MRC Tunnel House in 2022/23 can be transplanted into them for the 2023/24 season and prior to larger-scale EFV planters in a subsequent season, thus giving a head-start whilst the EFV facility is constructed and commissioned.

Figure 1. Images of the Plant & Food Research Lincoln ‘mini-lysimeter’ platform developed in the early 2010s for studying root function and water extraction in shallower-rooted pasture and arable crop stands.

Amongst techniques and methods developed by the PFR Lincoln team and which provide valuable lessons and opportunity for the EFV were validation of methods for using frequent crop stand/canopy infra-red (IR) temperature measurements, and data to estimate evapotranspiration (ET); the development of theory for combining canopy monitoring and ET modelling to give spatial estimates of potential ET; and a clear and developed understanding of experimental work measuring the effects of stone content on water extraction. Some of this work is summarised below in Figure 2 and is provided courtesy of Dr Hamish Brown, PFR Lincoln.

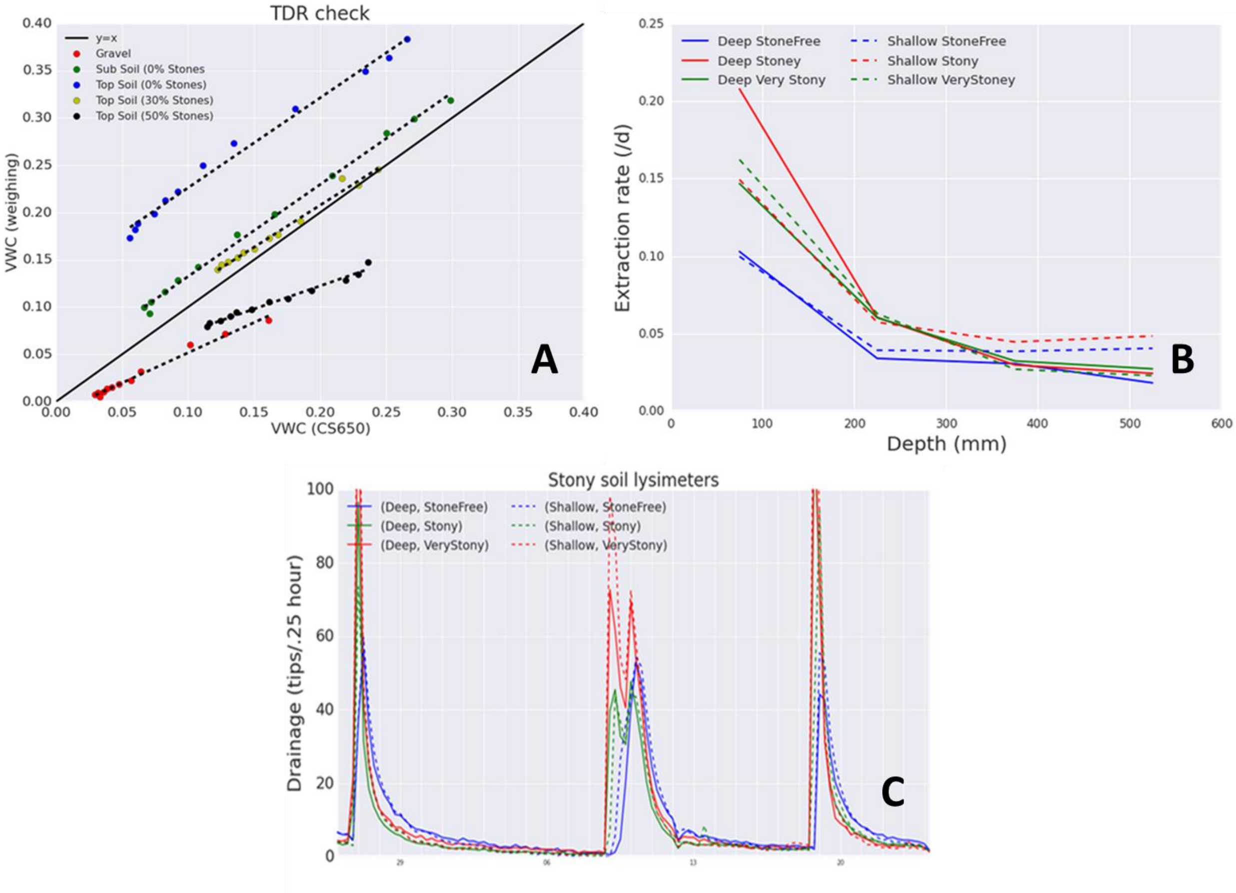

Figure 2. Snapshot of valuable data generated by the Plant & Food Research Lincoln ‘mini-lysimeter’ platform: A) calibration of different compositions of stony soils by lysimeter weighing versus volumetric water content soil sensors, B) moisture extraction rates from different compositions of stony soils and at different lysimeter depths, and C) leachate (water) drainage patterns from different compositions of stony soils. Data courtesy of Dr Hamish Brown, PFR Lincoln. TDR = time domain reflectometry.

3.2 Prototype planter construction

In designing a large-scale prototype lysimeter or planter for the future EFV facility, various options have been explored, including discussions for ‘bespoke’ designs with local Marlborough-based companies Indac and Ecopipe, and equally exploring modifiable “off-the-shelf” options. Whilst discussions with Indac and Ecopipe continue with regards to the final EFV infrastructure solution, for expediency in this project, an off-the-shelf solution was found in the form of 1.2-m lengths of cylindrical Acrowtube (Acrow Ltd, Christchurch, NZ) measuring 1.05 m in diameter and providing a fill volume of 1.04 m^3. Whilst typically single-use and disposable, Acrowtubes are light-weight PVC tubes (wall thickness approximately 6 mm) with superior strength and waterproof capabilities and commonly used in the construction industry as formwork in which to pour concrete and create for example, motorway fly-over supports and pillars. For our application, Acrowtubes appeared to be a suitable prototype solution meeting many of the requirements outlined in Section 2.1.1. above.

To one end of each Acrowtube length, a 20-mm thick marine plywood circular base was cut to fit tightly within, and then held in place using support washers and No.10 galvanised screws drilled through from the outer wall (Figure 3A). Internally within the planter, the plywood base and inside wall up to a height of 300 mm were coated and sealed twice using an acrylic polyurethane waterproofing membrane (Express Wet Area, Dunlop, NZ; Figure 3B). Prior to filling with soil, each individual prototype planter, of which four were constructed, was then permanently placed onto a strong plastic pallet (minimum dimension 1 x 1 m) for periodic portability using an available pallet truck with a necessary 2.5-tonne lifting capacity.

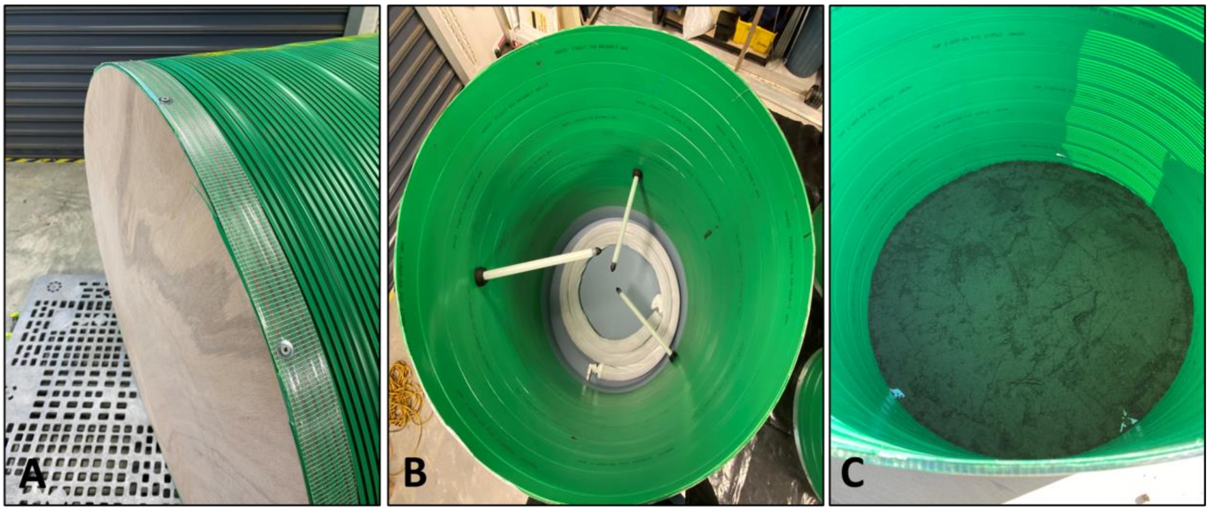

Figure 3. Prototype grapevine planter construction showing, A) attachment of 20-mm marine plywood base to Acrowtube, B) grey/light blue acrylic polyurethane waterproofing membrane, drainage system and placement of soil moisture sensor access tubes, and C) levelled and lightly compacted sand drainage layer.

3.3 Planter drainage

A drainage system for the collection of leachate comprising 5.8 m of Drainflow 65-mm diameter polypipe (Marley NZ, Auckland) and a protective FilterSLEEVE™ preloaded drain filter (Cirtex, Thames, NZ) was installed in each planter (Figure 3B above). The outlet of the drainage pipe was reduced and turned at a right angle to the main pipe using 25-mm PVC fitting which then exited through the wall of the pot 20 mm above the base. The drainage pipe was then covered with a 20-cm layer of coarse river sand (2–4 mm) referred to as “mortar sand” and sourced locally from the Crafar and Crouch Ltd, Wairau River Quarry, near Kaituna. Water was then added to the planter to above the line of the sand to help it settle around the pipe and to test the drainage function. Further sand was added to achieve a level surface on the drainage layer once the water had evacuated (Figure 3C above).

3.4 Reconstitution of silty soils

Subsoil silt to fill two of the four planters was sourced from the large stockpile on the Te Pūkenga Nelson Marlborough Institute of Technology (NMIT) campus left over from the BRI winery excavation. Cone penetrometer (Eijkelkamp, Giesbeek, The Netherlands) tests of nearby undisturbed vineyard subsoil provided readings of 600–800 Nm using a No. 4 cone tip.

Prior to filling with silt, a layer of DuraForce Geotextile (AS240; Cirtex, Thames, NZ) was laid over the sand drainage layer and 100 mm up the internal planter wall, to prevent ingress and potential damage (blocking) to the drainage system from future vine roots exploring the soil core (Figure 4A). Pots were filled in layers of approximately 5 cm depth with dry friable silt. Each layer was then compacted using a 205-mm square-based All Steel Tamper (earth rammer; Figure 4B). Penetrometer tests were regularly carried out and the soil was compacted to a minimum of 500–600 Nm to simulate densities of intact vineyard subsoil. As the pots filled, the weight of the silt itself contributed to the compaction. Less ramming was required to achieve the required soil compaction in the upper half of the planter, and penetrometer readings tended to increase into the 600–800 range.

Hardened semi-opaque plastic access tubes 500 mm long and 28 mm OD (Delta-T; Scott Technical Instruments, Hamilton, NZ) for receiving a portable soil moisture probe (Delta-T PR2/4 SDI-12; Scott Technical Instruments) were installed horizontally and secured to the planter wall through a 30-mm aperture tank fitting nut and flange at 900-, 600- and 300-mm depths during the filling process. Viewed from above, these access tubes were further offset from each other by 120° (Figures 3B above, and 4B below). Care was taken to ensure that soil was in close contact and for support (to prevent curvature) was adequately compacted on the underside of each tube along its full length. To avoid damage to the tubes, soil was then placed along the sides and on top of the tubes and firmly compacted by hand before carefully introduced compaction using the earth rammer.

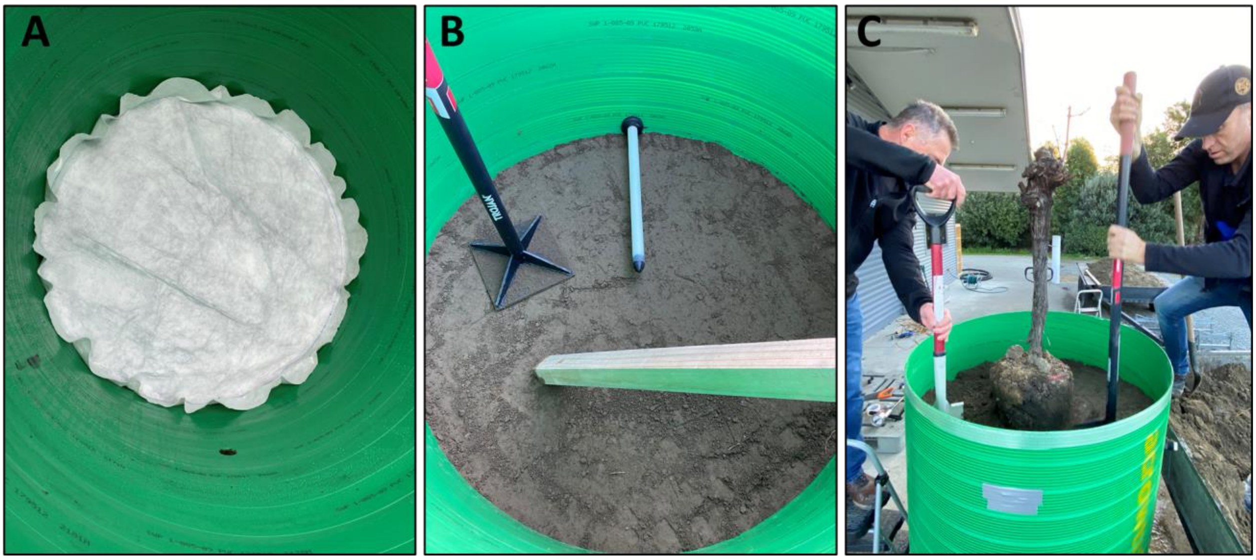

Figure 4. Prototype grapevine planter construction and filling with silt soil showing, A) DuraForce Geotextile membrane layer to prevent root penetration into sand drainage system beneath, B) compaction of silt soil using steel tamper (soil rammer) approaching level of first horizontal soil moisture sensor access tube, and C) levelling and tamping of final silt sub-soil layer around transplanted vine, prior to adding sods of intact topsoil from the Nelson-Marlborough Institute of Technology vineyard.

Using the same installation approach as access tubes for soil moisture sensing, two mini-rhizotrons per planter were also installed. Mini-rhizotrons are similarly tubular, 500 mm long with outside and inside diameters of 70 and 64 mm respectively, and constructed from clear acrylic (Cambrian Plastics, Henderson, NZ) with a flat acrylic base silicone sealed on one end and inserted horizontally into the soil column. These clear tubes into which an image scanning device (current CAPEX request for an CI-600 In Situ Root Imager (CID Bioscience Inc., Camas, Washington, USA; submitted by Dr Stewart Field, Te Pukenga) or specialist camera equipment can be inserted, are used to monitor root growth, size, branching and turnover. A mini-rhizotron was inserted at each of 600- and 300-mm depths and directly opposite (180°) the soil moisture access tubes. It was considered that mini-rhizotrons at greater depths (at least in silt soils) could be inserted retrospectively once vines were fully established in planters.

During development of prototype planters, we became aware of an innovative approach developed at Lincoln University in the potential collaborative group of Dr Eirian Jones (Shi et al. 2011), for the repeated in situ sampling and direct collection (or biopsy) of roots, rhizosphere, bulk soil and root exudates for amongst other objectives, monitoring soil carbon inputs and turnover (sequestration). Whilst filling planters and to provide subsequent access to the soil core, this required the creation of horizontal access cores 50 mm in diameter by 450 mm long and maintained (between sampling) by insertion of inflatable and thus removable tubes (modified bicycle inner-tubes). Three access cores were created in each planter at depths of 900, 600 and 300 mm.

In the silty soils, mature vines excavated with an intact soil root-ball from commercial vineyard sites as part of the MRCT-funded trunk disease research project (Mundy 2023), were transplanted into planters once the level of the sub-soil was approximately 500 mm from the top (Figure 4C). Filling of planters with the silty subsoil was terminated at 250 mm from the top.

Finally, intact 20-cm deep sods of topsoil sourced from the headlands of the adjoining NMIT vineyard were placed in the planters to provide a seamless understory cover and complete the filling process (Figure 5).

Figure 5. Finished 1.04-m^3 prototype grapevine planter containing leachate drainage and collection system, reconstituted, layered and compacted silt subsoil, various instrument sensing access tubes and intact transplanted mature vine from a commercial Marlborough vineyard.

3.5 Reconstitution of stony soils

The planter construction and drainage systems described in Sections 3.2 and 3.3 were also used for the reconstitution of stony gravel soils.

From both SMaps (https://smap.landcareresearch.co.nz/) soil texture data (Appendix 1) and detailed granulometry of Rapaura soils (Mills 2006), various mixes of aggregates were calculated, to provide the desired proportions of silt, sand and gravel for each soil horizon (Table 1).

Table 1. Particle size distribution of a Rakaiaf (2a.1) soil in the Rapaura road area of Marlborough.

Rakaia Stony gravels	Size Range	0–15 cm	15–30 cm	30–70 cm	70–150 cm
Cobble (%)	64–256 mm	15	20	28	34
Pebbles (%)	4–64 mm	13	20	35	53
Granule (%)	2.0–4 mm	0	0	1	1
Very coarse sand (%)	1.0–2.0 mm	0	0	1	1
Coarse sand (%)	0.5–1.0 mm	1	1	2	3
Medium sand (%)	0.25–0.50 mm	9	9	8	7
Fine sand (%)	0.063–0.25 mm	30	24	11	1
Coarse Silt (%)	0.031–0.063 mm	15	12	6	0
Medium Silt (%)	0.016–0.031 mm	12	10	5	0
Fine Silt (%)	0.004–0.016 mm	3	2	1	0

A range of aggregate sizes from sorted alluvium was sourced from the Crafar and Crouch Ltd, Wairau river quarry near Kaituna (Figure 6).

Figure 6. Selection of locally sourced Marlborough (Kaituna) aggregate for the reconstitution of stony soils. Clockwise from lower left, large stones, stones, plastering sand, large gravel, concrete mix, mortar sand, and pea metal (refer also Table 2 below).

Table 2 shows the approximate particle size distribution of the aggregates and the mix ratios (by weight) to achieve the target soil textures shown in Table 1.

Table 2. Aggregate sizes and the mix ratios (by weight) of sorted alluvium from a river quarry near Kaituna.

Quarry name	Size range	Mix (0–15 cm)	Mix (30–70 cm)
Large stones	> 100 mm	8%	17%
Stones	60–100 mm	7%	11%
Large gravel	40–60 mm	4%	10%
Gravel	20–40 mm	4%	9%
Concrete mix	16–19mm	3%	9%
Pea metal (river)	5–13 mm	3%	8%
Mortar sand	2–5 mm	1%	3%
Plastering sand	0.06–2 mm	38%	19%
River silt	< 0.06 mm	32%	14%

The mix proportions in the Table 2 recipes were used to manually fill an electric concrete mixer of approximately 100-kg capacity. The mixer was run for 5 minutes with an alternating wet/dry mix to simulate varying soil saturation conditions during the build-up of the soil layers. Stones (40–60 mm) were manually placed within the pots at regular intervals to avoid interference with the various access tubes being installed. The dry layers were lightly compacted using the earth rammer but not so hard as to cause a re-distribution of layering of the soil particle sizes within the batch from the concrete mixer. Occasional large stones (> 100 mm) were also manually placed to add realism to the reconstituted soil profile.

Installation of the access tubes for the soil moisture probe monitoring, mini-rhizotrons and access cores for root sampling was carried out as for the silty soils (Section 3.4), except that fine sand (< 2 mm) was used to fill gaps and assist with making a good contact between the tubes and the gravel.

4 Conclusions

Through the course of 2022/23 we have defined and tested the methodologies for reconstructing soils or installing intact vines and soil within a prototype modular planter system. This includes commissioning Cuddon Engineering to design tailor-made hardware to facilitate extraction of vines and soil cores. We have also identified the specific parameters and variables to measure within, on, or above the planter system as functions of specific research objectives.

We have established productive relationships with local companies such as Indac and Cuddon as well as Marlborough-based national firms (Infrapipe) as suppliers of choice for the key infrastructural components of the planter system. Preliminary meetings and discussions have successfully laid the foundation for a fruitful partnership, leveraging their expertise and incorporating their insights into the prototype design process.

Through field trials we have developed safe and practical approaches, operating procedures and protocols for reconstructing soils or transferring intact vines and soil into the planters. We have also conducted analyses of the cost, scope, and scientific application of the latest instrumentation and sensor equipment. This work was carried out in collaboration with PFR colleagues undertaking a similar task for the Instrument Orchard project within the Digital Horticulture Systems programme, which has resulted in a thorough understanding of their capabilities and utilisation in our research.

Sensor access tubes were successfully installed within soils of the planter prototypes, ensuring probe fit and sampling access requirements were met. A brief series of measurements have been taken and coupled with calibration data sourced from existing stony soil lysimeters, we have valuable data, serving as a starting point for further analysis and investigation.

Owing to high set up costs and the large-run nature of the plastic extrusion systems, it has not been possible to secure pre-production units of exactly the same design and materials as per the planter specifications. The prototypes were eventually built from lower cost, readily available materials to simulate size, weight and filling conditions. We have therefore not been able to test and evaluate the structural integrity and durability of these prototypes.

We have nevertheless successfully constructed and tested four prototype planter pots. This groundwork has been essential for the upcoming development of modular planters for the Experimental Future Vineyard facility. The prototype planters were filled with either silty or extremely gravelly material to provide a wide range of bulk density targets. Based on the prototype planter weights, the maximum planter weight we anticipate is 3.7 T. Our upper-end weights on the prototypes gave a soil bulk density of 1.8 T/m^3, a 300-L drainage wet load and a 300-kg planter+base weight. An efficient passive drainage system was designed and tested. Each pot was fitted with soil moisture, mini-rhizotron and root biopsy access tubes. Soil moisture probes were gravimetrically calibrated to a 5% or greater accuracy providing assurance that the access tube installation process and the chosen measurement technology were performing to requirements.

These results provide confidence that the sleeve, crane and Cravo specifications as at June 2023 are fit-for-purpose and PFR can confidently proceed with the contracting and ordering of the material required for the full construction of the first 16 planters.

5 Acknowledgements

We extend our gratitude to campus colleagues Glenn Kirkwood and Stewart Field from NMIT, Carmo Vasconcelos from Bragato Research Institute, and our PFR colleagues for generously giving their time and providing invaluable insights during the course of this work.

6 References

Mills T 2006. Relations among geology, soil type and Sauvignon Blanc vineyard variation in Marlborough, New Zealand. Masters of Science thesis. The University of Auckland. Auckland.

Mundy D 2023. Transplanting mature grapevines into pots. A Plant & Food Research report prepared for: The Marlborough Research Centre Trust. PFR SPTS No. 24207.

Shi S, Condron L, Larsen S, Richardson AE, Jones E, Jiao J, O'Callaghan M, Stewart A 2011. In situ sampling of low molecular weight organic anions from rhizosphere of radiata pine (Pinus radiata) grown in a rhizotron system. Environmental and Experimental Botany 70: 131-142

Simunek J, Jarvis NJ, van Genuchten MT, Gardenas A 2003. Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone. Journal of Hydrology 272(1-4): 14-35.

Vereecken H, Huisman JA, Bogena H, Vanderborght J, Vrugt JA, Hopmans JW 2008. On the value of soil moisture measurements in vadose zone hydrology: A review. Water Resources Research 44.

Wang YY, Ochsner T, Heitman J, Horton R, Xue XZ, Ren TS 2017. Weighing Lysimeter Data Confirm the Accuracy and Precision of the Heat-Pulse Technique for Measuring Daily Soil Evaporation. Soil Science Society of America Journal 81(5): 1074-1078.

Appendix 1

Manaaki Whenua Landcare Research 2023. Soil Report Rakaiaf 2a.1. Retrieved June 2023 from: https://api-factsheets-smap.landcareresearch.co.nz/reports?access=region&region=mdc&smapfactsheetid=786113b6-fb2e-41f0-a3d3-3e03b5298407&type=region-v2.

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Martin - Experiment

*In Word document: Double-click on above **icon** to open embedded documents.*

*In PDF: Double-click on relevant **Appendix** in left side 📎 “Attachments” pane.*

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