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Research Article

Assessing the Sustainable Economic Benefits of Clonal Tissue Culture in Fruit-Tree Industries: A Scenario-Based Avocado Case Study in Australia

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There is an increasing global demand for fruit/nut tree foods. Traditionally, these trees are propagated via grafting onto rootstocks grown from seeds or using the double-grafting technique, but this is laborious, expensive, and slow to provide seedlings to the industry. Although clonal tissue culturing can improve the supply and quality of seedling rootstock year-round, little is known if this propagation technique is economically viable at the commercial scale. This study aims to fill this gap by investigating the economic benefits to avocado growers of clonal tissue-cultured seedling adoption over traditional propagation methods. Queensland is the largest producer of Australian avocados; therefore, we used a bioeconomic model of an indicative Queensland avocado farm under different adoption scenarios. Bio-physical and economic data were collected from local Queensland farms, nurseries and advisors. Findings revealed that the scenario of supplying fruit trees a year earlier with clonal tissue culture rootstock had greatest financial benefits to growers. For an indicative 25-ha avocado farm, this included reduced investment costs of A$250k during the earlier years of production, a payback period shortened by 1.78 years, average earnings increased by A$3373/ha/year, and the grower's wealth increased by more than $840k after 20 years. This increased wealth is from earlier seeding supply, which equates to a similar benefit from increasing crop yields by 10% over the 20-year time horizon. This research contributes towards science technology adoption, product commercialisation, industry adoption theories, and provides further insights into the sustainable economic benefits of clonal tissue culture to avocado farmers' resilience through increased gross margins, reduced initial capital investment, shorter payback periods, and thereby reducing the risk typically associated with establishing perennial tree-crop enterprises. Globally, other fruit/nut tree industries may benefit from clonal tissue culture, not only through possible yield increases, but more importantly through shorter breeding cycles for cultivars to increase the supply of seedlings when required.

Keywords: avocado; clonal tissue culture; commercial feasibility; economic benefits; scenario modelling; sustainable development; traditional propagation

1. Introduction

The world is increasingly facing a supply shortfall in plant-based diets (PBDs) in response to their growing demand [1, 2]. Despite ever-increasing agricultural technology and production, there is a continued global gap between fruit and nut production and recommended consumption levels for a balanced nutritional diet, including edible tree-crop fruits and nuts [3, 4]. This shift in global demand is driven by consumers' increased awareness of the health benefits of

PBD [5–9]. Avocado (*Persea americana* [fam. Lauraceae]) is often included in PBD, with health benefits including improved cardiovascular health [10]; blood lipid profile, weight management, geriatric health [11]; better cholesterol management [12]; and better cancer and diabetes management [13]. By the year 2030, avocado is predicted to become the most commercially traded tropical fruit globally [14, 15]. There has also been increased avocado production for local supply and demand. For example, Australia is within the top 20 global avocado producers but imports and exports little, with a focus on local supply, the majority of which has traditionally come from Queensland [16]. There is also a need to develop new avocado varieties that can meet the increasing market demand, overcome biophysical production challenges (such as pests and diseases), maximise economic returns, and mitigate environmental impacts [17].

Increased avocado production increases growers' demand for seedlings. Avocado-tree nurseries can produce plants using different plant propagation techniques. This includes growing seed stock, using rootstocks, cuttings, air layering, and tissue culture grafting techniques [18, 19]. Production cycles of commercial nurseries vary based on the propagation techniques used. There are currently two primary methods of supplying fruit and nut tree seedlings to industry: (1) growing rootstock from seed, and (2) the double-grafting method; each method has benefits and limitations to meet industry demand [19].

Growing rootstocks from seed for desirable rootstock ensures plants are true to type, where bud-wood (scion) is grafted from desirable mature fruit trees. The selection of both the scion and rootstocks is based on biophysical attributes for both fruit quality and production. The scion is often selected for fruit quality, fruit set, and commercial preference, and the rootstock is selected for dwarfness, soil constraints, and pest and disease resistance [19]. While the scion is often readily available from mature trees, traditionally grown rootstock is often limited by seed supply to grow the rootstock. Additionally, the possibility of cross-pollination risks genetic instability [19]. It also takes time to grow seedlings from seeds. Both these physical restrictions result in a bottleneck in the rootstock supply for grafting.

Alternatively, Frolich and Platt [20] developed the double-grafting propagation technique over five decades ago, also called clone rootstock propagation, specifically for avocado trees, in which the scion root material is grafted onto a seedling. The grafted plant is then etiolated (growth that is pale and elongated due to suppressed light), to encourage the buds of the grafted scion to elongate. Rooting hormones are applied to the base of the etiolated shoot to encourage root growth. Once the roots are established, the plant is then allowed to harden off. The bud-wood scion is grafted to the cloned rootstock. Once established, the upper portion (the clone rootstock and grafted bud-wood scion) is removed from the original plant to produce a new clone seedling. The advantage of this process is that the plant is true to type; however, the process is laborious, expensive, and slow to provide seedlings to industry [19]. The long breeding cycle of traditional seedling propagation methods results in variability in tree size, yield, and fruit quality [18]. From the beginning of the propagation process, it takes up to 10 years for a plant to bear avocado fruit [19]. Purchased seedlings take around 3 years to reach commercial productivity and another 7 years to reach full yield maturity. This laborious and expensive technique of supplying clonal rootstocks is limiting avocado growers from obtaining desired seedlings and satisfying fruit supply [19, 21]. This constraint, delayed supply, is not uncommon in other fruit and nut tree industries.

In contrast, recent technological breakthroughs in clonal tissue cultured seeding techniques are believed to be one of the effective means to meet this supply shortage in PBD (avocados used as an example in this paper) [1, 19, 22, 23]. The development of clonal tissue culture technology to grow rootstock may remove the dependency on seed material for rootstock supply for many of these fruit and nut tree industries. Hiti-Bandaralage et al. [19] investigated the merits of using clonal tissue-cultured micropropagation techniques for avocado rootstock with an aim to produce hundreds of clonal seedlings from a single shoot tip. Since then, lab experiments at the University of Queensland have demonstrated that within a 12-month period, more than 500 seedlings can be produced from a single cut [24]. With the added advantage of only needing a single graft with the scion bud-wood to produce an industry-ready full clonal plant. Clonal tissue culture micropropagation has six main processing or growth stages [19] as follows:

1. Selection, sterilisation and callus induction stage: Explant (living tissue) cuttings are taken from the mother-stock plant, which itself could be grown from clonal tissue culture and are typically disease-free plants grown under greenhouse conditions. The cuttings are sterilised to ensure the material is not compromised and placed in a sterile, nutrient-rich medium in a controlled growth room.
2. Multiplication and shoot elongation stage: Nutrient-rich culture media are used to promote the multiplication and the elongation of shoots. These are then separated into single shoots with leaves, which will become individual clonal tissue-cultured plants.
3. Root regeneration and elongation: The culture media are then optimised to promote root regeneration and elongation.
4. In vitro hardening, root induction and acclimatisation of plants: The plants are carefully climatized to nursery conditions. The in vitro-grown plants initially lack proper leaf and root structures for external environmental conditions and therefore require a hardening phase. First, the plant stems and leaves are allowed to harden to become more resilient to non-in vitro climatic conditions. Then the roots are introduced to basal nutrient composition (potting medium) for both shoot and root induction. The plants are then acclimated to high-humidity nursery conditions until they have been fully climatized and ready for the grafting of the bud-wood (scion).

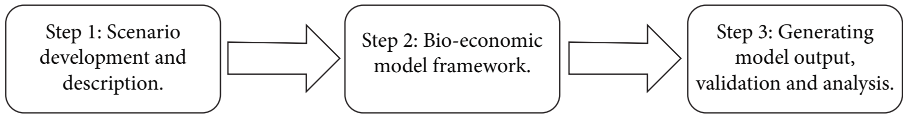

Figure 1: Steps involved in the scenario-based economic benefit analysis.

5. In vitro root generation: This is the most problematic stage, as it is a burdensome process and difficult to achieve. It is the latest technological breakthrough in this stage that has the potential to ameliorate restrictions to clonal tissue culture micropropagation adoption by industry.
6. Acclimatisation: This is the final stage, where plants transition from a sheltered tissue-culture environment that has a copious supply of mineral nutrients, moisture and light to less favourable external environmental conditions. The plant undertakes both anatomical and physiological changes through this process.

Although there are still scientific challenges to realise the full potential of avocado plant breading, clonal tissue technology, and micropropagation, the development of new technologies comes at the risk of non-adoption by industry [17, 21]. Despite the practical benefits of using clonal tissue culture in horticulture industries, very few commercial evaluations have investigated the potential, and no known studies have been undertaken into the benefits and costs of clonal tissue-cultured avocado trees on a commercial scale. Additionally, studies [e.g., 25] have also highlighted the importance of economic analysis as one of the key pillars to stakeholder adoption. Thus, our study seeks to fill some of these gaps by examining the commercial feasibility of adopting clonal tissue culture propagation in the Australian avocado industry. This will be based on studies [19, 22, 23] suggesting that clonal avocado tissue culture plant technology can enhance avocado farm sustainability and efficiencies through increased production, shorter breeding cycles, better fruit quality, plant uniformity, virus-free seedlings, increased crop yields and/or lower tree mortality rates by matching plant attributes to local environments. Thorne et al. [21] also surveyed Australian avocado growers' attitudes about adopting clonal tissue-cultured avocado seedlings, with interests in earlier supply, quality, and seedling pricing. Therefore, the main objective of our study is to use bioeconomic modelling at the farm production scale to develop seven simulations based on the following scenarios:

1. Base-case with traditional seedling propagation.
2. Cloned seedlings supplied 1 year earlier and yield a year earlier.
3. Price premium of the new fruit variety due to cloned seedlings availability.
4. Combined benefit of fruit price premium and receiving cloned seedlings a year earlier.
5. Fruit yield increased by 10% from better quality cloned seedlings.
6. Higher quality cloned seedlings reduced tree mortality from 10% to 2%.
7. Cloned seedlings cost more, but they were supplied a year earlier.

2. Materials and Methods

The study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of the University of Southern Queensland (Approval Number: H18REA131 in 2018). The data (e.g., biophysical and economic inputs) were collected from existing orchards (through interviews with eight growers and one nursery) and overlaying the clonal tissue culture characteristics (through two University of Queensland field trials) to extrapolate yields, costs and financial returns. These data have been further triangulated with reviewed literature and expert feedback prior to generating model output, validation, and analysis that subsequently produce seven simulated scenarios.

Scenario-based economic benefits analysis has been extensively used in many different studies in the past that involve creating different scenarios to evaluate the potential economic outcomes, such as changes in production, revenue, costs and profitability. These previous studies have used scenario-based economic benefits analysis to investigate various aspects, such as renewable energy [26], environmental benefits [27], agricultural waste [28] and ecological restoration [29]. This study has adopted a three-step approach to conducting the scenario-based economic benefits analysis (Figure 1). Step 1 develops scenarios and describes them. Step 2 develops the bio-economic model framework that sets out the input variables (e.g., biophysical and economic inputs) and the assumptions for each propagation technique (traditional and clonal tissue). Step 3 generates modelled production and economic output metrics for each scenario. Each of these steps will be discussed below.

2.1. Step 1: Scenario Development and Description. This involved developing scenarios and assumptions of an indicative avocado farm using traditional propagating techniques and tissue culture adoption scenarios. As proposed by Wiebe et al. [30] and Metzger et al. [31], the data collection and scenario development involved:

a. desktop review of literature and conducting five workshops with team members;
b. expert dialogues with avocado stakeholders: eight growers, one nursery;
c. developing assumptions and scenarios, based on literature review and expert feedback;
d. analysis scenarios impact assessment; and
e. validating scenario outcomes with stakeholders.

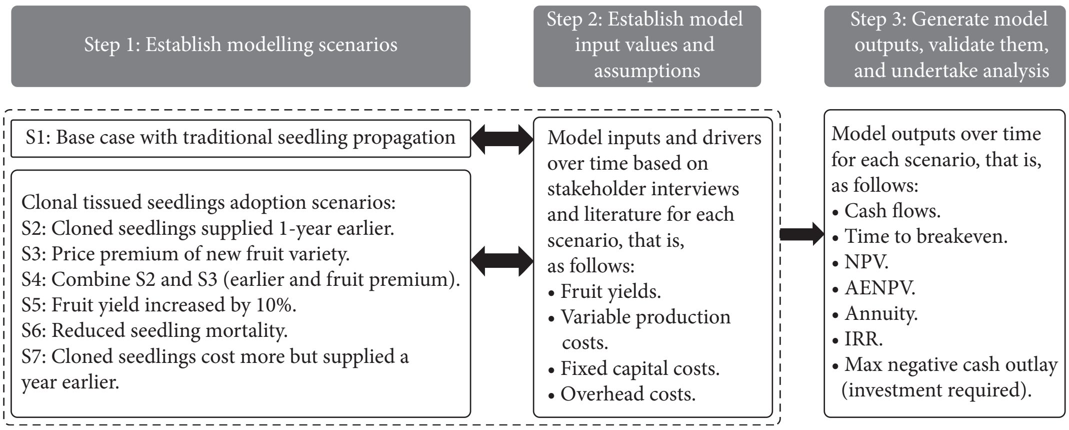

Figure 2: Bio-economic framework developed for this study.

This includes a baseline (S1: base case) using traditional propagation technique scenario and six alternative clonal tissue culture adoption scenarios (S2–S7):

1. S1: Base case, being an indicative 25-ha avocado farm established and run for 20 years using traditionally grafted seedlings.
2. S2: 1 year earlier yield from 1 year earlier tree seedling availability: if plants can be supplied to the orchard sooner than with traditional grafting, the plants can be planted sooner, and fruit yields brought forward by 1 year. The orchard will have higher yields every year until trees are at a steady state; therefore, cash flows should increase, and the payback period of capital investment should decrease.
3. S3: Price premium scenario for a new fruit variety (for 5 years): based on literature [32, 33] and conversations with industry stakeholders, we investigated a hypothetical scenario where the fruit of a new cultivar will receive a price premium for a few years. Therefore, we assume a new, higher-quality fruit variety can be sold in the market at a price premium for up to 5 years, and clonal tissue-cultured seedlings can meet this demand sooner than traditional grafted trees. The assumed price premium per year is Year 2 + $2.00/kg (100%), Year 3 +$1.60/kg (80%), Year 4 + $1.20/kg (60%), Year 5 +$0.80/kg (40%), Year 6 + $0.40/kg (20%) and Year 7 +$0/kg (0%) in addition the long-term average price of A$3.50/kg.
4. S4: 1 year earlier yield plus fruit price premium scenario (S2 + S3): assumes an orchard can expect an earlier yield (S2) from a new higher-quality fruit variety to the market from clonal tissue culture, attracting a premium price (S3) which diminishes over 5 years.
5. S5: 10% yield increase scenario: Assumes cloning of high-yielding varieties; clones will be developed that provide higher crop yields. In the absence of empirical evidence on the rate of increased yields, we relied on the advice of the avocado tissue culture project leader at Queensland Alliance for Food and Agriculture (QAAFI) at the University of Queensland. The QAAFI team hypothesised a 10% increase in yield based on their observed field trial data.
6. S6: Lower plant mortality scenario: This assumes that tissue culture technology can result in lower plant mortality rates. This assumption originates from the expectation of the QAAFI team, from field trials, that tissue culture plant mortality rate may reduce to 2% from an expected mortality rate of 10% with traditional planting. This scenario benefits growers from lower plant replacement costs of dead trees in the orchard.
7. S7: 1 year earlier yield from earlier plant availability and clonal tissue-cultured seedlings costing more than traditionally propagated seedlings: This scenario assumes growers' benefits from 1 year earlier yield due to increased seedling supply from the nursery, but at a higher plant price (from A$35/tree to A$70/tree). As the Australian nursery market is monopolistic in nature, the possible added cost of producing cloned seedlings and the demand for more plants may increase seedling prices.

2.2. Step 2: Bio-Economic Model Framework. Bioeconomic models are used to assess the ex-ante or ex-post effects on farm economic performance due to changes in technological or policy drivers [34, 35]. In this study, we adopted a simulation model [36] of an indicative 25-ha Australian avocado farm based on collected data from local Queensland farms, nurseries, advisors, and literature to capture local avocado practices and other attributes [37]. The bio-economic model combines bio-physical and economic inputs and drivers for each of the scenarios (Figure 2). The simulations include orchard establishment, fruit production and economic components include revenues, production costs and overhead costs over a 20-year period. We used the intuitive logics [38] of two groups: (1) expert participants, and (2) scholarly commentary in the literature [39]. One of the main benefits of using this intuitive-based scenario is that it facilitates a sense of 'internally consistent and challenging descriptions of possible futures' of avocado production to our diverse avocado growers and other fruit/nut tree industry audiences [40].

The farm-level bio-economic framework was run in Excel v16.0 Software on a Windows 11 computer. The two-sided arrows in Figure 2 indicate that the base-case

Table 1: List of modelling input parameters: base-case traditional grafting scenario (S1).

Parameters	Values
Plant purchase price	A$35/tree
Avocado farm gate price A$/kg	A$3.5/kg
Plant mortality (%; only in Year 1)	10% of traditionally grafted planted plants
Tree planting density	312 trees/ha
Hurdle rate/required rate of return	7%
Orchard capital structure	100% equity financing

scenario and clonal tissue cultures scenarios are interconnected with the model input, operations and output. This provided an understanding of typical production cost drivers, including pre-harvesting cost, harvesting cost, capital cost, and fixed overhead and revenue drivers, including farm gate price and sales quantity. The parameters were adjusted for each of the scenarios (S1–S7) within the bioeconomic model (refer to Supporting Information).

2.2.1. Biophysical and Economic Model Parameters and Assumptions. The S1: base-case key production input parameters over 20 years of simulations are presented in Table 1. Some of these parameters are adjusted for each specific scenario, for example, the marketable fruit yields (kg/tree/year). Inputs are reported in Table 2.

The biophysical inputs and the relevant costs in the first year of orchard establishment are presented in Appendix A (Table A1). The crop management inputs for Years 2–20 are presented in Appendix B (Table A2), and the associated costs are in Appendix C (Table A3). Capital costs and termination values for the S1: base case of an indicative 25-ha avocado farm, Years 0–20, are shown in Appendix D (Table A4), which includes items that are used for more than a year [41]. Orchard overheads, also known as fixed or ownership costs, arise from owning and using machinery, equipment, and buildings. The fixed overheads for the indicative 25-ha orchard are presented in Appendix E (Table A5), including general operating fuel, oil, power, office administration, insurance, permanent hired labour, repairs and maintenance, and rates.

2.3. Step 3: Generating Model Output, Validation and Analysis. In terms of key outputs of the avocado orchard model, we calculated: earnings before interest and taxes (EBIT), net present value (NPV), equivalent annual NPV (EANPV), maximum negative cumulative cashflow exposure (investment requirement), discounted payback period (DPP), and internal rate of return (IRR). The combination of these financial metrics is commonly used in the broader streams of agricultural research, such as avocado [42–44], apple [45, 46], forestry [47, 48], and farm technology [49]. These metrics are generated for each scenario (S1–S7).

While production and harvesting costs vary with the changes in crop yields in each scenario, farm overhead costs are expected to remain unchanged under all the S1–S7 scenarios. Production capital costs will also remain the same, but some move forward by 1 year in S2, S4 and S7 due to earlier crop production and increased yields. Risk and uncertainty are investigated with a sensitivity analysis [50]. This can highlight which drivers have the greatest impact on the enterprise's financial performance and are therefore deemed most risky. To do this, we increased and decreased each input category by 10% and then reported the average absolute change of each financial metric. This will only be undertaken for the base case (S1), being an indicative 25-ha avocado farm run for 20 years using traditionally grafted seedlings. This is due to the other scenarios (S2–S7) essentially resulting in very similar sensitivity to changes from market and production drivers.

3. Results

3.1. Economic and Financial Assessment of an Indicative 25-ha Farm Using Traditional Seedling Propagation. Orchard revenue is based on the total number of trees, marketable fruit yield (kg/tree), and farmgate avocado fruit price ($/kg) over time. From Years 0–2, there are no marketable crop yields; hence, the revenue is zero in these periods. Then crop yield gradually increases as trees mature, until they are fully mature, reaching steady-state production yields at Year 7 (Figure 3). This level of production persists for the remaining years over 20-year simulated investment horizon. The itemised details of average revenue per hectare, tree and per 5.5 kg tray are provided in Table 3 for traditional seedling propagation (S1).

There are high initial production and capital costs to establish the indicative 25-ha avocado orchard (Figure 3). The total cost includes crop establishment costs, production costs, capital costs and overhead costs. Some of the costs will be incurred before the end of the year in the first year, hence the negative capital costs in Year 0, as payments will be made throughout that year. As yields increase, total revenue increases. The difference between total revenue and total costs is the estimated annual enterprise profit measured as EBIT. Over 20-year period, the overall trend for each cost component of a 25-ha orchard is indicated in Figure 3.

The nature of different orchard cost behaviour has been summarised as follows:

- Tree establishment and management costs are greatest in Year 1. For the base case (S1) of the indicative 25-ha orchard, this is approximately A$609,000 (Figure 3). This is due to preparing the orchard site and buying seedlings. Over the 20 years, tree management costs equate to ~3.15% of the long-term average revenue (A$1410/ha/year, A$4.52/tree/year, and A$0.61/tray) (Table 3).
- Machinery operating cost is the next greatest production cost. For the base case (S1) indicative 25-ha avocado orchard, machinery fuel, oil, repairs and maintenance (FORM), and operation costs tend to be consistent over time. This cost was also the highest of all cost categories, around 15% of revenue being spent (Figure 3 and Table 3). The lowest machinery and operation costs (A$7,200/year) are in Year 1, as there is no fruit to pick and little machinery requirements; however, this increases over time until Year 7, where it stabilises at A$194,888/year. Over the 20 years,

Table 2: Avocado fruit yield over time (kg/tree/year) for each scenario.

Scenarios/Year	Yearly marketable fruit yield[a] (kg/tree)							
	0	1	2	3	4	5	6	7–20
S1: base case	0	0	0	12	26	38	45	50
S2: 1 year earlier trees and yields	0	0	12	26	38	45	50	50
S3: fruit price premium	0	0	0	12	26	38	45	50
S4: combination of S2 and S3	0	0	12	26	38	45	50	50
S5: 10 % yield multiplication	0	0	0	13	29	42	50	55
S6: lower plant fatality	0	0	0	12	26	38	45	50
S7: 1 year earlier yield and higher seedling price	0	0	12	26	38	45	50	50

[a]yield in scenario S2, S4 and S7 reaches maturity at Year 5 and remains constant in Years 6–20; yield in other scenarios reaches maturity at Year 6 and remains steady in Years 7–20.

Table 3: Average annual revenue and cost performance (A$) of an indicative 25-ha orchard under the base-case scenario with traditionally grafted seedlings (S1).

Average revenue and cost output parameters	Per ha	Per tree	Per tray	Percentage to revenue (%)
Average revenue	44,827	143.68	19.27	100
Average cost				
Machinery and operation	6810	21.83	2.93	15.19
Tree management	1410	4.52	0.61	3.15
Fertilisation	1910	6.12	0.82	4.26
Fruit protection	820	2.63	0.35	1.83
Irrigation	1990	6.38	0.86	4.44
Harvesting and freight	1537	4.93	0.66	3.43
Average total variable cost	14,477	46.40	6.22	32.30
Average gross margin	30,349	97.27	13.05	67.70
Other average costs				
Overhead	3909	12.53	1.68	8.72
Capital cost	1595	5.11	0.69	3.56
Average EBIT	24,845	79.63	10.68	55

machinery and operation costs equate to A$6,810/ha/year, A$21.83/tree/year, and A$2.93/tray (Table 3).

- Fertilisation and irrigation costs are almost equal in cost, slightly higher than 4% of the cost–revenue; both fertilisation and irrigation costs were equal to all cost categories of the 25-ha avocado orchard (Figure 3). Both costs gradually increase until Year 7. Over 20-year period, the average fertilisation cost was A $1,910/ha/year, A$6.12/tree/year, and A$0.82/tray. Irrigation costs equated to A$1,990/ha/year, A$6.38/tree/year and A$0.66/tray.
- Overheads are the second-largest cost to the 25-ha avocado orchard, averaging A$98,000/year with a yearly average of 8.7% of revenue (Figure 3 and Appendix E – Table A5). The average cost over the 20 years was A$3,909/ha/year, A $12.53/tree/year, and A$1.68/tray (Table 3).
- Capital costs (Appendix D – Table A4) were around 4% of the total cost for the base case, indicative 25-ha orchard (Table 3). The average capital expenditure over the 20 years is A$39,875/year, A$5.11/tree/year and A$0.68/tray (Table 3).

Table 4: Modelled financial performance of 25-ha orchard enterprise over 20 years.

Financial measures	Values
Net present value (NPV; A$ million over 20 years)	5.02
Equivalent annual net present value (EANPV; A$ million/year)	0.47
Maximum negative cumulative cashflow (A$ million)	−1.03
Discounted payback period (years)	5.96
Internal rate of return (IRR; %)	32.0

As illustrated in Figure 3, the EBIT is negative for the first 3 years but improves as crop production increases. The EBIT in Year 20 increased due to the terminal sale of capital equipment for $161,000. All capital equipment was sold in the final year of the project to realise the terminal cash flows in the last year and calculate the overall return for the 20 years. The average EBIT over the 20 years was A$496,899/year, A$24,845/ha/year, A $79.63/tree/year, and A$10.68/tray (Table 3).

The key financial metrics are summarised in Table 4, indicating the financial performance of the indicative 25-ha

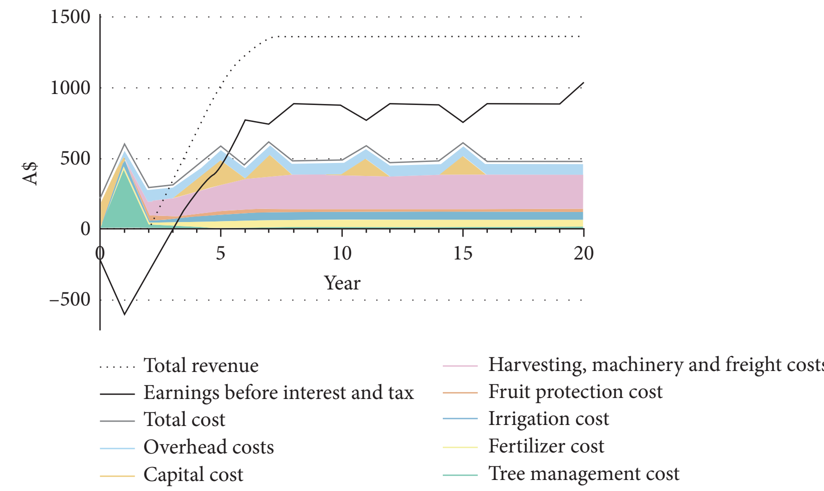

Figure 3: Total revenue, cost and earnings before interest and tax (EBIT) for an indicative base case 25-ha avocado enterprise over 20 years.

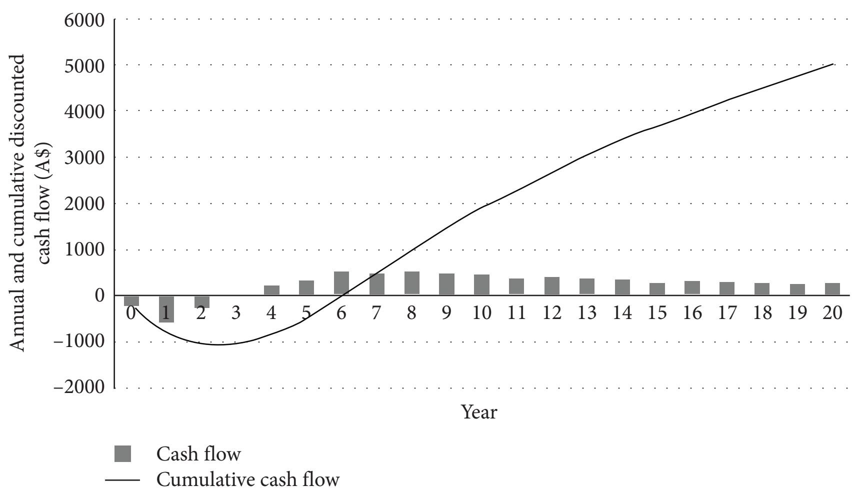

Figure 4: Indicative 25-ha Australian avocado orchard over 20 years, yearly and cumulative cash flow of the base-case scenario (S1) using traditional seedling propagation.

avocado farm enterprise using traditional propagation seedlings (S1) over a 20-year investment horizon. Each of the key financial output observations is explained in more detail as follows:

- NPV is the difference between the present value of cash inflows and cash outflows for an investment project over a given period using a discount rate [40]. We used a discount rate of 7% over a 20-year investment horizon, resulting in an NPV of A$5.02 million (Table 4).
- EANPV over of the 25-ha base case (S1) avocado orchard was A$474,025.
- The maximum cumulative negative cash flow has been taken as the level of investment required under each scenario; this is around A$1.03 million (Figure 4).
- DPP, being the number of years to break even, was estimated to be 6 years (Table 4 and Figure 4).
- IRR is the measure above the discount rate of 7%, being 32.00%.

The sensitivity analysis indicates how different market and production drivers (Table 3) affect each financial metric (Table 5). Production yield and avocado fruit price were grouped together as revenue; they affect revenue in a similar manner. A 10% change of either will change revenue by 10%. Revenue had the greatest effect on NPV, EANPV, DPP and IRR, followed by machinery and operation costs, and then overhead costs. Whereas, tree management costs, which include the purchasing of seedlings, had the greatest effect on investment costs (maximum negative cash flow). Changes in both yield and fruit prices due to clonal tissue seedling adoption are investigated in the following section on alternative clonal tissue seedling adoption scenarios.

3.2. Economic and Financial Assessment of Alternative Clonal Tissue Seedling Adoption Scenarios. The indicative 25-ha Australian avocado farm economic assessment under the six alternative clonal tissue-cultured seedling adoption scenarios (S2–S7) outperformed the traditionally grafted seedling

Table 5: Sensitivity analysis of changing average annual revenue and costs of an indicative orchard, reported as absolute average change of an increase and decrease of 10%.

Average revenue and cost parameters over 20 years	NPV (%)	EANPV (%)	Max negative cash exposure (%)	DPP (%)	IRR (%)
Revenue (saleable yield × price)	24.60	24.47	0.97	5.52	12.15
Machinery and operation costs	3.78	3.19	0.49	4.98	2.45
Tree management costs	1.20	1.06	4.37	4.88	2.65
Fertiliser costs	1.10	1.06	0.49	0.74	0.69
Fruit protection costs	0.5	1.06	0.49	0.55	0.46
Irrigation costs	1.20	1.06	0.49	0.93	0.90
Harvesting and freight costs	0.80	1.06	0.00	0.44	0.41
Overhead costs	2.09	2.13	1.46	4.93	2.16
Capital cost	1.20	1.06	1.94	5.18	2.13

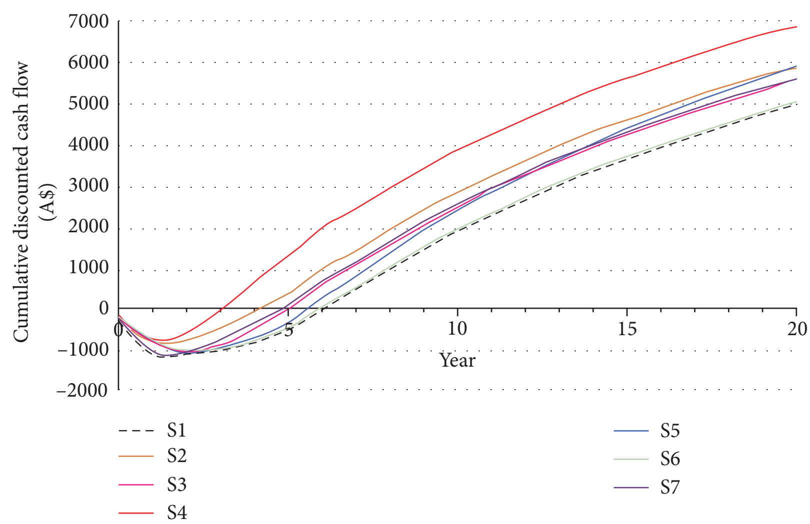

Figure 5: Cumulative discounted cash flow of a 25-ha avocado farm over 20 years, with traditional seedling propagation being the base case (S1) and alternative clonal tissue seedling adoption (S2–S7).

Table 6: Financial performance for a 25-ha indicative Australian avocado farm over 20 years using traditional seedling propagation S1 and clonal tissue culture seedling adoption (S2–S7) scenarios.

Financial measures	S1	S2	S3	S4	S5	S6	S7
NPV after 20 years (A$ million)	5.02	5.86	5.59	6.86	5.91	5.04	5.57
EANPV (A$ million/year)	0.47	0.55	0.53	0.65	0.56	0.48	0.53
Max negative cumulative cashflow (A$m)	−1.03	−0.78	−1.03	−0.78	−1.03	−1.01	−1.05
Discounted payback period (years)	5.96	4.18	5.04	3.24	5.94	6.48	4.85
Internal rate of return (IRR; %)	32.00	44.91	37.51	61.61	35.11	32.38	37.42

scenario (S1). Clonal tissue cultured adoption decreased maximum negative cumulative cash flow, decreased pay-back period and increased NPV (Figure 5 and Table 6).

Under each of the tissue culture seedling adoption scenarios, both revenues and operational costs changed, resulting in changes in the NPV, EANPV, DPP and IRR. The total capital investment and overhead costs remain unchanged from the traditional seedling propagation base case (S1). However, cost items came forward by 1 year in scenarios S2, S4 and S7 due to earlier production yield.

The S7 scenario had the greatest negative cumulative cash flow of all scenarios due to higher seedling costs, but also had a shorter DPP than the traditional base case (S1), due to earlier seedling availability and earlier crop production. This results in the greatest investment cost, which affects the IRR cost base.

The cumulative discounted cash flows over the 20-year time horizon varied due to the underlying scenario assumptions. Most financial metrics, including NPV, EANPV, maximum negative cumulative cash flow, DPP and IRR,

Table 7: The expected additional financial benefits over S1 by using clonal tissue culture for a 25-ha indicative Australian avocado farm over 20 years, adopting clonal tissue-cultured seedlings: scenarios S2–S7.

Clonal tissue culture scenarios	NPV (A$m)	EANPV (A$/year)	Max negative cumulative cash flow (A$)	Decreased DPP (years)	IRR (%)
S2 over S1	0.84	80,000	−250,000[a]	1.78	12.91
S3 over S1	0.57	60,000	0	0.93	5.52
S4 over S1	1.84	180,000	−250,000[a]	2.85	29.14
S5 over S1	0.89	90,000	0	0.02	3.11
S6 over S1	0.02	10,000	−20,000 [a]	0.52	0.38
S7 over S1	0.56	60,000	+20,000[b]	1.11	5.43

[a]Cash exposure reduced.
[b]Extra negative cumulative cash flow exposure and increased investment needed.

improved with tissue-culture cultured adoption scenarios (S2–S7) for the indicative 25-ha orchard (Table 6). The comparative additional benefits of tissue culture scenarios (S2–S7) over S1 are given in Table 7.

4. Discussion

4.1. Traditional Seedling Propagation Base-Case Scenario (S1) for a 25-ha Indicative Avocado Farm. Our economic and financial analysis of an indicative 25-ha Australian avocado farm using traditional seedling propagation (S1: base-case scenario) had a NPV of A$5.02 million over a 20-year investment horizon, requiring a A$1.03 million cash investment (being the maximum negative cumulated cashflow), which was paid back in 6 years, resulting in an EANPV of A$474,025/year (Table 6). This positive economic performance reinforces the fact that we should not undervalue the traditional grafting knowledge and practices that have been developed through experiments and experiences in a range of environmental conditions over an extensive period [51–53].

The sensitivity analysis (Table 5) revealed that the financial metrics were most sensitive to changes in revenue (crop yields and/or commodity prices), then machinery costs, followed by operation costs, and then overhead costs (Table 5). These are also the largest itemised values as shown in Table 3.

We understand that avocado growers might find themselves in an 'innovation paradox' [54] where there may be tension between wanting 'to produce avocado as usual' and 'to innovate away from their traditional grafting' due to influences from market forces, namely customers and productive efficiency needs. Customers' changing lifestyle and perceived quality of the product [55] (avocado fruit in this case) pose pressure on growers to innovate their product. The changing avocado fruit market dynamics (supply deficiency) also signal growers to respond to the changing environment with product and technology innovations.

4.2. Clonal Tissue Culture Seedling Adoption Scenarios. A survey conducted by Thorne et al. [21, p. 8] on the Australian avocado industry's attitude to tissue cultured seedlings, found that 'Industry members overwhelmingly rated the competitive pricing of tissue culture trees, reliable access to enough tissue culture trees, and access to desirable rootstock/scion combinations as the most influential in making tissue culture easier to use and subsequent adoption.' Therefore, we develop six clonal tissue-cultured seedling adoption scenarios to investigate the economic implications of these and other possible implications of clonal tissue culture seedling adoption by fruit/nut tree industries, using Australian avocado growers as a case study. Broadly, these can be grouped into concerns around seedling supply, seedling pricing, desirable rootstock/scion combinations (which affect fruit quality, crop yields, and plant survival [19]), and, in addition, seedling availability for higher valued fruit cultivars.

The supply of seedlings through the traditional grafting methods can be limited by seed supply, which is germinated for rootstocks (within season), as well as the time required to graft the scion to established industry-ready seedlings. This method is compounded by the difficulty of keeping both the rootstock and scion true to type [19]. One of the primary benefits of clonal tissue is that more than 500 seedlings can be produced from a single cutting [24] at any time of year, with the added advantage of only needing a single graft with the scion bud-wood to produce an industry-ready cloned plant. Therefore, the supply of seedlings can be improved with clonal tissue technology adoption to fruit/nut tree industries, when the technology is available. The economic benefits of this earlier seedling supply (by 1 year) were investigated explicitly in Scenario 2 (S2), as well as S4 and S7, to investigate compounding effects. The supply of seedlings is limited by the capacity of nurseries to supply seedlings to a specific fruit/nut tree industry. Therefore, due to the seasonal conditions and the demand of individual fruit/nut tree industry demand, seedling supply can be delayed beyond a single year, and the benefits of our analysis (1 year earlier) can be considered conservative. Our results for Scenario 2 show that receiving seedlings on time has clear economic benefits for the duration of the investment horizon. Based on a 25-ha indicative avocado orchard, simply by supplying seedlings a year earlier will increase growers' wealth by A$840k (increasing the NPV by 17%), over the 20-year investment horizon. Additionally, due to earlier fruit production, the cash flow improved in earlier years and resulted in requiring A$250k less cash investment, decreasing from A$1.03 to A$0.78 million, which also improved the IRR compared to traditionally grafted seedlings S1 (Tables 6 and 7). This was also the case with Scenario 4, which also received seedlings a year earlier. There is concern that clonal tissue seedlings may cost more and affect growers' financial returns [21]. Therefore, in Scenario 7 (S7), we assumed that seedlings cost twice as much (A$70/seedling) but were supplied a year earlier. The growers still increased their NPV by A$550k (over 20 years), increased average annual earnings (EANPV) of the 25-ha indicative orchard by A$60k/year, and decreased the DPP by 1.1 years compared to the traditional base-case scenario (S1) (Table 6). While this increased seedling cost increased the cash investment costs (max negative cashflow) by A$20k and slightly decreased the IRR, it still improved growers' overall cashflow and economic returns, compared to waiting for traditionally grafted seedlings.

Occasionally, there are new fruit or nut cultivars in the marketplace that can obtain a higher market price and offer higher financial returns for a period [32, 33], but this price premium diminishes when supply matches demand. Therefore, we investigated the effects of a fruit price-premium that diminished over a 5-year period. Unlike annual crops, where growers can readily increase or decrease production, perennial crops are long-term investment decisions requiring years of no or little yield production, and peak production occurs years after the decision to increase the supply of a particular fruit or nut cultivar has occurred. Therefore, we investigated this possibility with avocado prices for a new cultivar starting at A $5.50/kg (57% over the long-term average price of A$3.50) in Year 2 and gradually decreasing to A$3.50/kg in Year 7 and beyond. One of the key considerations is the availability of the new cultivar seedlings to grow a highly valued fruit or nut, this seedling shortage supply is assumed to be overcome with clonal tissued cultured seedlings in Scenario 3 (S3), this resulted in the 25-ha indicative orchard increasing the 20-year NPV by A$570k, the EANPV increasing by A$60k/year, the DPP decreasing by almost 1 year, and the IRR increasing by 5.52% over the traditional base-case scenario (S1). However, these financial returns can possibly be further improved with clonal tissue adoption by receiving the seedlings a year earlier, further capturing the price premium in Scenario 4 (S4). This offered the greatest economic returns of all the clonal tissue adoption scenarios (Table 7). The cash investment for the avocado enterprise decreased by A$250k due to buying the seedlings a year earlier and increasing fruit production, the NPV increased by A$1.84 million, EANPV increased by A$180k/year (>38% more than base case: S1), the IRR almost doubled to 61.6%, and the payback period was halved to 2.85 years, compared to the traditional base-case scenario (S1). Although the price premium, markets and growth rates of other fruit and nut trees will most likely be different, the above provides some insights into the possible benefits of clonal tissued-cultured seedlings adoption in new or emerging perennial fruit or nut tree industries.

Using clonal tissue technology to obtain desirable rootstock/scion combinations can possibly increase fruit quality, crop yields, and plant survival. Improved fruit quality can either increase the fruit price ($/kg) or increase marketable crop yields. In essence, the possible price premium scenario has essentially been captured in Scenarios 3 and 4 (S3, S4). Scenario 5 investigated the effects of increasing crop yields by 10% for every year of fruit production, and Scenario 6 investigated the effects of reduced seedling mortality by 10%. Compared to all the scenarios, reducing seedling mortality had the least effect on all the financial metrics (Table 7), but it still provided a benefit over the traditional base-case scenario (S1). Increasing crop yields by 10% (S5) had some of the greatest effects on the growers' wealth and cash flow, with the NPV increasing by A$890k, the EANPV increased by A $90k/year, payback period decreased by half a year, and the IRR increased by 3.1% (Table 7). Interestingly, these results are similar to Scenario 2 (S2), which received seedlings a year earlier. It might be possible for growers to combine both Scenarios 2 and 5 by increasing crop yields by 10% and receiving the seedlings a year earlier, further increasing growers' wealth and cash flows. Although other fruit and nut trees will most likely be different, the above provides some insights into clonal tissued-cultured seedlings adoption in new or emerging perennial fruit or nut tree industries and provides possible benefits for these industries.

While receiving seedlings 1 year earlier (S2) had similar economic benefits to a 10% yield increase over the whole investment horizon (S5), it is important to understand the underlying economic drivers of these different scenarios. Although the earlier supply of seedlings only increased yield production in the years prior to trees reaching maturity (steady-state production), these economic benefits were greatest due to the discounting of cash flows later in the investment horizon. In other words, a 10% increase in yields in the 20th year (S5) had far less benefit than receiving marketable yields shortly after investing in tree establishment and capital investment of production equipment (S2). This is likely to be the case with all perennial fruit/nut tree production systems, where increasing economic returns and cash flow early in the investment horizon is vitally important.

The above additional benefits may be achieved through innovation, which might require sending innovative agronomic and food science technology to farmers who do not yet possess it [56]. In revising their current planting practices, perennial fruit/nut tree growers might get trapped in 'recency bias' [57]. This 'recency bias,' the inclination to use the past experience (traditional grafting in this case) as the only baseline for the future, might lead the growers to stick to traditional grafting practices. This conservative attitude might limit perennial fruit/nut tree growers' credibility in responding to future fruit market needs and expectations [58]. Alternatively, perennial fruit/nut tree industries may adopt a gradual approach of clonal tissue culture technology adoption in their orchards. Following the view of innovation 'ambidexterity' [59–61], perennial fruit/nut tree growers may take a balanced position of exploitation of current (traditional propagation) practices and the exploration of new clonal tissue seedling adoption over time to incrementally increase orchard economic performance. This view is also consistent with the idea of 'innovation through tradition' [57].

The actual future benefits of clonal tissue are still unknown; therefore, the purpose of our study was to simulate the biophysical and economic drivers that may result in the likely benefits to growers, rather than predicting exact future outcomes from the adoption of clonal tissue-cultured seedlings.

4.3. Implications to the Australian Avocado Industry and Other Fruit and Nut Tree Industries. From an academic perspective, firstly, this study advances the Australian and global avocado literature in the context of sustainable economic development and feasibility analysis of traditional and clonal tissue culture grafting. This study also contributes to the broader horticulture literature on the sustainable commercialisation of clonal tissue culture technology of seedlings to the fruit/nut tree industries. These learnings can help growers, nurseries, consumers, market makers, and policymakers to improve their investment decisions that extend to perennial fruit and nut crops in other countries and industries. Avocado growers are likely to benefit financially from adopting tissue culture through shorter lead time of plant seedling supply, increasing the supply of plants, new varieties better matched to specific environments, and the potential for fruit price premiums and increased fruit productivity. Even under a scenario with significantly higher seedling prices from a limited number of nurseries monopolising the clonal tissue technology and seedling market, growers will still derive sustainable economic benefits from the adoption of clonal tissue-cultured seedlings, which are supplied earlier than traditional propagated seedlings.

Nurseries are likely to see sustainable financial benefits by shortening plant production time, increasing production scale, and bringing new varieties to market sooner, thereby increasing both plant and fruit supply to meet market demand. They can also potentially seek a price premium for clonal tissue-cultured plants in the short to medium term. Premium plant prices can also support investment costs to help further refine the clonal tissue culture technology and to facilitate a more sustainable development of the industry.

The increased production and productivity from new avocado varieties support Australian industry growth and production efficiency, thereby underpinning a reduction in imports and the development of fruit export markets. Clonal tissue culture provides opportunities for commercial Australian avocado growers to improve their economic outcomes more sustainably. Consumers would benefit from a greater variety of choice and fruit quality from clonal tissue culture plants. Finally, evidence has been provided for policymakers to support clonal tissue-cultured plant adoption, to develop a sustainable Australian avocado industry. This may include enhancing nursery-level capabilities to produce tissue culture plant production, improved avocado plant and fruit quality, investment in new product innovations for processing and food service to diversify, grow, and broaden avocado demand, and usage of diverse strategies to develop new export markets and reduce avocado imports.

4.4. Further Research. Simulation modelling is a powerful tool in improving decisions [62], especially in the context of the farming sector, where decisions are mediated by more intuitive justification [63]. However, there is a risk that the modellers as well as interpreters might misinterpret or over-interpret modelling outcomes due to differences in modelling approaches and input–output parameters chosen for the models [64]. Accordingly, we emphasise the following caveats and the opportunities for further research in this area.

The first caveat is that we have focused on the biophysical and economic characteristics of an indicative 25-ha avocado orchard in the Queensland region of Australia, adopting clonal tissue technology. The modelling results will vary when compared to other farms and fruit/nut tree industries due to differences in factors such as climate, farm size, geographical region, soil type, agronomic practices, capital investment, financing and market characteristics. Thus, further research can be undertaken by incorporating these into future feasibility assessments in other countries' contexts. Furthermore, environmental and social sustainability metrics can be explored in future research on their impact on clonal tissue culture adoption by individual farms. It is important to note that further validation of the modelling is required for specific representations.

The second caveat in our model is the application of a deterministic simulation model, rather than a stochastic model. Our rationale to choose this deterministic model was to develop simplified relationships using average figures for the input and output parameters chosen. Therefore, any year-to-year economic adjustment for seasonal variations in fruit production, sales quantity and prices, fruit quality problems (such as external blemishes, rots, mechanical damage, pulp injury, off flavours), and market forces (e.g., COVID-19 pandemic) are beyond the scope of this study. Future research can consider the use of stochastic modelling to capture the differences and uncertainties in agricultural systems, such as weather variability and market fluctuations.

Another important caveat is the planting density of avocado trees, which we considered in our model. We used 312 trees/ha based on the most common planting density of our interview participants and industry literature. The 312 trees/ha is reflective of the Australian avocado planting benchmark density range of 146–328 trees/ha across different regions [65]. Anecdotally, it is claimed that clonal tissue-cultured avocado plants may deliver greater yield advantage from higher-density plantings due to more uniformity in growth and yield characteristics [66]. Empirical evidence for existing high-density avocado orchards using traditional cultivars indicates that the yield benefits of high planting density are only viable in the early years of production [67–69]. According to these studies, the financial advantage of high-density plantings starts declining after the early years of production, as trees struggle significantly due to orchard canopy crowding. This may require future investment in thinning out the tree crops in later years.

5. Conclusions

In conclusion, this study has investigated the sustainable commercial feasibility of adopting clonal tissue culture propagation in the Australian avocado industry and provided insights into the potential benefits in other perennial fruit/nut tree industries. Bioeconomic modelling has been used to simulate seven scenarios that provide an initial assessment of the economics of the commercial viability of clonal avocado tissue culture at the farm level. This study did not intend to determine the best economically performing clonal tissue adoption scenario, but rather presented a range of indicative scenarios from the adoption of clonal tissue-cultured avocado plants. Findings suggested various benefits to key stakeholders (e.g., nurseries, growers and consumers) which include financial gains, increased production and productivity efficiencies, new and greater variety of choice, as well as improving export market opportunities. As such, the adoption of clonal tissue culture can facilitate a more sustainable development in the Australian avocado industry.

Appendix A

Table A1: Orchard establishment and costs: base case, Year 1.

Machinery and operations	Unit/ha	Quantity	Cost (A$/ha)
Operation: slashing + FWA Light FORM	h/ha	5	158
Self-propelled: sprayer FORM	h/ha	3.25	130
Tree management cost			
Cover crop	crops	1	250
Mound earth contract	h/ha	3	390
Avocado trees (inclusive of mortality)	trees/ha	343.2	12,012
Tree planting labour cost	h/tree	49.92	1348
Tree stakes	trees/ha	936	1404
Tree guards	trees/ha	312	156
Tree mulching: bale	round bales/ha	10	1300
Tree mulching: labour	h/ha	10	270
Soil analysis	ha/test	0.25	25
Fertilisation cost			
Nutrient: calcium nitrate (fertigate)	kgs/ha	300	240
Nutrient: nitro phoska	kgs/ha	312	312
Nutrient: lime or gypsum	kgs/ha	500	125
Fruit protection cost			
Herbicide: Gramoxone 250 (or other product) see label	L/ha	6	39
Herbicide: roundup	L/ha	3	19
Insectiside: rogor (dimethoate)	L/tree	0.2496	3
Fungicide: phosphorus acid (foliar)	—	46.48	195
Irrigation cost			
Irrigation: drip (FORM)	mL/ha	1.5	75
Consumable: water	mL/ha	1.5	90
Irrigation: water licence	mL/ha	1.5	90
Contract: labour sprinklers	h/ha	6	162
Irrigation: sprinklers	`/ha	312	624
Polypipe 1"	m/ha	1500	638
PVC 3 submain	m/ha	30	300
Misc irrigation material	`/ha	1	100
Harvesting, post-harvesting and freight cost	n/a	n/a	n/a

Appendix B

Table A2: Crop management inputs: base case, Years 2–20.

Biological parameters		Years					
Machinery and operations	**Units**	**2**	**3**	**4**	**5**	**6**	**7–20**
Operation: slashing + FWA light FORM	h/ha	5	5	5	5	5	70
Operation: spreader + FWA light FORM (multch)	h/ha	1	3	2	1	0	0
Self-propelled: sprayer FORM	h/ha	38	38	38	38	38	532
Operation: cherry picker	h/ha	0	33.6	72.8	106.4	126	1960
Operation: tree trimming (chain saw) FORM	h/ha	2	1	1	1	1	14
Wood chipper	h/ha	0	0	0	0	5	84
Tigergrip with excavator	h/ha	0	0	0	0	0	145.6
Tree management							
Soil analysis	tests/ha	0.25	0.25	0.25	0.25	0.25	3.5
Tree mulching: bale	round bales/ha	8	6	4	2	0	0
Tree mulching: labour	h/ha	8	3	2	1	10	140
Manual pruning: labour	h/ha	0	1.92	4.16	6.08	7.2	112
Fertilisation							
Nutrient: calcium nitrate: fertigate	kgs/ha	25	43	64	82	92.5	1400
Nutrient: SF14 by Supierio Fertiliser	kg/ha	312	536.64	798.72	1023.36	1154.4	17,472
Nutrient: urea (fertigate)	kg/ha	100	172	256	328	370	5600
Nutrient: zinc	kg/ha	12.5	21.5	32	41	46.25	700
Nutrient: foliar boron at flowering	L/ha	1.25	2.15	3.2	4.1	4.625	70
Nutrient: potassium sulphate	kg/ha	125	215	320	410	462.5	7000
Nutrient: lime	L/ha	625	1075	1600	2050	2312.5	35,000
Fruit protection							
Herbicide: Glyphosate 450CT	L/ha	2	2	2	2	2	28
Insecticide: transform (or other product)	kg/ha	1.5	1.5	1.5	1.5	1.5	21
Fungicide: Nordox 75	L/ha	1.2	1.2	1.2	1.2	1.2	16.8
Fungicide: Amistar	L/ha	0.4	0.4	0.4	0.4	0.4	5.6
Fungicide: phosphorus acid (foliar)	kg/ha	27	78	98	122	152	1162
Fungicide: metalaxyl (Medley 50G)	L/ha	62.4	0	0	0	0	0
Wetter	L/ha	1.6	1.6	1.6	1.6	1.6	22.4
Irrigtion							
Irrigation: sprinkler (FORM)	mL/ha	3	5.16	7.68	9.84	11.1	168
Consumable: water	mL/ha	3	5.16	7.68	9.84	11.1	168
Irrigation: water licence	mL/ha	3	5.16	7.68	9.84	11.1	168
Irrigation: labour maintaining irrigation	h/ha	1	1	1	1	1	14
Irrigation: sprinkler 10% replacement/year	/ha	31.2	31.2	31.2	31.2	31.2	436.8
Irrigation: polypipe 1” 10% replacement/year	m/ha	150	150	150	150	150	2100
Harvesting, post-harvesting and freight							
Fruit picking: labour	h/kg	0	17	36	53	62	971

Appendix C

Table A3: Crop management costs: base case, Years 2–20.

Orchard cost items	Years					
Machinery and operations	**2**	**3**	**4**	**5**	**6**	**7–20**
Operation: slashing + FWA Light FORM	158	158	158	158	158	2210
Operation: spreader + FWA Light FORM (multch)	33	98	66	33	0	0
Self-propelled: sprayer FORM	3434	3434	3434	3434	3434	48,072
Operation: cherry picker	0	840	1820	2660	3150	49,000
Operation: tree trimming (chain saw) FORM	80	40	40	40	40	560
Wood chipper	n/a	n/a	n/a	n/a	250	4200
Tigergrip with excavator	n/a	n/a	n/a	n/a	n/a	5096
Tree management						
Soil analysis	25	25	25	25	25	350
Tree mulching: bale	1040	780	520	260	0	0
Tree mulching: labour	216	81	54	27	270	3780
Manual pruning: labour	n/a	52	112	164	194	3024
Fertilisation						
Nutrient: calcium nitrate: fertigate	20	34	51	66	74	1120
Nutrient: SF14 by Supierio Fertiliser	156	268	399	512	577	8736
Nutrient: urea (fertigate)	55	95	141	180	204	3080
Nutrient: zinc	18	30	45	57	65	980
Nutrient: foliar boron at flowering	7	13	19	24	27	410
Nutrient: potassium sulphate	138	237	352	451	509	7700
Nutrient: lime	156	269	400	513	578	8750
Fruit protection						
Herbicide: Glyphosate 450CT	12	12	12	12	12	162
Insecticide: transform (or other product)	375	375	375	375	375	5251
Fungicide: Nordox 75	16	16	16	16	16	227
Fungicide: Amistar	19	19	19	19	19	263
Fungicide: phosphorus acid (foliar)	112	328	410	512	640	4880
Fungicide: metalaxyl (Medley 50G)	1023	n/a	n/a	n/a	n/a	n/a
Wetter	12	12	12	12	12	169
Irrigtion						
Irrigation: sprinkler (FORM)	150	258	384	492	555	8400
Consumable: water	180	310	461	590	666	10,080
Irrigation: water licence	180	310	461	590	666	10,080
Irrigation: labour maintaining irrigation	27	27	27	27	27	378
Irrigation: sprinkler 10% replacement/year	62	62	62	62	62	874
Irrigation: polypipe 1" 10% replacement/year	64	64	64	64	64	893
Harvesting, post-harvesting and freight						
Fruit picking: labour	0.00	449	973	1423	1685	1872

Appendix D

Table A4: Capital cost: base case of indicative 25-ha avocado farm, Years 0–20.

Years	0	2	4	5	7	10	11	15	Term value
Tractors and vehicles									
Tractor 80 hp	80,000	—	—	—	—	—	65,000	—	21,500
Tractor 100 hp	—	—	—	90,000	—	—	—	70,000	55,000
Car hilux	40,000	—	—	—	—	—	33,000	—	10,300
650 quad	4000	—	—	—	—	3500	—	—	500
Utility truck (second hand)	—	—	—	—	—	—	—	—	—
Four wheel bike	—	—	—	—	—	—	—	—	—
Sub-total	124,000	0	0	90,000	—	3500	98,000	70,000	87,300
Implements									
Slasher (8 ft)	8000	—	—	—	—	—	8000	—	—
Sprayer	2000	—	—	—	—	—	—	—	—
Air blast sprayer	—	—	35,000	—	—	—	—	35,000	17,500
Chippers and chainsaws	—	—	30,000	—	—	—	—	25,000	17,500
Cherry picker	—	—	—	65,000	—	—	—	—	20,000
Cherry picker (2)	—	—	—	—	65,000	—	—	—	5000
Mulcher spreader	—	—	—	15,000	—	—	—	—	2000
Trailer	—	—	1500	—	—	—	—	1500	750
Trailer (2)	—	—	—	—	—	—	—	—	—
Machanto tiger grip	—	—	—	—	18,000	—	—	—	2700
Excavator (second hand)	—	—	—	—	55,000	—	—	—	8250
Fertiliser spreader	—	2000	—	—	—	2000	—	—	—
Fertigation station	5000	—	—	—	—	5000	—	—	—
Soil moisture metres 1/4ha (MEA)	20,000	—	—	—	—	—	—	—	—
Sub-total	35,000	2000	66,500	80,000	138,000	7000	8000	61,500	73,700
Irrigation infrastructure									
Irrigation tanks 01:130 kL	12,000	—	—	—	—	—	—	—	—
Irrigation tanks 02:130 kL	12,000	—	—	—	—	—	—	—	—
Pump	2500	—	—	—	—	—	2500	—	—
Pump	2500	—	—	—	—	—	2500	—	—
Sub-total	29,000	—	—	—	—	—	5000	—	—
Buildings and sheds	—	—	—	—	—	—	—	—	0
Shed	20,000	—	—	—	—	—	—	—	—
Total	208,000	2000	66,500	170,000	138,000	10,500	111,000	131,500	161,000

Appendix E

Table A5: Overheads: base case of indicative 25-ha avocado farm, Years 0–20.

Items	Cost ($/year)	Proportion (%)
Fuel and oil: unspecified	18,750	19.19
Power and gas	6250	6.40
Office and administration	10,000	10.23
Insurance	6250	6.40
Permanent hired labour	51,480	52.68
Repairs and maintenance	2500	2.56
Rates	2500	2.56
Total	97,730	100.00

Data Availability Statement

The data presented in this study are available upon request from the corresponding author due to privacy, legal or ethical reasons.

Consent

Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Mohd Mohsin: conceptualisation, methodology, formal analysis, visualisation, writing – original draft, writing – review and editing. **Geoff Slaughter**: funding acquisition, conceptualisation, methodology, writing – review and editing. **Andrew Zull**: conceptualisation, methodology, formal analysis, visualisation, writing – original draft, writing – review and editing. **Eric Ng**: funding acquisition, conceptualisation, methodology, writing – review and editing.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. (*Supporting Information*) Simplified Excel model template updated.xlsx.

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