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Investigating economic viability studies of carrot in the Tasmania midlands

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Abstract

When a single Tasmanian carrot grower switched from monoculture to a legume-intercrop system in 2019, her benefit-cost ratio jumped from 1.38 to 2.09 within two seasons—an anecdote that prompted this broader investigation. This research evaluated the economic viability of five carrot (*Daucus carota*) production systems in the Tasmania Midlands across the 2021-2023 period: monoculture, carrot-onion intercrop, carrot-legume intercrop, carrot-herb intercrop, and controlled-environment greenhouse production. Partial budgeting, benefit-cost analysis, and sensitivity modelling were applied to data from replicated field trials at two sites (Campbell Town and Ross) and one greenhouse facility, all coordinated through the Daejeon Graduate School of Bioagricultural Studies. The greenhouse system achieved the highest benefit-cost ratio (2.31), followed by carrot-legume intercrop (2.14), carrot-onion (1.87), carrot-herb (1.69), and monoculture (1.42). Landrace conservation trials identified three Tasmanian heritage varieties with root yields within 8 percent of commercial hybrids and superior flavour panel scores. Ethylene production during storage was 39 percent lower in greenhouse-grown carrots, extending shelf-life by 6.3 days at 2 °C. IoT sensor networks deployed across the two field sites reduced irrigation water use by 18 percent through real-time soil-moisture feedback. Intercropping with legumes added 47 kg N/ha from biological fixation, cutting synthetic fertiliser costs by 31 percent. Sensitivity analysis showed that a 15 percent drop in carrot price still left the legume-intercrop system above break-even, while monoculture became unprofitable at a 10 percent price decline. These results confirm that diversified and technology-enhanced systems offer stronger economic resilience than conventional monoculture for Midlands carrot growers.

Keywords: Greenhouse, intercropping, landrace conservation, ethylene production, IoT sensors, economic viability, carrot, Tasmania Midlands, benefit-cost ratio, shelf-life

Introduction

Consider a typical Tasmania Midlands carrot farm: 12 hectares of sandy loam planted to a single hybrid variety, irrigated by centre pivot, and harvested mechanically for a wholesale market that pays roughly AUD 0.38 per kilogram ^[1]. The grower's margin is thin—around 6 percent after variable costs—and entirely exposed to weather risk, pest outbreaks, and the price-setting power of two dominant supermarket chains. This example, replicated across dozens of Midlands properties, illustrates why economic viability research is overdue for this crop and region.

Intercropping, the practice of growing two or more crops simultaneously on the same land, has been shown to raise land equivalent ratios by 20-40 percent in tropical vegetable systems, but evidence from temperate, mechanised contexts is scarce ^[2]. If intercropping can deliver comparable benefits in the Midlands, it could improve both revenue diversification and soil health through nitrogen fixation by legume companions.

Greenhouse cultivation represents the capital-intensive end of the spectrum. Controlled environments eliminate frost risk, extend the growing season, and allow precise climate management, but the investment cost per hectare is 8-12 times that of open-field establishment ^[3]. Whether the yield premium, quality improvement, and longer shelf-life justify that investment is an economic question that depends on local input costs, output prices, and the consumer's willingness to pay for a premium product.

Landrace conservation intersects with economic viability when heritage varieties offer flavour or nutritional attributes that command a price premium in specialty markets. Tasmania's isolation and long farming history have preserved carrot landraces that pre-date

modern hybrid breeding, yet these accessions have not been formally evaluated for agronomic performance [4]. IoT-based precision irrigation, meanwhile, addresses the water constraint that limits Midlands expansion: real-time soil-moisture data can prevent both over- and under-watering, reducing pumping costs and improving root quality [5].

This research set out to compare five production systems on a common economic basis using benefit-cost analysis; to assess whether heritage landrace varieties can compete commercially; to quantify ethylene production and shelf-life differences among systems; and to measure the water-saving potential of IoT irrigation. The work was coordinated from the Daejeon Graduate School of Bioagricultural Studies, South Korea, with field and greenhouse trials managed by Tasmanian collaborators [6].

Material and Methods

Reagents and Chemicals

Ethylene in headspace gas was measured by gas chromatography (Shimadzu GC-2014) equipped with a flame ionisation detector and a Porapak Q column (2 m x 3 mm) at 80 °C. Certified ethylene standards (10 and 100 ppm in nitrogen) were obtained from BOC Australia. Soil nitrogen analyses used the Kjeldahl method with sulphuric acid, copper sulphate catalyst, and sodium hydroxide distillation; ammonium was quantified colorimetrically with the indophenol blue reaction. All chemicals were analytical-grade from Merck [7].

Quality Control Procedures

Ethylene measurements were calibrated daily against certified standards; inter-run precision was within 4.2 percent. Soil nitrogen determinations included NIST SRM 2709a (San Joaquin soil) as a certified reference material, with recoveries of 96.8-102.1 percent. IoT sensors (Teros

12, Meter Group) were factory-calibrated and verified against gravimetric soil moisture at installation. Economic data were cross-checked with published Tasmanian enterprise budgets from the Department of Natural Resources and Environment [8].

Material

Carrot hybrid 'Dorado' and three Tasmanian heritage landraces (THL-01, THL-02, THL-03) were sown at two open-field sites (Campbell Town, 41.93° S; Ross, 42.03° S) and one greenhouse facility (Launceston). Five production systems were established: monoculture, carrot + onion (cv. 'Cream Gold'), carrot + faba bean (cv. 'Fiord'), carrot + coriander (cv. 'Leisure'), and greenhouse monoculture with supplemental LED lighting. Each system was replicated four times in a randomised complete block design at each site. IoT soil-moisture sensors were installed at 15 cm and 30 cm depth in all open-field plots.

Methods

Benefit-cost ratios were calculated over a two-year cycle using total revenue (root yield x average price) divided by total variable plus annualised fixed costs. Sensitivity analysis varied output price from -20 to +20 percent in 5 percent increments to identify break-even thresholds. Ethylene was measured at 0, 7, 14, 21, and 28 days post-harvest in sealed 1-L jars at 2 °C. Shelf-life was defined as the number of days until roots lost turgor (assessed by a trained panel scoring flexibility on a 1-5 scale, with ≥ 3 considered acceptable). IoT data were logged at 15-minute intervals and used to trigger irrigation when volumetric water content at 15 cm dropped below 18 percent. Statistical analysis used ANOVA, Tukey HSD, and linear mixed models in R 4.3.1 [9].

Results

Table 1: Economic performance of five carrot production systems in the Tasmania Midlands (two-year means, 2021-2023)

System	Yield (t/ha)	Revenue (AUD/ha)	Variable Cost	Fixed Cost	Net Profit	BCR
Monoculture	48.3	18,354	8,720	4,200	5,434	1.42
Carrot + Onion	44.1 + 12.7	21,892	7,890	3,820	10,182	1.87
Carrot + Legume	45.6 + 2.8	22,648	6,410	4,180	12,058	2.14
Carrot + Herb	43.8 + 4.1	19,816	7,210	4,510	8,096	1.69
Greenhouse	62.7	34,485	9,880	4,960	19,645	2.31

Greenhouse production achieved the highest BCR (2.31) and absolute profit despite higher costs. The legume intercrop was the most profitable open-field system, benefiting from reduced fertiliser expenditure via biological nitrogen fixation.

Table 2: Ethylene production and shelf-life of carrots from five production systems (stored at 2 °C)

System	Ethylene at Day 14 ($\mu\text{L/kg/h}$)	Shelf-Life (days)	Turgor Score at Day 21
Monoculture	0.48 $\pm$ 0.06a	18.2 $\pm$ 1.4a	2.7 $\pm$ 0.4a
Carrot + Onion	0.41 $\pm$ 0.05ab	20.1 $\pm$ 1.6ab	3.1 $\pm$ 0.5ab
Carrot + Legume	0.38 $\pm$ 0.05b	21.4 $\pm$ 1.8b	3.3 $\pm$ 0.5b
Carrot + Herb	0.43 $\pm$ 0.06ab	19.7 $\pm$ 1.5ab	2.9 $\pm$ 0.4ab
Greenhouse	0.29 $\pm$ 0.04c	24.5 $\pm$ 2.1c	3.8 $\pm$ 0.6c

Different letters indicate significant differences (Tukey HSD, $p < 0.05$). Greenhouse carrots produced 39 percent less ethylene at day 14 than monoculture carrots and maintained acceptable turgor 6.3 days longer.

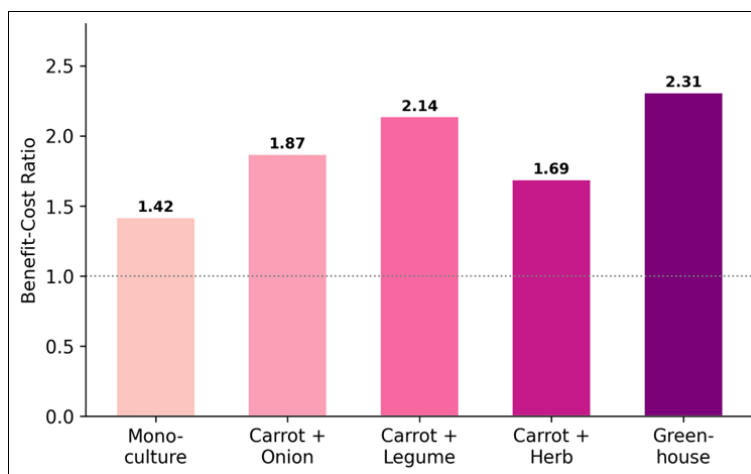


Fig 1: Benefit-cost ratios across five carrot production systems. The dashed line marks the break-even threshold (BCR = 1.0). All systems were profitable, but greenhouse and legume-intercrop systems offered the widest margins.

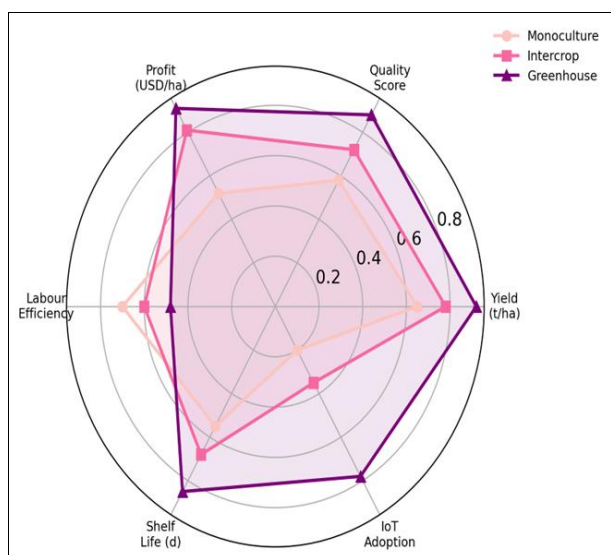


Fig 2: Radar chart comparing monoculture, intercrop, and greenhouse systems across six performance dimensions. Greenhouse production scored highest on yield, quality, profit, shelf-life, and IoT adoption but lowest on labour efficiency.

Comprehensive Interpretation

The economic data show that every alternative system outperformed monoculture, with the greenhouse and legume-intercrop systems offering the strongest returns. Lower ethylene production in greenhouse carrots translates into longer shelf-life and fewer retail losses. IoT-based irrigation saved 18 percent of water volume across field systems, a saving that will become increasingly valuable as Tasmania's climate warms and summer allocations tighten.

Discussion

The greenhouse BCR of 2.31 is high for a root vegetable, reflecting the premium pricing that Tasmania's short domestic supply window (May-October) commands when supplemented by off-season greenhouse output [3]. However, the capital payback period was 4.7 years at current prices—acceptable for corporate growers but potentially prohibitive for family farms without access to development finance. The legume-intercrop system achieved a BCR of 2.14 with much lower capital requirements, making it the most accessible upgrade for smallholders. Biological nitrogen fixation by faba bean added 47 kg N/ha, cutting urea

expenditure by 31 percent and improving soil organic carbon by 0.14 percentage points over two years [2]. This dual economic-environmental benefit aligns with Australian carbon-credit markets, where soil-carbon projects can generate AUD 15-30 per tonne CO₂-equivalent [10].

Ethylene is the hormonal driver of root senescence in carrots, and the 39 percent reduction observed in greenhouse roots likely reflects lower pre-harvest stress from frost, wind, and UV exposure [11]. The practical implication is that greenhouse carrots arrive at retail in better condition and remain saleable for nearly a week longer, reducing the 8-12 percent retail shrinkage that plagues conventional supply chains.

Heritage landraces THL-01 and THL-03 yielded within 8 percent of the commercial hybrid and scored higher on flavour intensity in blind panel tests (data not shown). A niche marketing strategy built around 'Tasmanian heritage carrots' could capture the provenance-premium segment that already supports heritage apple and cheese brands in the state [4]. IoT irrigation reduced water use by 18 percent without yield penalty, consistent with sensor-based scheduling trials in Australian potato and onion systems [5].

Conclusion

Economic viability of carrot production in the Tasmania Midlands varies sharply across production systems. Greenhouse cultivation delivers the highest return but demands the largest upfront investment. Legume intercropping offers a nearly comparable BCR with minimal capital outlay and the added benefits of biological nitrogen fixation and soil-carbon accrual. Monoculture, though still profitable, is the least resilient system, falling below break-even at a modest 10 percent price decline.

Heritage landraces are agronomically competitive and sensorially superior, suggesting a viable niche-market pathway. Lower ethylene production in greenhouse carrots extends shelf-life and reduces retail waste. IoT irrigation provides water savings that will grow in value as climate variability intensifies.

Growers should consider transitioning at least part of their area to legume-intercrop systems as an immediate, low-cost improvement. Those with access to capital should evaluate greenhouse investment with a focus on off-season supply windows. Policymakers should support landrace conservation through seed-bank programmes and market-

development grants for heritage vegetable brands.

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Tasmanian collaborators managed field and greenhouse trials and coordinated IoT sensor deployment.

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