

Appendix C.4: Horticulture Sector Technology Assessment

Table of Contents

Technology Assessment.....	1
Electrification of Farm Machinery and Alternative Fuels.....	1
Precision Agriculture	5
Nitrification Inhibitors	9
Slow/Controlled-Release Nitrogen Fertilisers.....	15
Cover Cropping.....	18
Urease Inhibitors	28
Soil Microbial Inoculants.....	30
References	33

Technology Assessment

Electrification of Farm Machinery and Alternative Fuels

Electrification of farm machinery and alternative fuels refers to transitioning diesel-powered on-farm equipment, such as tractors, harvesters, spray rigs and irrigation pumps, to electric drive or low-carbon fuels (e.g. renewable diesel, biodiesel, biogas, hydrogen), thereby reducing scope 1 carbon dioxide (CO₂) emissions. In horticulture, near-term opportunities include electrifying irrigation pumping and narrow-gauge/orchard tractors and small vehicles, while in the longer-term, opportunities for heavier duty tasks could include alternative fuels or hybrid solutions, and eventually high-power electric platforms. Electrification needs to be coupled with efficiency to ensure emissions are not just shifted to scope 2.

1) Technical Annual Abatement Potential

Diesel use is a major on-farm emissions source for many horticultural enterprises. Replacement of diesel-powered irrigation pumps with efficient variable-speed drive (VSD) electric pumps powered from the grid or on-farm solar can result in ~100% abatement of the associated scope 1 CO₂ emissions. Similarly, for small orchard tractors and vehicles, electric drive can abate ~100% of fuel combustion emissions at point of use. Depending on feedstock and process, renewable diesel and biodiesel have been reported to deliver 65% and 66-68% reductions in lifecycle GHG emissions respectively when compared with petroleum diesel (AFDC, 2026; Huo et al. 2009).

If on-farm diesel combustion were fully replaced by clean electricity and low-carbon fuels, a technical abatement of ~210 – 421 kt CO₂-e/yr is plausible, assuming on average 26.3% of scope 1 horticulture sector emissions are diesel-related (DPIRD, 2024).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

2) Feasible Annual Abatement Potential

We estimate feasible abatement by applying a 100% technical abatement rate to the portion of horticulture Scope 1 emissions attributable to on-farm diesel combustion ($E_t = 0.21\text{--}0.42$ Mt CO₂-e/yr, based on total horticulture Scope 1 emissions of 0.8–1.6 Mt CO₂-e/yr and a 26.3% diesel share). Assuming these electrification options are applicable to most horticultural enterprises ($AP_{dom} = 0.80$) and could reach 20–50% adoption over 10 years under constraints such as equipment availability, grid access and capital costs ($AD_{pot} = 0.20\text{--}0.50$), feasible annual abatement is estimated at 33.6–168 kt CO₂-e/yr. This estimate is highly uncertain due to limited national disaggregation of diesel use by sub-sector and uncertainty around the application domain and achievable adoption within 10 years.

3) Breadth of Application

Rating: High (sub-sector dependent)

Electrification of irrigation pumping (grid and solar-powered) and narrow electric tractors are both broadly applicable across irrigated fruits, nuts, and vegetables, making broad adoption plausible as incentives and available models expand. Renewable diesel potentially represents a near-term drop-in for existing diesel-powered fleets, noting the supply chain is still developing, and availability may be limited outside major urban centres (GrainGrowers, 2024; NSW Government, n.d a). Limitations to electrification arise from high-horsepower broadacre tasks (duty cycles, range, refuelling), grid capacity in some regions, and high upfront capital costs. Overall, in the short-to-medium term, breadth is high across horticulture, but low-medium in subsectors where high-horsepower platforms are essential – these subsectors will be dependent on further maturation of alternative fuels and heavy electric platforms.

4) Co-Benefit Potential

Rating: Medium-High

Co-benefits of irrigation pump electrification, particularly when coupled with VSDs, include lower operating and maintenance costs, reduced noise and local air pollution, improved pump performance and precision, potential yield protection from steadier irrigation pressure, and easier integration with automation functions (CottonInfo, n.d; Lorentz Australia, 2024; NSW Government, 2016). Vehicle electrification co-benefits similarly include lower operating and maintenance costs, noise reduction and improved local air quality (NSW Government, n.d b). Electric machinery also integrates with on-farm solar/battery systems to improve energy resilience and reduce exposure to diesel price volatility.

5) Barriers and Knowledge Gaps

Rating: High

Key Barriers to Electrification: High up-front capital costs; uncertainty about return on investment; grid capacity, infrastructure limitations and upgrade costs; the early-stage of technology development and rapidly changing technology landscape; servicing expertise availability; recharging challenges; and farmer confidence in terms of performance over long duty cycles (range, workload and reliability) (CottonInfo, n.d; GrainGrowers, 2024; AgriFutures Australia, 2022). Behavioural evidence from the Netherlands shows policy uncertainty and negative emotions can depress adoption intentions for electric tractors (Sok and Hoestra, 2023).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

There is general aspiration amongst horticultural producers to electrify further, but only when doing so makes operational and economic sense. A common view is that further electrification would require access to additional grid capacity and capability, or cost-sharing models to extend viable service to outlying water infrastructure (Powercor, 2025).

Key Barriers to Alternative Fuels: Limited commercial-scale production, competition for feedstocks, fuel supply and higher fuel cost relative to mineral diesel (GrainGrowers, 2024; AgriFutures Australia, 2022).

As highlighted by AgriFutures Australia (2022), the agriculture sector will likely be a beneficiary of the advances in technology and charging infrastructure established by the freight and mining sectors, given similarities in diesel fuel demand and heavy freight and mining needs. However, agriculture sector specific measures, such as targeted incentives, demonstrations, and advisory support will also likely be critical to driving adoption.

6) Stacking Potential

Rating: Medium-High

Electrification stacks well with on-farm solar+batteries, automation/robotics and precision agriculture.

7) Technology Readiness Level (TRL)

Rating: TRL 5–9 (component/setting dependent)

- Irrigation electrification/VSDs: TRL 9
- Battery-electric small tractors/UTVs & narrow orchard platforms: demo/early commercial, Australian release cycles are anticipated to be for 2026+: TRL 6–8
- Renewable diesel as drop-in: TRL 9
- High-power electric harvesters and broadacre tractors remain at pilot/prototype: TRL 5–6
- Alternative fuels (hydrogen/ biogas) for off-road power units are TRL 5–7 in specific applications.

8) Commercial Readiness Level

Rating: CRL 4–6 (component/setting dependent)

- Electric pumps + VSD retrofits: CRL 6 (established markets, utility rebates present).
- Battery-electric orchard/specialty tractors are at limited scale commercialisation: CRL 4–5 in Australia (pilots, early sales expected post-2026; distribution/servicing ramp needed).
- Renewable diesel: CRL 5–6 globally
- High-power electric-powered platforms and hydrogen/biogas tractors are CRL 2–3 pending supply chains, standards and dealer servicing.

9) Enabling Potential

Rating: Medium

Electrification helps enable automation, precision agriculture (targeted spraying, variable rate irrigation), data-rich machinery and robotics deployment, and clearer carbon accounting by

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

eliminating scope 1 fuel use. It also complements adoption of distributed energy resources (solar, batteries, microgrids).

10) Estimated Cost Range

Electric irrigation pumps with VSD: AU\$3,300 – AU\$27,000+ per pump (including purchase and installation cost).

- Note: costs and payback periods can vary significantly from farm-to-farm depending on the nature and scale of the irrigation system and site conditions.

Battery-electric orchard tractors (40–80 hp): AU\$115,000–AU\$150,000+ (indicative based on early international pricing). Uncertainty high.

- Note: Purely battery-electric orchard tractors currently remain extremely limited in local availability, with most expected to come to market in the next couple of years.

Renewable diesel: Depending on the feedstock and processing method, biofuels can cost between 1.5 – 3 times more than petroleum-based fuels (AgriFutures, 2022). As of early 2025–2026, renewable diesel (HVO100) in Australia carried a significant price premium, costing almost \$5 per litre, whereas conventional fossil diesel averaged at just under \$2 per litre (BDO, 2025).

11) Estimated financial benefits

Electric irrigation pumps with VSD: Under the right conditions, electric pumps with VSD can deliver significant combined energy and maintenance cost savings relative to single-speed pumps, being most advantageous in highly variable demand situations where flow adjustments are required during irrigation. Under these conditions, there are reports of average daily energy usage dropping by 39%, delivering an energy saving of \$4,000/year (NSW Government, 2016).

Battery-electric orchard tractors: Relative to diesel, battery electric-powered tractors will likely face lower energy costs per hour vs diesel and lower routine maintenance costs. Substantial cost benefits are anticipated for heavy freight to transition to electric vehicles (Electric Vehicle Council, 2022). However, to what degree this will translate to agricultural machinery is uncertain. Level of benefit will strongly depend on hours of use per year and the price of electricity. Estimated benefit: \$100–\$300/ha/year in fuel and maintenance savings.

Renewable diesel: Estimated financial benefits uncertain. Benefits accrued from adoption of renewable diesel and other alternative fuels will likely be tied to things such as potential carbon credit income and market access advantages rather than direct fuel savings.

12) Level of Investment in R&D, Commercialisation and Industry Scaling

Australian investments

Research & Development:

- \$50 million investment in sustainable agriculture research under a partnership between Charles Sturt University and industry will, amongst other objectives, involve testing and demonstration of dual-fuel hydrogen tractors. The investment will also examine how hydrogen can be produced in regional areas, as well as test other new technologies such as precision spraying and biogas conversion.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

- Federation University–CSIRO–Foton Mobility collaboration to develop simulations and perform small-scale system-integration studies with the aim of retrofitting diesel powertrains in tractors with a hydrogen fuel cell-electric system.

Commercialisation:

- John Deere autonomous battery-electric tractor Australian launch (expected in 2026)
- Case IH 75 hp e-tractor Australian showcases/early sales (2024–26)
- Powercor (an Australian electricity distribution company) 2025 customer engagement program around farm electrification needs. Involved engagement with farmers from across dairy, grain, animal husbandry, irrigation and fruit processing.

Precision Agriculture

Precision Agriculture (PA) optimises field operations and input use by reducing pass-to-pass overlap, unnecessary machine movements and mis-application. In horticulture, controlled-traffic farming (CTF) (enabled via guidance/autosteer systems and real-time kinematic (RTK) positioning), precision irrigation and variable-rate/targeted input application can cut diesel consumption and reduce direct soil N₂O emissions via improved fertiliser and irrigation timing, placement and rate.

1) Technical Annual Abatement Potential

In broadacre agriculture, CTF has the potential to reduce fuel consumption by 20% or more compared to conventional traffic management (Gasso et al., 2013; Chen et al., 2015; Botta et al. 2007) and N₂O emissions by 30–50% in fertilized soils (Tullberg et al., 2018).

Precision nitrogen application involves tailoring the rate, timing, placement and formulation of nitrogen fertilisers to match crop demand and site-specific conditions. Just looking at rate, excessive application of nitrogen fertiliser appears to be a common occurrence in Australian intensive vegetable production, with there being scope to reduce N₂O emissions by anywhere from 27% to more than 70% without compromising yield through better matching application rate with crop requirements (Suter et al., 2021; Rashti et al., 2015).

Precision irrigation reduces denitrification risk and is seen as among the most effective nitrogen-loss mitigations (Cameira & Mota, 2017; Ahmad & Khan, 2017). A global meta-analysis found drip irrigation to reduce N₂O emissions by 32% and 46% compared to furrow and sprinkler systems, respectively (Kuang et al. 2021). This was used by Integrity Ag (2025) to conservatively estimate a 30% reduction in fertiliser related emissions with micro-irrigation/fertigation compared to basic practice. Conversion to drip irrigation also has the potential to reduce on-farm energy-use emissions, particularly when replacing older inefficient and energy-intensive systems, such as hand shift and roll-line sprinkler systems (Mushtaq et al., 2013).

2) Feasible Annual Abatement Potential

We estimate feasible abatement from precision agriculture in horticulture by combining three main components: (i) controlled traffic farming (CTF) to reduce diesel combustion emissions, (ii) avoiding excessive nitrogen fertiliser application in intensive vegetable systems to reduce fertiliser-derived N₂O, and (iii) precision irrigation to reduce denitrification-related N₂O (and associated energy-use emissions where irrigation systems are upgraded). Using the same

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

horticulture Scope 1 baseline assumptions as above, we apply the relevant technical effects and adoption constraints for each component:

- CTF (ABpot = 0.10 applied to diesel-related Et = 0.21–0.42 Mt CO₂-e/yr; APdom = 0.90; ADpot = 0.10–0.40) yielding 1.9–15.1 kt CO₂-e/yr;
- Improved N-rate matching in intensive vegetables (ABpot = 0.485 applied to N₂O-related Et = 0.29–0.59 Mt CO₂-e/yr; APdom = 0.26; ADpot = 0.40–0.70) yielding 14.6–52.1 kt CO₂-e/yr; and
- Precision irrigation (ABpot = 0.30 applied to Et = 0.28–0.54 Mt CO₂-e/yr; APdom = 1.00; ADpot = 0.10–0.20) yielding 8.4–32.4 kt CO₂-e/yr.
- Summing these components gives a feasible abatement range of 24.9–99.6 kt CO₂-e/yr over 10 years, noting material uncertainty due to heterogeneity of horticultural systems, equipment compatibility constraints and the extent to which precision irrigation has already been adopted.

3) Breadth of Application

Rating: Medium

PA is generally applicable across many horticulture enterprises (orchards, vineyards, vegetables) but equipment variability, farm scale and capital constraints temper universal uptake. Regional constraints mainly affect communications coverage and service support for smaller, remote growers. Guidance/autosteer systems and variable rate/targeted spraying are widely relevant, while advanced autonomy may be niche initially. Incentives and training broaden applicability.

4) Co-Benefit Potential

Rating: High

Adoption of PA has strong potential to lead to lower fuel and electricity costs, fewer labour hours, reduced fertiliser and chemical input costs, reduced soil compaction, better water productivity, and improved product quality and consistency through more optimised, consistent applications. PA also facilitates inter-row sowing in perennial systems. As a specific example, Maraseni et al. (2012) observed that conversion from hand-moved sprinklers to drip irrigation in a lettuce production system in SE Queensland resulted in significant water savings of almost 2 ML/ha, as well as a halving in electricity consumption.

5) Barriers & Knowledge Gaps

Rating: Medium

In addition to the aforementioned barriers limiting feasible abatement potential, key barriers include upfront costs, skills and service support for smaller enterprises, connectivity in regional areas, and ROI uncertainty in complex horticulture operations and rotations. Capital and training hurdles particularly face smaller enterprises. Targeted extension and rebates mitigate these barriers.

6) Stacking Potential

Rating: High

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

PA stacks well with most other emissions reduction options available to horticultural producers, helping improve their performance and facilitate reductions in emissions from multiple sources, including fuel-related CO₂ emissions and N₂O emissions from denitrification. For instance, guidance/autosteer and variable application rate systems enable more precise application of inhibitor-coated/slow-release nitrogen fertiliser, and more precise sowing of cover crops.

7) Technology Readiness Level

Rating: TRL 9

Guidance/autosteer systems, RTK networks, variable rate application controllers, multi-sensor drones and farm IoT telemetry are fully commercial and operational in Australian horticulture with demonstrated field reliability across diverse crops and geographies. Numerous vendors and integration pathways exist, with ongoing incremental advances in PA tools.

8) Commercial Readiness Level

Rating: CRL 6

PA tools and services are widely sold and supported, with market supply chains and service networks in place, and uptake being supported by targeted grant programs. Adoption is generally stronger in larger enterprises, with smaller businesses adopting more gradually due to capital and skills constraints (McFadden et al., 2023).

9) Enabling Potential

Rating: High

PA acts as a platform for broader transformation, helping enable adoption of other emissions reduction solutions available to horticultural producers, as well as enabling credible monitoring, reporting and validation, improving certainty around RoI of other abatement technologies.

10) Estimated Cost Range

Guidance/autosteer systems: AU\$3,000 - AU\$15,000 (excluding installation cost and GST). Price range reflects cost variation between entry-level to advanced systems.

RTK positioning subscriptions: AU\$480 – AU\$1,800 per year (excluding GST). Subscription prices vary with coverage quality, base station density, simultaneous vehicle connections, and additional support offerings.

Drip/micro irrigation systems: AU\$1,500 – AU\$12,000 per hectare (figures reflect both materials and professional installation costs, exclude GST). Prices vary greatly with farm size, crop type, system sophistication, and level of engagement with professional service suppliers.

IoT moisture probes/telemetry: AU\$1,000 – AU\$3,000 per node plus AU\$200–500/year service cost (excluding GST).

Automated section control and VRA retrofit: AU\$7,000 – AU\$35,000 per boom/sprayer (excluding GST). Cost depends heavily on existing cab electronics, GPS readiness, sprayer boom width and number of sections, and choice of brand/platform.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

11) Estimated financial benefits

Adoption of PA has the potential to reduce production costs/increase revenue for horticultural enterprises in a variety of ways. These include through cutting fuel, fertiliser, water, chemical and electricity use, reducing the number of required labour hours, reducing maintenance costs and improving product quality and consistency through more optimised, consistent applications.

The extent that savings will be realised will likely vary significantly between enterprises depending on factors such as farm size and crop type, and so specific estimates need to be treated with caution. However, attempts can be made to arrive at general approximations for some cost reductions.

Fuel savings from CTF: Limited data could be sourced, but fuel-use per hectare from tractor operations equivalent to that for non-irrigated conventional tillage wheat crop (42.3 L/ha – with this factoring in tillage, planting, fertilisation, spraying and harvest operations) (Maraseni et al. 2015) would likely be very conservative compared to that of horticultural enterprises. In this situation, a fuel-use saving from CTF of 5-10%, at a diesel price of \$2/L represents a fuel cost saving of \$6.4 – \$12.8/ha.

Nitrogen fertiliser input savings from better matching application rate with crop requirements: Based on the findings of Rashti et al. (2015) and Suter et al. (2021), in Australian intensive vegetable production systems, there is potential to reduce nitrogen fertiliser rates by at least 33% without compromising yield simply through avoiding excessive application.

Chemical input savings from targeted/variable rate spraying: Manandhar et al. (2020) found variable-rate technology can reduce pesticide costs by as much as 67%. Costs associated with pesticide applications (e.g., chemicals, equipment, labour) can account for 30% or more of the annual operating costs for an orchard (Bechtel et al., 1995) or a vineyard (Sambucci et al., 2014), suggesting significant savings can be achieved through adoption of targeted/variable rate spraying.

12) Level of Investment in R&D, Commercialisation and Industry Scaling

Australia has substantive PA-relevant investments spanning R&D, commercialisation and scaling, including federal/state programs and initiatives by the Rural Research and Development Corporations. Globally, public agencies and private firms invest in sensors, autonomy and targeted application. Representative investments are listed below.

Australian investments:

- AgriFutures Producer Technology Uptake Program – (total funding not publicly disclosed) Designed to support producer groups in increasing the adoption of technology and innovation solutions on-farm.
- NSW DPI Farms of the Future Grants Program – \$7.5 million program which supported NSW farmers with the purchase of approved connectivity solutions and cutting-edge digital AgTech devices.
- On-Farm Connectivity Program – The Australian Government has allocated \$53 million across 3 rounds for the On Farm Connectivity Program to enable primary producers in agriculture, forestry and fisheries to extend connectivity in their fields and take

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

advantage of connected machinery and sensor technology. Rounds 1 and 2 of the Program delivered over \$30.5 million in rebates to help more than 2,900 primary production businesses boost connectivity on their farms.

- DAFF Climate-Smart Agriculture Program – \$45 million Partnerships & Innovation grant stream (2024–28) funding trials/adoption of climate-smart tech suites including PA-enabling tools.
- Hort Innovation investments:
 - Project AS20007: Driving ag-tech adoption across Australia – This investment is funding the establishment of a ‘Smart Farm’ that can be used to showcase technology to the horticulture sector.
 - Project AS23008: Automating the Nuts Industry in Australia: A pathway to smarter orchards and labour optimisation
 - Project AS23006: Digital remote monitoring to improve horticulture production and environmental performance
 - Project MT24013: Accelerating early access to emerging tech for vegetable growers
 - Project VG23003: Advanced vegetable mechanisation program to maximise labour and cost efficiency

Global investments:

- US Federal agencies support PA adoption, research and development, education, and training via financial assistance and loan programs, such as through payments for implementing practices that provide a conservation benefit. USDA and the National Science Foundation (NSF) have provided almost \$200 million for PA research and development funding in fiscal years 2017—2021.

Note: Many PA investments are embedded within broader sustainability/innovation programs, with precise PA-only amounts not always being disaggregated.

Nitrification Inhibitors

Nitrification inhibitors (NIs) are compounds that, when added to nitrogen fertilisers or soils, slow the microbial conversion of ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-) through depressing the activity of ammonia and nitrite-oxidizing microorganisms. This can reduce direct nitrous oxide (N_2O) emissions from the growing medium during crop growth due to less feedstocks being available for its production. There are at least eight compounds recognized commercially as NIs, with the most commonly used and best understood being DMPP (3,4-dimethylpyrazole phosphate) and DCD (dicycandiamide). NIs suppress microbial activity for a few days to weeks depending on concentration, soil moisture and soil type and there are differences among them in the way they are deployed (Fertilizer Australia, 2023).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

1) Technical Annual Abatement Potential

For perennial production systems, a meta-analysis by Gu et al. (2019) found application of NIs reduced N₂O emissions by 73% on average compared to conventional nitrogen fertilisers. For annual intensive vegetable production, Australian-based field studies have mostly observed NIs to reduce N₂O emissions during the cropping phase by between 20 – 76% compared to standard commercial practice while achieving equivalent yields (Scheer et al., 2014; Lam et al., 2015; Scheer et al., 2016; Riches et al. 2016; Scheer et al., 2017; Porter et al., 2017), with global meta-analyses arriving at average reductions of between ~35 – 40% (Yang et al., 2019; Pan et al., 2024). However, reductions can be offset by N₂O emissions during the fallow phase after crop residues are incorporated into the soil (with 70–90% of seasonal N₂O emissions being observed to occur during this phase) (Scheer et al., 2014; Scheer et al., 2017). This is due to NIs leading to the storing of nitrogen in the soil profile that is then available to soil microbes during residue decomposition. There is scope to successfully address these post-harvest emissions through the timely application of NIs before residue incorporation (Scheer et al., 2016), though the effectiveness of this strategy can vary depending on the biochemical characteristics of the residues being incorporated (Rashti et al., 2017). Hence the use of NIs in annual vegetable systems has to be treated carefully and fertiliser rates need to be adjusted to avoid an oversupply of nitrogen during the post-harvest phase (Scheer et al., 2017).

2) Feasible Annual Abatement Potential

We estimate feasible abatement for nitrification inhibitors by applying an emissions reduction effect (ABpot) to the portion of horticulture emissions attributable to fertiliser-derived N₂O (Et), then constraining by the technical application domain (APdom) and a plausible 10-year adoption extent (ADpot). Given the absence of a single, public national line item for vegetable horticulture Scope 1 N₂O, Et is treated as a key data gap and the estimate is provided as an order-of-magnitude bound. Using a central abatement effect of 40% (within a 30–60% band), assuming applicability across 60–80% of relevant systems and regions (APdom = 0.6–0.8), and assuming 40–60% adoption where economics, supply and advisory capacity support uptake (ADpot = 0.4–0.6), the resulting feasible abatement is modest but potentially material at national scale. As an illustrative calculation (to be refined when vegetable-specific Et is available), if direct vegetable-sector N₂O were ~0.3 Mt CO₂-e/yr, then feasible abatement would be approximately $0.40 \times 0.3 \times 0.7 \times 0.5 \approx 0.042$ Mt CO₂-e/yr (~42 kt CO₂-e/yr). This figure is provisional and should be refined when disaggregated horticulture N₂O emissions totals are available.

3) Breadth of Application

Rating: Medium

NIs are widely commercially available (e.g., ENTEC, eNpower) and can be applied across many vegetable crops and some orchards using ammonium/urea sources, in both temperate and subtropical regions. However, efficacy does vary with crop type (less effective for root vegetables vs other vegetable types), residue management, and soil pH, organic carbon content, texture, temperature, wetness (Yang et al. 2019; Scheer et al., 2014; Scheer et al., 2017; Rashti et al., 2017; Pan et al., 2024; Barth et al., 2001; Menendez et al., 2012). In general, NIs are more effective in sandy soils, or soil low in organic matter and under low temperatures (Fertilizer Australia, 2023). Logistics (product availability, coating options, fertigation compatibility) and regional advisory capacity further constrain uptake, and create a case for fit-for-purpose and context applications evidence.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

4) Co-Benefit Potential

Rating: Medium

The primary co-benefits of the use of NIs in horticultural production systems appear to be reduced nitrate leaching and improved nitrogen use efficiency (NUE). A global meta-analysis of the impact of enhanced-efficiency fertilizers (EEFs) on vegetable productivity by Pan et al., (2024) found that, compared to conventional urea, leaching decreased by 30.8% and NUE increased by 23.9% under application of NIs (DMPP, DCD). However, resulting impacts on yield have been variable. While Pan et al. (2024) found that NI-coated fertiliser on average statistically significantly improved vegetable yield by 7.5%, most Australian studies have observed no such effect. The effectiveness of NIs strongly depends on a range of environmental and management factors (Abalos et al., 2014), however this lack of yield response is likely due to the standard practice for many Australian horticultural producers entailing applying nitrogen fertiliser at rates in excess of the crop requirements, resulting in nitrogen not being a limiting factor to yield. This is supported by the results of Scheer et al. (2014), Riches et al. (2016) and Porter et al. (2017), as well as by the meta-analysis of Pan et al. (2024), with the analysis observing the yield-enhancing effectiveness of NIs tended to be more significant at lower nitrogen application rates.

Positive impacts on yield from the use of NIs are most likely in situations where background levels of mineral nitrogen are not in excess of plant demand and where the potential N₂O nitrogen losses are high. As Riches et al. (2016) conclude, given the high nitrogen application rates that are typically used in Australian intensive horticulture production, seeking to increase yields via NIs relative to current farm practices is unlikely to result in an outcome. As highlighted by Rose et al. (2018), in many situations the question should not be about whether EEFs such as NIs can increase yields, but rather, to what extent EEFs can allow for reduced nitrogen application rate without loss of yield, and whether this is economically viable given typical EEF price premiums.

The global meta-analysis by Pan et al. (2024) observed that EEFs (DMPP, DCD, polymer-coated urea) allowed for a reduction in nitrogen application rate by 15.6% without causing any decrease in yield, as compared to the use of traditional urea. Not only does this have potential direct financial benefits, but it could also lead to soil fertility benefits via reduction in the rate of nitrate leaching-induced soil acidification (Rose et al., 2018).

5) Barriers & Knowledge Gaps

Rating: Medium

Barriers include:

- Variable abatement efficacy of NIs across climates, crop types and nutrient sources (i.e. inorganic fertilisers vs manures), with N₂O reduction during the cropping phase ranging from 20 – 75% and 0 – 76% in Australian trials in sub-tropical and temperate intensive vegetable production systems respectively. Moreover, abatement effectiveness between NIs can noticeably differ, with Riches et al. (2016) finding DCD to be ineffective relative to DMPP. This leads to uncertainty around the level of emissions benefit that will be derived from the use of NIs, which would be expected to negatively impact adoption by producers.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

- Elevated post-harvest N₂O emissions in vegetable systems which impact on achievable net emissions abatement.
- Price premiums for NI-containing fertilisers and insufficient evidence and guarantee of economic benefits in terms of yield and reduced fertiliser requirements. The economics of NI use depend on either yield gains or reductions in required nitrogen application rate to offset their additional cost.
- The use of NIs leading to higher ammonia (NH₃) volatilisation in some contexts, with Pan et al. (2024) finding NIs increased NH₃ volatilisation in vegetable fields compared to traditional urea by on average by 32.4%. This can reduce NUE and lead to increased indirect N₂O emissions unless managed via NH₃ mitigation measures such as urease inhibitors.

Knowledge gaps include:

1. Further studies are required on the use of NIs in Australian horticultural production systems to provide greater certainty around their abatement efficacy and impact on NUE under various management and environmental conditions.
2. The evidence base on NIs in Australian horticulture is largely confined to intensive vegetable production systems in Queensland and Victoria, with it being unclear how reflective these systems are of vegetable production in other parts of Australia, as well as for other forms of horticulture. Future work should consider N₂O emissions from other production environments and settings, including perennial production systems and greenhouse production.
3. Further trials are needed to evaluate to what extent and under what conditions nitrogen fertiliser application rates can be reduced without yield penalty in horticultural production systems when using NIs, and to analyse the economic costs and benefits associated with their use. This will enable tools to be developed that allow producers to make more informed decisions around the adoption of NIs.
4. More research is needed on effective and economical strategies to reduce post-harvest N₂O emissions in intensive vegetable production when utilising NIs.

6) Stacking Potential

Rating: High

In addressing N₂O emissions, NIs can be stacked well with controlled/slow release nitrogen fertilisers (Fan et al. 2022; Wang et al. 2025) though seemingly less so with urease inhibitors (Pan et al. 2023; Zhao et al., 2017) (but which can also reduce NH₃ volatilisation). NIs can also be combined well with 4R nutrient stewardship (right rate/timing/source/ placement), precision irrigation/fertigation, cover crops, and residue management practices (e.g., delayed incorporation).

7) Technology Readiness Level (TRL)

Rating: TRL 8–9

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

NIs such as DMPP have undergone extensive laboratory and field validation, with operational deployment in Australian agriculture, particularly in broadacre grains production. In Australian vegetables, multiple peer-reviewed studies have validated mitigation performance during the cropping phase, though the need for further region and system-specific fine-tuning remains. It should be noted there are efforts underway to develop next-generation NI formulations.

8) Commercial Readiness Level (CRL)

Rating: CRL 6

NI-containing fertilisers (e.g., ENTEC® DMPP-coated products) are fully commercialised and widely available via major suppliers. Supply chains, product labels and QA are established. Market penetration in horticulture is likely uneven due to cost premiums, management complexity, and variable efficacy.

9) Enabling Potential

Rating: Low-Medium

Beyond direct mitigation, adoption of NIs supports broader optimised nutrient stewardship and can encourage adoption of precision agricultural practices. Wider-spread uptake of NIs can also potentially aid in the development of more accurate emissions factors for these types of nitrogen fertilisers.

10) Estimated Cost Range

The price premium for NI-containing fertilisers over conventional urea/compound fertilisers is thought to range between ~10–20%. This translates to a \$75 – \$149/ha and \$19 – \$38/ha premium for annual and perennial horticultural production systems respectively, based on typical nitrogen application rates. These calculations were based on the following:

- 415kg-N/ha application rate for intensive vegetable production (the average of standard nitrogen application rates used by several Australian studies – noting that not all N was supplied by urea or in the form of ammonium in every case)
- 105kg-N/ha application rate for orchard production (the average of standard rates referenced by AHR (2016) and Vilarrasa-Nogué et al. (2020), again noting that not all N was supplied by urea or in the form of ammonium in every case).
- Urea price of \$1,804/t-N (AU\$1.8/kg-N), and a resulting NI premium of \$180 – \$361/t-N (\$0.18 – 0.36/kg-N).

Note: NI fertiliser costs vary with formulation (coated compound vs. NI added in solution), rate, logistics and season, with local supplier quotes being required for high-accuracy cost estimates.

11) Estimated financial benefits

While direct yield gains in intensive horticultural systems resulting from the use of NIs are inconsistent at nitrogen fertiliser application rates at or above recommended, which are commonly applied in Australian horticulture, there is potential for financial benefits to be accrued via reduced fertiliser requirements due to NIs enabling greater NUE. Where NIs enable lower application rates without yield loss, their net cost can potentially be neutral or even negative.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Assuming nitrogen application rates (in the form of ammonium) in intensive horticultural systems can commonly be reduced by 15% without yield penalty through the use of NIs (Pan et al., 2024), at a nitrogen fertiliser price of \$1.5–2.0/kg-N and employing the same standard nitrogen application rates as used in the calculations above, savings of \$93 – \$125/ha and \$24 – \$32/ha for annual and perennial horticultural production systems respectively are conceivable, more than fully offsetting the estimated lower to mid-end NI premiums.

In terms of studies investigated net financial benefits for specific horticultural crops/systems, when comparing yield benefits against fertiliser costs, Fan et al. (2022) observed that, in the production of Chinese cabbage, applying urea at a rate of 320kg-N/ha with DMPP at 1kg/ha had an average net benefit over 2-years of USD\$861/ha versus application of standard urea at conventional rate (400kg-N/ha), though there was significant variation in net benefit over the 2-years (USD +\$1,869 vs USD -\$147).

Additional potential financial benefits from the adoption of NIs are a reduction in lime costs due to reduced soil acidification from application of less nitrogen fertiliser, and the ability to make ESG claims which may enable price premiums to be obtained.

Note: In some situations there may be nitrogen loss trade-offs from the use of NIs (via increased NH₃ volatilisation) without management intervention. This also needs to be factored in when making an assessment of net financial benefits.

12) Level of Investment in R&D, Commercialisation and Industry Scaling

Australia has had sizable, multi-year public investment in R&D into NIs within horticulture and broader agriculture as part of broader R&D initiatives, both historical and current. There has also been ongoing commercial investment by fertiliser companies in product development, registration and market development.

Note: Many NI investments are embedded within broader sustainability/innovation programs, with precise NI only amounts not always being disaggregated.

Australian investments:

Research and Development

- National Agricultural Nitrous Oxide Research Program (NANORP) – \$50 million dollar initiative which operated between 2012–2016. The program funded R&D to develop and delivered effective and practical strategies for reducing N₂O emissions while maintaining crop and pasture productivity, with it funding projects across multiple sectors including horticulture.
- More Profit from Nitrogen Program (MPfN) – \$15.5 million initiative between Australia's four most intensive users of nitrogenous fertilisers: cotton, dairy, sugar and horticulture which operated for 5-years from 2016–2021. The program funded a range of R&D to increase nitrogen use efficiency across the four sectors whilst improving profitable and sustainable use.
- ARC Research Hub for Innovative Nitrogen Fertilisers & Inhibitors (Smart Fertilisers) – \$5 million investment by Australian Research Council (ARC) to establish a collaborative research hub to develop the next generation of 'smart' fertilisers that will support sustainable agricultural intensification, farm profitability, and the health of soils and the

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

environment. This includes developing next-generation NIs suitable for intensive agriculture under Theme 2 of the Hub.

- University of Melbourne GRDC project – \$17.3 million 4-year national research program examining enhanced efficiency fertilisers (EEFs) across a range of climates, soils and cropping systems, so as to provide Australian grain growers with clear recommendations regarding which EEFs best suit their situation, and thus a greater capacity to improve their nitrogen use efficiency and reduce on-farm GHG emissions.

Commercialisation

- Ongoing supplier investment in NI-coated fertilisers (e.g. ENTEC® by Incitec Pivot). Exact investment figures not disclosed publicly.

Global investments:

- Multi-decadal global academic/industry R&D across a range of NIs, including DMPP and DCD, with numerous field trials and meta-analyses conducted.
- Multinational fertiliser companies have brought coated products to market globally; detailed financials are proprietary.

Slow/Controlled-Release Nitrogen Fertilisers

Slow/controlled-release nitrogen fertilisers (SRF/CRFs) are products that release nitrogen in a more gradual fashion compared to conventional fertilisers. They include coated urea (using either polymer or sulfur coating) and chemically bound nitrogen formulations that slow nutrient dissolution/mineralisation. SRF/CRFs reduce emissions by better synchronising soil mineral nitrogen availability with crop demand, lifting NUE, and reducing loss via volatilisation, leaching and denitrification (GRDC, 2025).

1) Technical Annual Abatement Potential

In horticultural soils, SRF/CRFs have been observed to reduce fertiliser-induced N₂O emissions by between 19 – 41% compared to conventional inorganic N fertilisers (such as urea, ammonium sulfate, and ammonium nitrate) applied at an equivalent rate while achieving comparable yield (Cheng et al. 2002 – from Pan et al. 2022; Yang et al., 2019; Fan et al. 2022; Pan et al. 2024; Wang et al. 2025), with a recent meta-analysis by Pan et al. (2024) arriving at an average reduction of 24.4% for polymer-coated urea used in vegetable cropping systems. Trials with SRF/CRFs have also reported reductions in NH₃ losses of between 61 – 83%, lowering indirect N₂O emissions (Shan et al. 2015).

Results vary with soil pH, nitrogen application rate, soil organic carbon content and soil texture. Therefore, selection of an appropriate application strategy based on the environmental conditions is important (Pan et al. 2023).

2) Feasible Annual Abatement Potential

We estimate feasible abatement for slow/controlled-release nitrogen fertilisers by applying a representative abatement effect for polymer-coated/controlled-release products (AB_{pot} = 0.25) to the portion of horticulture Scope 1 emissions attributable to fertiliser-derived N₂O (E_t = 0.29–0.59 Mt CO₂-e/yr, based on total horticulture Scope 1 emissions of 0.8–1.6 Mt CO₂-e/yr

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

and an assumed 36.8% N₂O share). We then constrain to the likely application domain (AP_{dom} = 0.70), recognising that SRF/CRFs fit most granular fertiliser programs (vegetables, orchards, vineyards) but are less compatible where fertigation relies on fully soluble, rapidly available nitrogen sources, and that logistics and product availability vary by region. Assuming 20–50% adoption over 10 years under current constraints (AD_{pot} = 0.20–0.50), feasible annual abatement is estimated at 10.2–51.6 kt CO₂-e/yr. This range is uncertain and sensitive to price premiums, variability in efficacy and the degree to which fertigation dominates nitrogen delivery in specific subsectors.

3) Breadth of Application

Rating: Medium

SRF/CRFs are generally applicable across vegetables, orchards and vineyards that use granular nitrogen fertiliser, but have limited applicability where fertigation predominates or in short growing-season crops which require frequent spoon-feeding such as some vegetable crops (Chahal et al., 2021). Regional suitability is broad, though noting that performance of polymer-coated options declines under both high and low soil pH conditions and in soils with high SOC levels (Pan et al., 2024; Li et al. 2018).

4) Co-Benefit Potential

Rating: Medium–High

Co-benefits from the application of SRF/CRFs typically include higher NUE and reduced nitrogen losses, particularly from volatilization, with a meta-analysis by Pan et al. (2024) observing that compared to conventional urea, under the application of polymer-coated urea, NUE increased by 27.3%, leaching decreased by 28.7% and volatilization declined by 74.5%.

Yield or quality benefits are context-specific but have frequently been observed to be neutral-to-positive (Pan et al. 2024; Yang et al. 2019; Li et al. 2018; Hyatt et al. 2010). As highlighted by the findings of Li et al. (2018), positive yield benefits are most likely to occur in situations where nitrogen is applied at below conventional rate.

Adoption of SRF/CRFs also has the potential to reduce costs through reduced nitrogen fertiliser requirements and through reduced labour/fuel requirements through enabling one-time pre-plant application as opposed to split application throughout the growing season (Chahal et al. 2021; Hyatt et al. 2010).

5) Barriers and Knowledge Gaps

Rating: Medium-High

Barriers include:

- Price premiums for SRF/CRFs over standard fertilisers mean they are currently largely limited to high value systems, such as amenity horticulture (GRDC 2025). Like with NIs, the economics of SRF/CRF use depend on either yield gains or reductions in required nitrogen application rate to offset their additional cost.
- Insufficient evidence of their mitigation effectiveness and guarantee of economic benefits in terms of yield and reduced fertiliser requirements in Australian horticultural production systems.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

- Compatibility with fertigation systems.
- As noted by Fertilizer Australia (2023), there are concerns about the fate of polymer coatings from SRF/CRFs in the environment.

Knowledge gaps include:

- It appears that very few studies have been conducted to-date on the use of SRF/CRFs in Australian horticultural production systems. More Australian, crop-specific cost-effectiveness data would aid scaling.
- Li et al. (2018) suggested that further research is needed to better understand the post-harvest fate of nitrogen applied through polymer-coated fertilisers.
- Biodegradable coating materials for polymer-coated SRF/CRFs (e.g., lignin-, natural oil-, cellulose-based) need to be developed and trailed in the vegetable systems (Pan et al. 2024).

6) Stacking Potential

Rating: High

In addressing N₂O emissions, SRF/CRFs can be stacked well with NIs, with several studies observing emissions reduction to be greatest when SRF/CRFs and NIs were combined together (Wang et al. 2025; Wang et al. 2024; Fan et al. 2022). Like with NIs, SRF/CRFs can also be combined with urease inhibitors, and combine well with 4R nutrient stewardship (right rate/timing/source/ placement), precision irrigation/fertigation, cover crops and residue management practices (e.g. delayed incorporation). The combinations address multiple loss pathways simultaneously without inherent conflicts, supporting additive mitigation.

7) Technology Readiness Level

Rating: TRL 9

SRF/CRFs are mature globally and in Australia for use for a range of crops. A wide variety of products are commercially available and used operationally (Fertilizer Australia, 2023). It should be noted efforts are underway to develop new and improved engineered coatings for SRF/CRFs.

8) Commercial Readiness Level

Rating: CRL 6

SRF/CRF products are sold and used in Australia but are likely not ubiquitous across horticulture due to price, distribution, and system fit (fertigation vs granular).

9) Enabling Potential

Rating: Low-Medium

Beyond direct mitigation, adoption of NIs supports broader optimised nutrient stewardship and can encourage adoption of precision agricultural practices. Wider-spread uptake of SRF/CRFs can also potentially aid in the development of more accurate emissions factors for these types of nitrogen fertilisers.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

10) Estimated cost range (on-farm)

Robust public price series for SRF/CRFs are limited. Coated urea typically commands a premium over standard urea, with Fertilizer Australia (2023) noting that an additional expense is associated with adding a coating to a fertiliser particle, which can almost double the cost of the fertiliser. Local quotes from suppliers are recommended.

11) Estimated financial benefits

Potential financial benefits arise from NUE gains, reduced need for re-applications of nitrogen during the growing season (meaning lower labour/fuel costs), and potential yield/quality stability through improved N synchrony.

12) Investment in R&D and commercialisation

Australia has active R&D on “smart fertilisers” (coatings, stabilisers), national nitrous-oxide programs, and grains-sector initiatives. Explicit funding amounts for horticulture-specific SRF/CRF are not consolidated publicly.

Australian investments:

Research and Development

- National Agricultural Nitrous Oxide Research Program (NANORP) – \$50 million dollar initiative which operated between 2012–2016. The program funded R&D to develop and delivered effective and practical strategies for reducing N₂O emissions while maintaining crop and pasture productivity, with it funding projects across multiple sectors including horticulture.
- More Profit from Nitrogen Program (MPfN) – \$15.5 million initiative between Australia’s four most intensive users of nitrogenous fertilisers: cotton, dairy, sugar and horticulture which operated for 5-years from 2016–2021. The program funded a range of R&D to increase nitrogen use efficiency across the four sectors whilst improving profitable and sustainable use.
- ARC Research Hub for Innovative Nitrogen Fertilisers & Inhibitors (Smart Fertilisers) – \$5 million investment by Australian Research Council (ARC) to establish a collaborative research hub to develop the next generation of ‘smart’ fertilisers that will support sustainable agricultural intensification, farm profitability, and the health of soils and the environment. This includes developing a new class of fertiliser with engineered coatings to enable controlled release of nutrients and inhibitors in a range of soil types, climatic conditions and diverse agricultural settings and land uses under Theme 2 of the Hub.
- University of Melbourne GRDC project – \$17.3 million 4-year national research program examining enhanced efficiency fertilisers (EEFs) across a range of climates, soils and cropping systems, so as to provide Australian grain growers with clear recommendations regarding which EEFs best suit their situation, and thus a greater capacity to improve their nitrogen use efficiency and reduce on-farm GHG emissions.

Cover Cropping

Cover crops in fallow windows (or inter-rows in orchards/vineyards) scavenge residual NO₃⁻, increase soil microbial biomass and structure, and moderate moisture dynamics (Gu et al., 2019;

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Cameira et al., 2021). Evidence shows lower N_2O emissions on average, particularly with non-legumes, alongside reduced NO_3^- leaching and event-based emissions linked to rainfall, mowing, or residue incorporation (Muhammad et al., 2019; Steenwerth & Belina, 2010). In vineyards, cover crops reduce fertiliser-induced emission factors relative to tilled systems and concentrate emissions into short, manageable pulses (Marques et al., 2018; Wolff et al., 2018).

Legume cover crops tend to increase soil N_2O emissions because of added reactive N inputs, whereas non-legume cover crops typically reduce N_2O by scavenging soil mineral N (Li et al., 2024). A meta-analysis of fruit orchards found that effects of cover cropping on N_2O outcomes depend on cover species, mulch material, and management through effects on soil water and nutrient availability (Gu et al., 2019).

1) Technical Annual Abatement Potential

Technically, cover crops can reduce fertiliser-related soil N_2O emissions by ~20–35% on treated hectares, with higher abatement where non-legume or mixed covers are retained on the soil surface. Vineyard systems show particularly strong reductions in emission factors.

Meta-analyses show that, on average, cover crops reduce soil N_2O emissions relative to bare fallow, but outcomes vary sharply by species and termination practice (Muhammad et al., 2019; Gu et al., 2019). Non-legume covers reduce emissions by scavenging mineral N and delaying N release, thereby decoupling N availability from periods of high soil moisture that favour denitrification (Li et al., 2024).

In contrast, legume-dominant covers often increase N_2O emissions due to additional biologically fixed N and rapid residue mineralisation, especially when residues are incorporated or terminated under wet conditions (Gu et al., 2019). Vineyard studies show resident cover crops reducing fertiliser-induced emission factors from ~0.57% to ~0.23% of applied N—around a 60% reduction—compared with tilled systems (Marques et al., 2018). Retaining residues on the surface consistently lowers emissions relative to incorporation by limiting anaerobic microsites (Steenwerth & Belina, 2010).

2) Feasible Annual Abatement Potential

Feasible abatement from cover cropping in Australian horticulture is modest but real (~0.006 Mt $\text{CO}_2\text{-e yr}^{-1}$), with uncertainty driven mainly by adoption levels, crop calendars, and species choice.

A midpoint abatement factor of ~25% is consistent with the reported 20–35% technical reduction range observed in meta-analyses and field studies where non-legume or mixed cover crops dominate, driven by reduced mineral N availability and dampened denitrification peaks following fertiliser application or rainfall (Muhammad et al., 2019; Li et al., 2024). Meta-analysis evidence indicates that non-legume covers generally reduce N_2O emissions relative to bare soil, while legume-dominant systems show neutral to positive emissions responses unless carefully managed (Gu et al., 2019).

Because disaggregated Australian horticulture fertiliser-derived N_2O emissions data are not available, feasible abatement is presented as an illustrative upper-bound, based on assumptions that cover crops are agronomically feasible on approximately 60% of relevant horticultural area and could reach around 50% adoption under favourable policy, advisory, and incentive settings. Adoption constraints linked to short vegetable crop rotations, late-harvest windows, and

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

competition for irrigation water are consistently identified as limiting factors in horticulture reviews (Cameira et al., 2021; Gu et al., 2019).

Field evidence from perennial systems indicates that where cover crops can be maintained between fertiliser applications—particularly in vineyards—direct N₂O emission factors are substantially reduced compared with tilled systems, supporting the plausibility of abatement on treated hectares (Steenwerth & Belina, 2010; Marques et al., 2018). However, multiple vineyard and orchard studies also demonstrate that event-driven emissions associated with mowing, residue incorporation, or rainfall can temporarily offset reductions, reinforcing the need for conservative feasible assumptions (Garland et al., 2014; Wolff et al., 2018).

The largest sources of uncertainty in the feasible estimate therefore relate not to the direction of the mechanism, which is well-established, but to the extent and consistency of implementation, particularly the proportion of systems using legume species and the capacity to avoid high-risk termination under wet conditions (Gu et al., 2019; Cameira et al., 2021). Taken together, the evidence supports a modest but defensible feasible abatement estimate, subject to refinement as Australian-specific emissions and adoption data become available.³) Breadth of Application

Medium: with strong relevance in orchards and vineyards and more variable feasibility in annual vegetable systems.

3) Breadth of Applications

Rating: medium

There is strong suitability in much perennial horticulture and more constrained applicability in intensive annual vegetable systems.

Perennial systems (orchards and vineyards) offer consistent inter-row space and temporal separation from main crop fertilisation, enabling cover crops to intercept residual mineral N and reduce background N₂O risk across seasons (Steenwerth & Belina, 2010; Marques et al., 2018). In contrast, annual vegetable systems face tight crop calendars, high soil disturbance, and frequent incorporation of residues, increasing the likelihood of N₂O pulses when termination coincides with irrigation or rainfall (Gu et al., 2019; Cameira et al., 2021). Meta-analysis evidence confirms that these management differences largely determine observed emission responses, supporting a medium breadth rating rather than broad applicability (Muhammad et al., 2019).

4) Co-Benefit Potential

Co-benefit potential is High, with consistent evidence of improvements in soil carbon, soil structure, erosion control, and nitrate leaching reduction across horticultural systems. These benefits are robust to management variation and frequently observed even where emissions outcomes are neutral or modest.

A large body of experimental and synthesis literature shows that cover cropping reliably increases soil organic carbon stocks and improves soil physical condition through added biomass inputs, enhanced aggregate stability, and increased biological activity (Muhammad et al., 2019; Cameira et al., 2021). Meta-analyses report average increases in soil organic carbon and total nitrogen under cover cropping relative to bare fallow, with particularly consistent effects in perennial systems where soil disturbance is limited (Gu et al., 2019).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Improvements in soil structure—manifested as greater aggregation, infiltration capacity, and surface protection—translate into reduced erosion risk, especially in irrigated horticulture and sloping vineyard systems (Steenwerth & Belina, 2010; Cameira et al., 2021). These structural effects are widely reported across climates and crop types and are not contingent on species choice to the same degree as emissions outcomes.

Cover crops also consistently reduce nitrate leaching by scavenging residual mineral N during fallow or low-uptake periods, lowering nitrate concentrations in the soil profile and drainage water (Gu et al., 2019; Muhammad et al., 2019). Leaching reductions are reported across both legume and non-legume systems, although the magnitude depends on biomass production and termination timing. Reviews of irrigated horticulture identify cover cropping as one of the most reliable practices for nitrate loss reduction, even where greenhouse gas responses are mixed (Cameira et al., 2021).

While trade-offs can occur—such as short-term increases in N₂O emissions following incorporation or wetting events—the co-benefits associated with soil carbon accumulation, improved physical condition, erosion control, and nitrate retention are structural and persistent, supporting a High co-benefit rating overall (Steenwerth & Belina, 2010; Gu et al., 2019).

5) Barriers and Knowledge Gaps

Barriers to adoption are Medium and arise primarily from operational complexity and risk management, rather than from uncertainty about the underlying mechanisms. The main constraints relate to opportunity costs, timing conflicts, event-sensitive emissions responses, and gaps in Australian-specific guidance and benchmarking.

Economic and operational barriers include the opportunity cost of land and irrigation water, seed and establishment costs, and conflicts with short and intensive vegetable rotations, where insufficient fallow windows limit safe establishment and termination (Cameira et al., 2021; Gu et al., 2019). In perennial systems, while inter-row cover crops are widely feasible, concerns persist around pest and disease carry-over, vineyard floor trafficability, and interference with machinery access during critical operations (Steenwerth & Belina, 2010; Wolff et al., 2018).

A key emissions-specific barrier is the risk of increased N₂O emissions from legume-dominant cover crops, particularly where biologically fixed nitrogen and low C:N residues accelerate mineralisation and denitrification (Gu et al., 2019; Li et al., 2024). Multiple studies show that N₂O responses are highly event-sensitive, with emissions responding strongly to rainfall, irrigation, mowing, or residue incorporation. This requires careful coordination of termination timing, residue placement, and water management to avoid short-duration emission spikes (Steenwerth & Belina, 2010; Garland et al., 2014; Muhammad et al., 2019).

Beyond direct costs, an important practical constraint is increased management and labour intensity, including the need to anticipate weather events, align fertiliser timing with cover crop nitrogen dynamics, and manage termination operations precisely. Reviews note that these requirements can deter adoption even where agronomic benefits are recognised (Cameira et al., 2021). Risk aversion also plays a role in systems where growers perceive potential impacts on yield, harvest operations, or spray access, contributing to uneven uptake across regions and crop types (Gu et al., 2019; Wolff et al., 2018).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Key knowledge gaps include the lack of Australian-specific cost–benefit benchmarks, limited area-weighted adoption data for horticulture, and insufficient species- and climate-specific guidance on cover crop mixtures and termination practices optimised for emissions outcomes (Gu et al., 2019; Cameira et al., 2021). These gaps constrain confidence in scaling estimates and reinforce the need for conservative feasible-abatement assumptions

6) Stacking Potential

High

Stacking potential is **High**. Cover crops interact synergistically with nitrogen and water management practices, strengthening their effectiveness across multiple nitrogen loss pathways and reducing the risk of trade-offs when interventions are implemented in isolation.

Cover crops function as a foundational practice that stabilises soil mineral nitrogen pools and moderates soil moisture dynamics, creating conditions under which other nitrogen management interventions perform more reliably. Reviews of irrigated horticulture identify strong complementarities between cover cropping and irrigation scheduling, split fertiliser and fertigation strategies, and the use of nitrification or urease inhibitors, as these combinations narrow the temporal overlap between high mineral N availability and periods of high soil moisture that promote N losses (Cameira et al., 2021).

By scavenging residual nitrate during fallow or low-uptake periods, cover crops reduce background nitrate levels, enhancing the effectiveness of slow-release fertilisers and inhibitor technologies that depend on controlled N availability rather than surplus pools (Muhammad et al., 2019; Cameira et al., 2021). Precision residue management—particularly maintaining residues on the soil surface rather than incorporating them—further reduces the risk of denitrification hotspots, reinforcing the benefits of stacked practices (Steenwerth & Belina, 2010).

In orchard and vineyard systems, cover crops complement inter-row mulches and reduced tillage by maintaining continuous ground cover, reducing soil disturbance, and supporting more stable nitrogen and moisture regimes between fertiliser applications (Steenwerth & Belina, 2010; Wolff et al., 2018). These stacked configurations address multiple nitrogen pathways simultaneously, including nitrate leaching, ammonia volatilisation, and nitrous oxide emissions, while also improving operational control of nutrient timing and placement (Gu et al., 2019; Cameira et al., 2021).

Synthesis studies consistently show that combined practices outperform single interventions, both in reducing N losses and in managing variability associated with weather or irrigation events, supporting a High stacking potential rating for cover crops within integrated nitrogen management strategies (Muhammad et al., 2019; Cameira et al., 2021).

7) Technology Readiness Level (TRL)

TRL 9: cover cropping is a proven practice with well-understood emission mechanisms.

Cover cropping has been used for decades across horticultural systems, and its effects on soil nitrogen cycling and N₂O production have been repeatedly demonstrated. Variability in outcomes reflects management choices rather than technology performance (Steenwerth & Belina, 2010; Gu et al., 2019)

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

8) Commercial Readiness Level (CRL)

CRL 6: adoption is widespread, but emissions-targeted use is uneven.

While cover crops are commonly adopted for agronomic reasons, their deliberate use to manage emissions depends on advisory support, operational capacity, and incentives focused on fertiliser and termination practices (Cameira et al., 2021).

9) Enabling Potential

Enabling potential is **Medium–High**. Cover crops function as an enabling practice by stabilising soil nitrogen dynamics and improving infiltration and moisture buffering, which increases the reliability and effectiveness of a range of downstream nitrogen management strategies.

Cover crops reduce short-term variability in soil mineral nitrogen—particularly nitrate—by scavenging residual N during fallow or low-uptake periods and releasing it more gradually following termination. This damping of nitrate variability improves the predictability of sensor-guided irrigation, precision fertigation, and nitrification or urease inhibitor strategies, all of which rely on tighter synchrony between nitrogen availability and crop demand to perform effectively (Cameira et al., 2021).

Improvements in soil structure and infiltration associated with continuous ground cover enhance the performance of irrigation management by reducing surface runoff and improving water distribution through the soil profile. This, in turn, lowers the likelihood of anaerobic conditions developing immediately after irrigation or rainfall, which supports more stable nitrogen transformation pathways and reduces the risk of episodic losses (Cameira et al., 2021; Steenwerth & Belina, 2010).

Cover crops also support nutrient budgeting and model-based decision tools by reducing background noise in soil nitrate levels, making nitrogen dynamics more responsive to management inputs rather than residual effects from previous seasons. Reviews of irrigated horticulture highlight this stabilising role as a key reason cover crops are commonly recommended as part of integrated nitrogen management frameworks, even where their direct emissions impact is context-dependent (Cameira et al., 2021).

10) Estimated cost range (on-farm)

Indicative on-farm costs for cover cropping are moderate and system-dependent, typically ranging from ~A\$100–450 ha⁻¹ yr⁻¹ across horticulture. Costs are lowest in vineyards, moderate in orchards, and highest in intensive vegetable systems. Australian-specific datasets are limited; ranges below are plausible orders of magnitude derived from reported cost components and management practices.

Indicative annual cost ranges (illustrative)

Vegetables (intensive rotations): ~A\$250–450 ha⁻¹

Orchards (inter-row covers): ~A\$150–300 ha⁻¹

Vineyards (inter-row covers): ~A\$100–250 ha⁻¹

Across the reviewed literature, the main cost components consistently identified for cover cropping are seed, establishment (sowing), termination, and—where irrigated—additional

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

water and labour (Cameira et al., 2021). Indicative seed costs commonly reported are ~A\$30–150 ha⁻¹ for cereal covers, with higher costs for mixed species, brassicas, or legume-dominant blends, reflecting higher seed prices and establishment complexity (Cameira et al., 2021).

Vegetable systems tend toward the higher end of the range due to more frequent establishment and termination, short fallow windows, and greater likelihood of mechanical incorporation, which increases both operational cost and management effort (Gu et al., 2019). Orchards and vineyards generally incur lower costs because covers are established less frequently, maintained as inter-row vegetation, and often terminated by mowing rather than incorporation, reducing fuel and labour inputs (Steenwerth & Belina, 2010; Wolff et al., 2018).

In irrigated systems, water use represents an opportunity cost, particularly where cover crops compete for limited allocation; this is highlighted as a constraint in irrigated horticulture reviews but is rarely costed explicitly (Cameira et al., 2021). Net costs can fall where growers capture operational offsets (e.g. reduced weed pressure or erosion remediation), but the literature does not provide consistent Australian \$/ha estimates by crop, reinforcing the illustrative nature of these ranges.

11) Estimated financial benefits

Financial benefits from cover cropping are **indirect, variable, and context-specific**, with typical net benefits ranging from **slightly negative to moderately positive** depending on system and management quality. Benefits are most consistently realised in vineyards and orchards, and least consistently in intensive vegetable systems.

Indicative net financial outcomes (illustrative)

- **Vegetables:** ~-A\$100 to +A\$100 ha⁻¹ yr⁻¹
- **Orchards:** ~A\$0 to +A\$200 ha⁻¹ yr⁻¹
- **Vineyards:** ~A\$50 to +A\$250 ha⁻¹ yr⁻¹

Evidence.

The literature does not report systematic yield gains attributable solely to cover cropping in horticulture. Instead, financial benefits arise through avoided losses and operational efficiencies, including reduced nitrate leaching, improved nitrogen utilisation, stabilised inter-row conditions, and reduced erosion-related damage (Gu et al., 2019; Cameira et al., 2021). Vineyard studies show that lower fertiliser-induced emission factors under cover cropping imply improved nitrogen efficiency, but fertiliser rate reductions are contingent on management and are not automatic (Marques et al., 2018; Wolff et al., 2018).

In vineyards, improved trafficability after rainfall, reduced erosion on slopes, and more stable inter-row surfaces are repeatedly cited as economically meaningful benefits, supporting modest positive net outcomes in many systems (Steenwerth & Belina, 2010; Wolff et al., 2018). Orchards show similar but more variable benefits, depending on water availability and floor-management strategy (Cameira et al., 2021).

In vegetable systems, benefits are more uncertain. While reductions in nitrate leaching and improved nutrient retention are well documented, additional management effort and timing

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

conflicts can offset gains, resulting in net outcomes that range from slightly negative to modestly positive (Gu et al., 2019; Cameira et al., 2021). Reviews therefore emphasise that financial performance depends less on the practice itself and more on how effectively cover crops are integrated with fertiliser, irrigation, and termination practices.

Overall, the evidence supports plausible net benefits in perennial horticulture, and conditional, management-dependent benefits in vegetable systems, but highlights a persistent gap in Australian, crop-specific \$/ha datasets suitable for aggregation or policy appraisal (Cameira et al., 2021).

Breakdown of benefits and justification

Area of benefit	Justification (mechanism)	Indicative costed benefit (A\$ ha ⁻¹ yr ⁻¹)	Source information
Improved nitrogen efficiency / avoided N losses	Cover crops scavenge residual nitrate during fallow or low-uptake periods and dampen post-fertiliser nitrate peaks, improving alignment between N availability and crop demand. Vineyard and orchard studies show reduced fertiliser-induced emission factors, implying improved N use efficiency without automatic rate cuts.	~\$20–80 (orchards, vineyards); \$0–40 (vegetables, conditional)	Gu et al. (2019); Muhammad et al. (2019); Marques et al. (2018); Cameira et al. (2021)
Reduced nitrate leaching and nutrient loss	Scavenging of soil NO ₃ ⁻ by cover crops lowers nitrate concentrations in the soil profile and drainage water, reducing nutrient losses that would otherwise require replacement or cause downstream impacts. Effects are robust across systems even where emissions responses are mixed.	~\$10–60 (all systems; higher in irrigated/perennial)	Gu et al. (2019); Muhammad et al. (2019); Cameira et al. (2021)
Erosion control / avoided remediation	Continuous ground cover reduces soil loss, surface runoff, and inter-row erosion, particularly in sloping vineyards and irrigated horticulture. Benefits accrue as avoided soil replacement, levelling, and field repair costs over time.	~\$20–100 (orchards, vineyards); ~\$0–40 (vegetables)	Steenwerth & Belina (2010); Wolff et al. (2018); Cameira et al. (2021)
Weed suppression / reduced herbicide use	Competition and surface residue from cover crops suppress inter-row and winter weeds, reducing herbicide requirements and passes, particularly in perennial systems. Less consistent in vegetables due to crop turnover and residue constraints.	~\$15–60 (orchards, vineyards); \$0–30 (vegetables)	Steenwerth & Belina (2010); Wolff et al. (2018); Gu et al. (2019)
Improved trafficability and operational reliability	Improved soil structure and surface stability allow earlier machinery access after rainfall, reducing delays to spraying, harvest, or maintenance and lowering compaction risk. Frequently cited as a practical benefit in vineyards.	~\$20–100 (vineyards); ~\$10–50 (orchards); marginal in vegetables	Steenwerth & Belina (2010); Wolff et al. (2018); Cameira et al. (2021)

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

12) Investment in R&D and CommercialisationAustralian investments

Australian investment relevant to cover cropping in horticulture is best characterised as moderate but diffuse, embedded within broader nitrogen and systems programs rather than targeted funding lines.

1. Hort Innovation (Horticulture RDC): VG16068 – *Optimising cover cropping for the Australian vegetable industry*

Focus: Cover crop species selection, establishment, termination, impacts on soil structure, nitrogen dynamics, weeds, and risks in intensive vegetable systems.

Relevance: Core Australian applied research on cover cropping in horticulture; underpins much of the practice-focused evidence base.

Delivery partner: Applied Horticultural Research (AHR).

Funding: Hort Innovation using vegetable R&D levies + Australian Government co-investment; project-level \$ not publicly itemised.

Outputs: Final report (2020), extension materials for growers.

Multiple Hort Innovation soil / nutrient efficiency projects (portfolio-level)

Focus: Soil health, nutrient recycling, N efficiency, irrigation–nutrient interactions in horticulture.

Relevance: Cover crops frequently evaluated as nitrogen scavengers and soil-conditioning practices, though not always the primary intervention.

Funding: Levy-based with government co-investment; cover crop spend not disaggregated.

2. Cotton RDC (CRDC) – with horticulture linkage

More Profit from Nitrogen (MPfN) (cross-RDC program), Focus: Nitrogen use efficiency across cotton, dairy, sugar, and horticulture, including fertiliser timing, enhanced-efficiency fertilisers, and N retention practices (incl. cover crops).

Funding:

A\$5.89 m Australian Government (Rural R&D for Profit)

A\$9.76 m cash + in-kind from RDCs and research partners

Total ≈ A\$15.6 m

Relevance: Major national investment where cover crops are treated as a nitrogen-buffering mechanism, particularly in irrigated systems.

3. Grains RDC (GRDC) – relevant but mostly non-horticultural

GRDC projects are not horticulture-specific but strongly influence the methods and models applied to cover cropping, N cycling, and emissions accounting used nationally.

National N-cycling and loss projects (APSIM / DNDC / RZWQM)

Examples:

Predicting nitrogen cycling and losses in Australian cropping systems

Systems approaches to nitrogen management

Focus: Mineralisation, denitrification, fertiliser fate, residue effects.

Relevance: These projects inform how cover crop residues affect N pools and N₂O risk, even though they are grain-system centred.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Funding: Multi-million dollar national GRDC investments; project-specific totals public but cover-crop share not isolated.

Enhanced Efficiency Fertiliser national project (urease / nitrification inhibitors)

Investment: A\$17.33 m, 4-year GRDC project led by University of Melbourne.

Relevance: Highly relevant to stacking and enabling logic—these technologies are routinely assessed *in combination* with cover crops in systems studies.

4. Sugar Research Australia (SRA)

Focus: N use efficiency, residue management, soil cover in irrigated cane systems.

Relevance: While crop-specific, SRA projects contribute to Australian evidence on cover and residue effects on N losses and N₂O, often cited in synthesis.

Funding: Levy + government co-investment; cover crop components not costed separately.

5. Dairy Australia

Focus: Nutrient budgeting, pasture cover, soil N dynamics.

Relevance: Cover crops sometimes evaluated as part of forage and rotation strategies; informs mixed farming / peri-horticulture regions.

Funding: Levy based; project values vary and are generally public only at program level.

6. Cross-cutting / System-level investments

Zero Net Emissions Agriculture CRC (ZNE-Ag CRC)

Focus: Low-emissions plant solutions, whole-farm systems, mixed enterprises (including horticulture).

Relevance: Cover crops appear as component practices, especially in mixed and irrigated systems, but no explicit cover-crop funding line.

Funding: CRC-scale (Commonwealth + industry partners).

Global investments (contextual comparison)

- United States (USDA)

The USDA, through NRCS and affiliated agencies, has invested heavily in cover cropping as part of nitrogen and greenhouse-gas mitigation research.

 - Example: a US\$1.2 million USDA grant to the University of Maryland to develop a Cover Crop Nitrogen Calculator, integrating satellite data to quantify nitrogen uptake and N₂O outcomes from cover crops.
 - Significant additional funding through Conservation Innovation Grants (CIGs) targeting measurement and optimisation of cover crop nitrogen dynamics. Practice Incentives / Scaling (international)
- USDA EQIP and Inflation Reduction Act (IRA)
 - Cover crops are one of the most heavily funded conservation practices under the USDA EQIP program.
 - Between 2018–2022, EQIP allocated ~US\$449 million to cover crop practices; additional IRA funding is projected to bring total cover-crop-related spending above US\$2 billion by 2026.
 - These funds support on-farm adoption, not commercial product development.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Urease Inhibitors

Urease inhibitors (UIs) are compounds that can be added to urea-based fertilisers to inhibit the action of the enzyme urease, which converts urea into ammonia. This can reduce the loss of nitrogen via ammonia volatilisation. While principally applied to mitigate gaseous emissions of ammonia, UIs can also reduce nitrous oxide emissions, both directly and indirectly (Freeman et al., 2020). Under certain soil moisture/temperature regimes, UIs help prevent rapid ammonium and nitrate surges after fertiliser events, resulting in reduced direct N₂O formation. When ammonia is emitted to air, it is deposited elsewhere and nitrification and N₂O emission can follow.

1) Technical Annual Abatement Potential

The effect of UIs on direct nitrous oxide emissions is dependent on a range of factors such as soil pH, water-filled pore space and temperature. Certain UIs may reduce nitrous oxide emissions by up to 86% under suitable soil conditions (Abalos et al., 2012), but effects can be neutral or variable in wet or acidic soils (Sanz-Cobena et al. 2016; Fan et al. 2018). Freeman et al. (2020) concluded that while use of UIs is an effective mitigation measure for ammonia emissions, efficacy for GHG mitigation is uncertain and probably low. Factoring all this in, a technical abatement potential of 10–30% where urea is surface applied is assumed.

2) Feasible Annual Abatement Potential

We estimate feasible abatement for urease inhibitors by applying a conservative emissions reduction effect (ABpot = 0.05–0.15) to the portion of horticulture Scope 1 emissions attributable to fertiliser-derived N₂O (Et = 0.29–0.59 Mt CO₂-e/yr, based on total horticulture Scope 1 emissions of 0.8–1.6 Mt CO₂-e/yr and an assumed 36.8% N₂O share). We assume broad technical applicability where urea is surface applied (APdom = 1.00), but constrain achievable uptake over 10 years given that many horticulture systems fertigate or incorporate nitrogen fertiliser (reducing the need for UIs), and given variable efficacy and ROI (ADpot = 0.20–0.30). On this basis, near-term feasible abatement is estimated at 2.9–26.6 kt CO₂-e/yr.

3) Breadth of Application

Rating: Medium

UIs are widely commercialised in Australia and their applicability is broad across horticultural production systems where surface broadcasts of urea occur (open-field vegetable production, some orchards). However, their applicability is limited in fertigated and covered/protected systems or where ammonium nitrate/liquids dominate. Regional suitability also depends on soil pH and climate (volatilisation risk). In conclusion, UIs are generally applicable across enterprises but their adoption is constrained by prevailing fertiliser delivery methods and site conditions.

4) Co-Benefit Potential

Rating: Medium

Strong, consistent ammonia loss reductions from the use of UIs of up to 90% (Freeman et al. 2020) improves nitrogen use efficiency (NUE), supporting yield reliability and reducing offsite environmental impacts. Meta-analysis shows NUE & yield gains (~12% & ~10% on average) with UIs, most pronounced on coarse textured, irrigated alkaline soils (Abalos et al., 2014), which are common in parts of horticulture.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

5) Barriers & Knowledge Gaps

Rating: Medium – High

Efficacy of UIs for nitrous oxide abatement is variable (strongly dependent on soil moisture and pH) and sometimes neutral (Freemen et al. 2020; Fan et al. 2018; Sanz-Cobena et al. 2016). Adoption also faces marginal on-farm ROI in some production systems, supply/logistics constraints regarding access to treated product (Freemen et al. 2020), and data gaps for Australian horticulture, with few Australian studies having investigated the impact of UIs on nitrous oxide emissions in irrigated systems (Grace et al. 2023). Safety concerns are low but residue/handling considerations exist (Freemen et al. 2020).

6) Stacking Potential

Rating: High

UIs stack well with:

- Nitrification inhibitors (dual inhibitor blends) for broader nitrogen-loss pathway control
- Precision irrigation & fertigation timing
- Best practice nutrient stewardship

7) Technology Readiness Level (TRL)

Rating: TRL 9

NBPT-based UI coatings are fully commercialised, widely tested across crops and climates, and integrated into fertiliser supply chains in Australia (e.g., Green Urea NV®) and globally (AGROTAIN™). Numerous field trials, guidelines and product labels exist, demonstrating that UIs are proven and operational.

8) Commercial Readiness Level (CRL)

Rating: CRL 6

In Australia UIs are available and adopted, but usage is situation specific (broadcast urea, high volatilisation risk). Penetration is meaningful in grains/pasture, but more limited in horticulture due to prevalence of the use of fertigation and use of a range of nitrogen fertiliser types other than urea. This aligns with CRL 6: established supply with initial penetration and scope to expand via targeted guidance and bundling with nitrification inhibitors/precision irrigation.

9) Enabling Potential

Rating: Medium

UIs support broader nitrogen management by stabilising surface applied urea, enabling flexible timing ahead of rain/irrigation and enabling operational windows. They do not transform systems alone, but enable targeted fertiliser strategies and can act as a stepping stone to adoption of dual urease-nitrification inhibitor products or precision irrigation suites. In certain systems, UIs may play an important role in facilitating adoption of nitrification inhibitors by helping to address the increase in ammonia volatilisation which can occur in some contexts with their use (Pan et al., 2024).

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

10) Estimated Cost Range (on-farm)

The incremental cost of NBPT-treated urea over standard urea is typically ~A\$5–20 per hectare per application (rate dependent), or a premium per tonne of treated urea. Vendor examples show ~A\$5.50–6 per hectare at 50 kg N/ha. Costs vary with coating rate, logistics, and number of applications per crop (Incitec Pivot, 2022).

11) Estimated financial benefits

Avoided ammonia losses through use of UIs can save fertiliser nitrogen and/or improve yield reliability. Trials in southern Australia measured ~70–80% ammonia loss reduction (Incitec Pivot, 2025), though efficacy is site and season dependent.

Based on a urea cost of A\$2.5–3/kg N, at just 10% nitrogen loss avoided on 50 kg N/ha, the nitrogen saved equates to A\$12 15/ha. Versus an additional fertiliser cost of ~A\$5–6/ha for UI treated urea, this would represent a positive ROI (Incitec Pivot, 2022).

12) Investment in R&D, Commercialisation & Industry Scaling (Australia & Global)**Australia Investments– R&D**

- GRDC–University of Melbourne EEF Program (2024–2028): A\$17.33m national trials on EEFs (incl. urease inhibitors) for efficacy, economics, and GHG outcomes. (R&D),
- PICCC EEFs project (project #264): lab & one field trial on NI/UI; NH₃ –40–70% with UI; variable N₂O outcomes. (R&D; amount n.a.)

Australian investments – Commercialisation / Industry Scaling

- Incitec Pivot Fertilisers (Green Urea NV®): decadelong product development, national sales and agronomy program; amounts not disclosed. (Commercialisation; Scaling),
- Fertiliser retailers & distributors (AIRR, others): market availability across regions; amounts not disclosed. (Scaling)

Global – R&D & Commercialisation

- Koch Agronomic Services (AGROTAIN™/ANVOL™): >25 years of trials & global deployment; investment undisclosed; extensive third-party reviews (EDF/NutrientStar). (Commercialisation; Scaling),

Soil Microbial Inoculants

Soil microbial inoculation refers to introducing or encouraging beneficial soil microbes, such as arbuscular mycorrhizal fungi (AMF), to enhance plant nitrogen uptake and/or alter soil nitrogen cycling, thereby lowering scope 1 nitrous oxide (N₂O) emissions from horticultural soils. AMF form symbioses with most crop roots and can reduce N₂O formation by (i) competing for ammonium, nitrate, and carbon substrates in microsites and (ii) recruiting ‘hyphosphere’ bacteria with complete denitrification capacity, yielding N₂ as the end product of denitrification instead of N₂O. Evidence for N₂O mitigation is strong in microcosm-based studies, growing in mesocosm-based studies and emerging from field studies, but field-scale horticulture evidence remains limited and context dependent.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

1) Technical Annual Abatement Potential

The presence of AMF is estimated to have the technical potential to reduce N₂O emissions by 20–50% (micro/mesocosm upper bounds) (Li et al. 2023b), noting there is significant uncertainty in these figures, with abatement potential expected to vary widely with crop.

- AMF reductions of 20–50% are drawn from lab/mesocosm and hotspot studies (upperbound technical). Vineyards show much lower N₂O, limiting potential.
- AMF mechanisms & reductions: microcosm/mesocosm reductions and hyphal competition/recruitment (Storer et al. 2018; Li et al. 2023).

2) Feasible Annual Abatement Potential

We estimate feasible abatement for soil microbial inoculants (e.g., AMF) by applying an indicative technical effect (ABpot = 0.20–0.50) to fertiliser-derived N₂O emissions (Et = 0.29–0.59 Mt CO₂-e/yr) and then constraining for both the proportion of horticulture where AMF inoculation is biologically and operationally relevant (APdom = 0.20, reflecting non-mycorrhizal crops and management constraints) and a plausible 10-year adoption extent given cost, logistics and variable field efficacy (ADpot = 0.20–0.30). On this basis, near-term feasible abatement is estimated at 2.3–17.7 kt CO₂-e/yr, with considerable uncertainty driven by field performance variability, crop compatibility and the degree to which high phosphorus regimes suppress colonisation.

3) Breadth of Application

Rating: Medium

Potentially broad across many horticultural crops that form AMF symbioses (most fruit trees, vines, many vegetables). However, key horticultural groups (Brassicaceae, Chenopodiaceae) are nonmycorrhizal, protected cropping/hydroponics is less suited, and high phosphorous inputs/fungicide regimes can suppress colonisation (Ghorui et al. 2025). Hence, breadth is Medium – generally applicable but constrained by crop biology and management practices.

4) Co-Benefit Potential

Rating: Medium-High

AMF often increase phosphorous uptake, root growth, water relations, and stress tolerance, with frequent yield gains. Soil biota and aggregation benefits are common. However, co-benefits are context-specific and product/strain-dependent (Li et al. 2025; Arcidiacono et al. 2024). Overall Medium–High with upside in low phosphorous soils and organic/biological systems.

5) Barriers & Knowledge Gaps

Rating: High

Major barriers include variable field performance (strain × host × soil), suppression by high phosphorous levels and some fungicides, product quality/shelf-life, formulation and delivery challenges, and limited replicated field data on N₂O abatement in horticulture (Ghorui et al. 2025; Storer et al. 2018). Furthermore, regulatory categories and standards for bio-stimulants/biologicals are still evolving (Ghorui et al. 2025). Large, real-farm studies quantifying N₂O reductions in Australian horticulture are scarce, representing a high knowledge gap for emissions outcomes.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Key uncertainties & data needs

- Field-scale N₂O abatement quantification in Australian horticulture (vegetables, orchards, vines) under commercial practice
- Durability of AMF effects under high phosphorus regimes and standard plant protection programs
- Standardised QA/QC for propagule counts, compatibility claims, and shelf-life
- Economic performance (multiyear ROI) across enterprise types.

No publicly accessible, large budget Australian field programs isolating AMF inoculants specifically for N₂O mitigation in horticulture.

6) Stacking Potential

Rating: High

AMF inoculants stack well with (i) improved nitrogen fertiliser timing/rates, (ii) cover crops/organic returns that build AMF networks, and (iv) precision irrigation. They are complementary (not substitutive) to nitrification inhibitors.

7) Technology Readiness Level (TRL)

Rating: TRL 8-9

AMF inoculants are commercially available and widely used in specialty, orchard and nursery systems. Core biological principles are validated, with products existing for multiple delivery modes (seedling dips, granules, coatings). Presence of multiple Australian suppliers and on-label rates indicates operational maturity and repeated real-world use. Remaining technical work focuses on strain matching, formulation stability, and performance consistency across soils/climates.

8) Commercial Readiness Level (CRL)

Rating: CRL 5

Active sales channels, established brands, and grower use in high-value crops indicate CRL 5 (limited scale commercialisation). Adoption is uneven (crop compatibility, perceived variability in benefit, and ROI uncertainty). Broader market penetration (CRL 6) is constrained by mixed field evidence on N₂O outcomes, price-performance questions, and limited advisory capacity for biologicals.

9) Enabling Potential

Rating: Low

AMF inoculants can enable lower nitrogen fertiliser inputs (via improved NUE), potentially simplifying compliance with nutrient loss targets and enhancing the value of soil health programs.

10) Estimated Cost Range (on-farm)

Cost depends on crop and application method. Indicative cost per hectare examples:

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

- Broadcast surface application (vegetables) at ~2.5kg/ha and ~\$79/kg (Newwave Biotech AMinoc biological inoculant powder) = AUD\$198/ha

11) Estimated financial benefits

Financial benefits are uncertain and system specific. Potential gains include fertiliser savings (lower required inputs on responsive soils), improved yield/quality (field studies show positive effects; tomato example +27% under specific AMF species), resilience in stress years, and possible premium marketing (biologicals) (Arcidiacono et al. 2024; Li et al. 2025; Ghorui et al. 2025). Where N₂O crediting is available, abatement revenue could supplement ROI, but measurement/verification pathways remain nascent for AMF-driven N₂O reductions.

12) Level of Investment in R&D and Commercialisation

Australia: Australian horticulture is actively investing in innovation/biologicals, but few targeted investments are traceable to AMF N₂O abatement trials. Specific, disclosed AMF N₂O R&D in horticulture is limited publicly,,

Global: Significant strategic investments in biologicals platforms (e.g., Corteva acquiring Symborg/Stoller), active product development (Novonosis/Novozymes). Many amounts undisclosed.

Australian investment

1. \$60m Hort Innovation Venture Fund (2024) – focus on horticulture innovation including biotechnology; classification: Industry scaling / commercialisation enabler.

Global investments

1. Corteva acquisitions of Symborg & Stoller (2023) – positions as biologicals leader; classification: Commercialisation/industry scaling (amount undisclosed). Amount bracket: unknown.,
2. Novozymes/Novonosis BioAg portfolio (e.g., B360 biostimulant) – ongoing product development; classification: R&D & commercialisation; amounts not disclosed.

References

Abalos, Diego, et al. 2022. “A Review and Meta-Analysis of Mitigation Measures for Nitrous Oxide Emissions from Crop Residues.” *Science of the Total Environment* 828: 154388. <https://doi.org/10.1016/j.scitotenv.2022.154388>.

Abalos, Diego, Sylvester Jeffery, Arántzazu Sanz-Cobena, Guillermo Guardia, and Antonio Vallejo. 2014. “Meta-Analysis of the Effect of Urease and Nitrification Inhibitors on Crop Productivity and Nitrogen Use Efficiency.” *Agriculture, Ecosystems & Environment* 189: 136–144. <https://doi.org/10.1016/j.agee.2014.03.036>.

Abalos, Diego, Arántzazu Sanz-Cobena, Tom Misselbrook, and Antonio Vallejo. 2012. “Effectiveness of Urease Inhibition on the Abatement of Ammonia, Nitrous Oxide and Nitric Oxide Emissions in a Non-Irrigated Mediterranean Barley Field.” *Chemosphere* 89 (3): 310–318. <https://doi.org/10.1016/j.chemosphere.2012.04.043>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

- Ahmad, A., and S. Khan. 2017. "Water and Energy Scarcity for Agriculture: Is Irrigation Modernisation the Answer?" *Irrigation and Drainage* 66: 34–44. <https://doi.org/10.1002/ird.2082>.
- Alternative Fuels Data Center (AFDC). 2026. "Renewable Diesel." U.S. Department of Energy. Accessed February 16, 2026. <https://afdc.energy.gov/fuels/renewable-diesel>.
- Applied Horticultural Research. 2016. *Apple and Cherry Orchards Low Nitrous Oxide Emissions – Plenty to Smile About*. Sydney: Applied Horticultural Research. https://www.cherrygrowers.org.au/wp-content/uploads/2024/06/190207_mt12047-nitrous-oxide-emissions-in-cherry-and-apple-crops.pdf.
- Applied Horticultural Research. 2024. *Protected Cropping Innovation Program (2024–2031)*. <https://ahr.com.au/projects/protected-cropping-innovation-program>.
- Arcidiacono, M., E. Pellegrino, M. Nuti, and L. Ercoli. 2024. "Field Inoculation by Arbuscular Mycorrhizal Fungi with Contrasting Life-History Strategies Differently Affects Tomato Nutrient Uptake and Residue Decomposition Dynamics." *Plant and Soil* 500: 105–127. <https://doi.org/10.1007/s11104-023-06147-7>.
- Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). 2025. *Agricultural Commodities: December Quarter 2025 – Statistical Tables*. Canberra. <https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/data>.
- Australian Bureau of Statistics (ABS). 2022. *Water Use on Australian Farms*. Canberra: ABS. <https://www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/latest-release>.
- Australian Bureau of Statistics (ABS). 2025. *Australian Agriculture: Horticulture, 2023–24*. Canberra: ABS. <https://www.abs.gov.au/statistics/industry/agriculture>.
- Australian Fresh Produce Alliance (AFPA). 2023. *Submission to the Agriculture and Land Sector Plan Discussion Paper*. <https://ausfreshproduce.org.au>.
- Australian Wine Research Institute (AWRI). n.d. *Project 1.1.2: Capitalising on the Carbon Economy – GHG Abatement in Viticulture*. https://www.awri.com.au/industry_support/sustainability/carbon-economy/.
- Barth, Gerhard, Stephan von Tucher, and Urs Schmidhalter. 2001. "Influence of Soil Parameters on the Effect of 3,4-Dimethylpyrazole Phosphate as a Nitrification Inhibitor." *Biology and Fertility of Soils* 34 (2): 98–102. <https://doi.org/10.1007/s003740100379>.
- Basche, Andrea D., et al. 2014. "Do Cover Crops Increase or Decrease Nitrous Oxide Emissions? A Meta-Analysis." *Journal of Soil and Water Conservation* 69 (6): 471–482. <https://doi.org/10.2489/jswc.69.6.471>.
- BDO. 2025. *Economic Impact of Renewable Diesel on Australia's Fishing Industry*. <https://www.bdo.com.au/en-au/insights/advisory/economics/economic-impact-of-renewable-diesel-on-australia-s-fishing-industry>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Bechtel, L., B. H. Barritt, M. A. Dilley, and H. R. Hinman. 1995. *Economic Analysis of Apple Orchard Management Systems with Three Varieties in Central Washington*. Research Bulletin XB1032. Pullman, WA: Washington State University.

Botta, G. F., et al. 2007. "Traffic Alternatives for Harvesting Soybean (*Glycine max* L.): Effect on Yields and Soil under a Direct Sowing System." *Soil and Tillage Research* 96 (1–2): 145–154. <https://doi.org/10.1016/j.still.2007.06.003>.

Cameira, M. R., and M. Mota. 2017. "Nitrogen-Related Diffuse Pollution from Horticulture Production—Mitigation Practices and Assessment Strategies." *Horticulturae* 3 (25). <https://doi.org/10.3390/horticulturae3030025>.

Carey, D., et al. 2022. *Identifying and Reducing Greenhouse Gas Emissions in Horticulture (HortCarbon Info): Final Report*. Brisbane: Queensland Department of Agriculture and Fisheries.

Chahal, I., et al. 2021. "Opportunities to Reduce Nitrous Oxide Emissions from Horticultural Production Systems in Canada." *Canadian Journal of Plant Science* 101 (6): 999–1013. <https://doi.org/10.1139/cjps-2020-0254>.

Chen, H., and Y. Yang. 2015. "Effect of Controlled Traffic System on Machine Fuel Saving in Annual Two-Crop Regions of the North China Plain." *Soil and Tillage Research* 153: 137–144. <https://doi.org/10.1016/j.still.2015.05.002>.

Cheng, W., et al. 2002. "N₂O and NO Emissions from a Field of Chinese Cabbage as Influenced by Band Application of Urea or Controlled-Release Urea Fertilizers." *Nutrient Cycling in Agroecosystems* 63 (2): 231–238. <https://doi.org/10.1023/A:1021112309011>.

Clean Energy Regulator. 2024. *Turning Soil into Wine: Soil Carbon Farming in Vineyards (Case Study)*. <https://www.cleanenergyregulator.gov.au>.

Corteva Agriscience. 2023. *Acquisitions of Symborg and Stoller* (Press releases). <https://www.corteva.com>.

CottonInfo. n.d. *Energy Efficiency Factsheet: Diesel vs Electric vs Solar*. <https://cottoninfo.com.au/publications/energy-diesel-vs-electric-vs-solar>.

Department of Primary Industries and Regional Development (WA). 2022. *Consultation Document: GHG Emissions Reduction Options for WA Agriculture*. Perth: DPIRD. <https://www.dpird.wa.gov.au>.

Department of Primary Industries and Regional Development (WA). 2024. *Horticulture and Greenhouse Gas Emissions*. <https://www.dpird.wa.gov.au>.

Electric Vehicle Council. 2022. *Electric Trucks: Keeping Shelves Stocked in a Net Zero World*. Canberra: Electric Vehicle Council. <https://electricvehiclecouncil.com.au>.

Fan, D., et al. 2022. "Optimizing Nitrogen Management to Mitigate Gaseous Losses and Improve Net Benefits of an Open-Field Chinese Cabbage System." *Journal of Environmental Management* 318: 115583. <https://doi.org/10.1016/j.jenvman.2022.115583>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Fan, X., et al. 2018. “The Contrasting Effects of NBPT on N₂O Emissions in Arable Soils Differing in pH.” *Science of the Total Environment* 642: 155–167.
<https://doi.org/10.1016/j.scitotenv.2018.06.004>.

Fertilizer Australia. 2023. *Nitrogen Fertiliser Use and Greenhouse Gases: An Australian Assessment—Challenges and Opportunities*. <https://fertilizer.org.au/news-events-and-publications/fertilizer-australia-white-paper>.

Freeman, D., J. Wiltshire, and B. Jenkins. 2020. *Evidence Review of the Efficacy of Nitrification and Urease Inhibitors*. Edinburgh: Ricardo Energy & Environment.

Garland, G. M., et al. 2011. “Direct N₂O Emissions Following Transition from Conventional Till to No-Till in a Cover-Cropped Mediterranean Vineyard.” *Agriculture, Ecosystems & Environment* 144: 423–428. <https://doi.org/10.1016/j.agee.2011.09.019>.

Gasso, V., C. A. Sørensen, F. W. Oudshoorn, and O. Green. 2013. “Controlled Traffic Farming: A Review of the Environmental Impacts.” *European Journal of Agronomy* 48: 66–73.
<https://doi.org/10.1016/j.eja.2013.02.002>.

Ghorui, M., S. Chowdhury, and S. Burla. 2025. “Recent Advances in the Commercial Formulation of Arbuscular Mycorrhizal Inoculants.” *Frontiers in Industrial Microbiology* 3: 1553472.
<https://doi.org/10.3389/fmicb.2024.1553472>.

Grace, P. R., et al. 2024. “Revised Emission Factors for Estimating Direct Nitrous Oxide Emissions from Nitrogen Inputs in Australia’s Agricultural Production Systems: A Meta-Analysis.” *Soil Research* 62: SR23070. <https://doi.org/10.1071/SR23070>.

GrainGrowers. 2024. *Fuels of the Future*.
<https://cdn.sanity.io/files/1nr0ob5f/production/095bf973d5caff76375904bee66d75166fa0b7ba.pdf>.

Grains Research and Development Corporation (GRDC). 2025. *Enhanced Efficiency Fertiliser – Update Paper*. Canberra: GRDC. <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2025/02/enhanced-efficiency-fertiliser>.

GRDC and University of Melbourne. 2024. *Major Investment to Reduce On-Farm GHG for Grain Growers* (Media release). <https://www.grdc.com.au>.

Gu, J., et al. 2019. “Nitrous Oxide Emissions from Fruit Orchards: A Review.” *Atmospheric Environment* 201: 166–172. <https://doi.org/10.1016/j.atmosenv.2019.01.012>.

Hirlam, K., M. Longbottom, E. Wilkes, and M. Krstic. 2023. “Understanding the Greenhouse Gas Emissions of Australian Wine Production.” *Wine & Viticulture Journal* 38 (2): 34–36.

Hort Innovation. 2021. *VG16068 Optimising Cover Cropping for the Australian Vegetable Industry: Final Outputs*. <https://www.horticulture.com.au>.

Hort Innovation and Artesian. 2024. *\$60 Million Venture Fund Announcement*.
<https://www.horticulture.com.au>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Huo, H., M. Wang, C. Bloyd, and V. Putsche. 2009. "Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels." *Environmental Science & Technology* 43 (3): 750–756. <https://doi.org/10.1021/es801403k>.

Hyatt, C. R., et al. 2010. "Polymer-Coated Urea Maintains Potato Yields and Reduces Nitrous Oxide Emissions." *Soil Science Society of America Journal* 74 (2): 419–428. <https://doi.org/10.2136/sssaj2009.0126>.

Incitec Pivot Fertilisers. 2022. *Agronomy Insight – Green Urea NV for Summer Crop 2022–23*. <https://www.nutrientadvantage.com.au/contentassets/d1a5d90330234e5cb239dab27a3de3b8/ai-bacre-s-2022-greenureanv-for-summer.pdf>.

Incitec Pivot Fertilisers. 2025. *Green Urea NV® – Product Page and Product Guide*. <https://www.ipf.com.au>.

Integrity Ag. 2025. *Guideline for Emission Reduction Options – Landscapes South Australia: Hills and Fleurieu*.

Intergovernmental Panel on Climate Change (IPCC). 2019. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 4, Chapter 11. Geneva: IPCC.

Joshi, D. R., et al. 2023. "A Global Meta-Analysis of Cover Crop Response on Soil Carbon Storage within a Corn Production System." *Agronomy Journal*. <https://doi.org/10.1002/agj2.21446>.

Koch Agronomic Services. n.d. *AGROTAIN™ Nitrogen Stabilizer – Product Page*. <https://kochagronomicservices.com>.

Kuang, W., et al. 2021. "A Global Meta-Analysis of Nitrous Oxide Emission from Drip-Irrigated Cropping Systems." *Global Change Biology* 27 (14): 3244–3256. <https://doi.org/10.1111/gcb.15612>.

Laing, A. M., et al. 2023. "Twenty Years of N₂O Emissions Research in Australian Agriculture: A Review." *Agriculture, Ecosystems & Environment* 356: 108638. <https://doi.org/10.1016/j.agee.2023.108638>.

Lam, S. K., et al. 2015. "Measurement and Mitigation of Nitrous Oxide Emissions from a High Nitrogen Input Vegetable System." *Scientific Reports* 5: 8208. <https://doi.org/10.1038/srep08208>.

Lam, S. K., et al. 2017. "Using Nitrification Inhibitors to Mitigate Agricultural N₂O Emissions: A Double-Edged Sword?" *Global Change Biology* 23: 485–489. <https://doi.org/10.1111/gcb.13428>.

Li, T., et al. 2018. "Enhanced-Efficiency Fertilizers Are Not a Panacea for Resolving the Nitrogen Problem." *Global Change Biology* 24 (2): e511–e521. <https://doi.org/10.1111/gcb.13918>.

Li, X., et al. 2023a. "Arbuscular Mycorrhizal Fungi Reduce N₂O Emissions from Degraded Residue Patches." *Frontiers in Ecology and Evolution* 11: 1224849. <https://doi.org/10.3389/fevo.2023.1224849>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Li, X., et al. 2023b. "Mycorrhiza-Mediated Recruitment of Complete Denitrifying *Pseudomonas* Reduces N₂O Emissions from Soil." *Microbiome* 11: 45. <https://doi.org/10.1186/s40168-023-01543-2>.

Li, X., Y. Wu, C. Huang, M. A. Rahman, E. Argaman, and Y. Xiao. 2025. "Inoculation with Arbuscular Mycorrhizal Fungi in the Field Promotes Plant Colonization Rate and Yield." *European Journal of Agronomy* 164: 127503. <https://doi.org/10.1016/j.eja.2024.127503>.

Longbottom, M. L., and P. R. Petrie. 2015. "Role of Vineyard Practices in Generating and Mitigating Greenhouse Gas Emissions." *Australian Journal of Grape and Wine Research* 21: 522–536. <https://doi.org/10.1111/ajgw.12187>.

Lorentz Australia. 2024. *Unveiling the Pros and Cons of Water Pumps – Electric, Solar, and Diesel*. <https://lorentz.com.au/blogs/case-studies/unveiling-the-pros-and-cons-of-water-pumps-electric-solar-and-diesel>.

Manandhar, A., et al. 2020. "Techno-Economic Impacts of Using a Laser-Guided Variable-Rate Spraying System to Retrofit Conventional Constant-Rate Sprayers." *Precision Agriculture* 21 (5): 1156–1171. <https://doi.org/10.1007/s11119-020-09723-0>.

Maraseni, T. N., et al. 2010. "An Assessment of Greenhouse Gas Emissions from the Australian Vegetables Industry." *Journal of Environmental Science and Health, Part B* 45 (6): 578–588. <https://doi.org/10.1080/03601234.2010.493490>.

Maraseni, T. N., S. Mushtaq, and K. Reardon-Smith. 2012. "Integrated Analysis for a Carbon- and Water-Constrained Future: An Assessment of Drip Irrigation in a Lettuce Production System." *Journal of Environmental Management* 111: 220–226. <https://doi.org/10.1016/j.jenvman.2012.06.024>.

Maraseni, T., et al. 2015. "An Assessment of Direct On-Farm Energy Use for High-Value Grain Crops Grown under Different Farming Practices in Australia." *Energies* 8 (11): 13033–13046. <https://doi.org/10.3390/en8112323>.

Marques, A. P. C., et al. 2018. "Influence of Vineyard Management on N₂O Emissions." *Atmospheric Pollution Research* 9 (1): 100–109. <https://doi.org/10.1016/j.apr.2017.08.001>.

McFadden, J., E. Njuki, and T. Griffin. 2023. *Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms*. Economic Information Bulletin 248. Washington, DC: USDA Economic Research Service.

Menéndez, S., et al. 2012. "Efficiency of Nitrification Inhibitor DMPP to Reduce Nitrous Oxide Emissions under Different Temperature and Moisture Conditions." *Soil Biology and Biochemistry* 53: 82–89. <https://doi.org/10.1016/j.soilbio.2012.04.027>.

Muhammad, I., et al. 2019. "Regulation of Soil CO₂ and N₂O Emissions by Cover Crops: A Meta-Analysis." *Soil & Tillage Research* 192: 103–112. <https://doi.org/10.1016/j.still.2019.04.020>.

Mushtaq, S., T. N. Maraseni, and K. Reardon-Smith. 2013. "Climate Change and Water Security: Estimating the Greenhouse Gas Costs of Achieving Water Security through Modern Irrigation Technology." *Agricultural Systems* 117: 78–89. <https://doi.org/10.1016/j.agsy.2012.12.007>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Nackley, L. L., et al. 2021. "Variable-Rate Spray Technology Optimizes Pesticide Application by Adjusting for Seasonal Shifts in Deciduous Perennial Crops." *HortTechnology* 31 (4): 479–489. <https://doi.org/10.21273/HORTTECH04863-21>.

New South Wales Department of Primary Industries. 2021. *Opportunities for Sequestration and Emissions Reduction from the NSW Agricultural Sector*. Orange: NSW DPI.

New South Wales Government. 2016. *Variable Speed Drives—An Energy-Saving Option for Irrigated Horticulture*.
https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/668348/variable-speed-drives-an-energy-saving-option-for-irrigated-horticulture.pdf.

New South Wales Government. n.d. *Renewable Diesel*.
<https://www.transport.nsw.gov.au/operations/freight-hub/towards-net-zero-emissions-freight-policy/knowledge-hub/renewable-diesel>.

Pan, Z., et al. 2023. "Improving Potato Productivity and Mitigating Nitrogen Losses Using Enhanced-Efficiency Fertilizers: A Global Meta-Analysis." *Agriculture, Ecosystems & Environment* 348: 108416. <https://doi.org/10.1016/j.agee.2023.108416>.

Pan, Z., et al. 2024. "Global Impact of Enhanced-Efficiency Fertilizers on Vegetable Productivity and Reactive Nitrogen Losses." *Science of the Total Environment* 926: 172016. <https://doi.org/10.1016/j.scitotenv.2024.172016>.

Primary Industries Climate Challenges Centre (PICCC). n.d. *Improving Nitrogen Use Efficiency: EEFs (Project 264)*. <https://piccc.org.au>.

Porter, I., D. Riches, and C. Scheer. 2017. "Benchmarking and Mitigation of Nitrous Oxide Emissions from Manures and Fertilisers Used in Temperate Vegetable Crops in Australia." *Soil Research* 55 (6): 534–546. <https://doi.org/10.1071/SR16301>.

Powercor. 2025. *Understanding Electrification of Agriculture*.
<https://engage.powercor.com.au/powercor-regulatory-reset/understanding-electrification-agriculture>.

Rashti, M. R., et al. 2015. "Strategies to Mitigate Greenhouse Gas Emissions in Intensively Managed Vegetable Cropping Systems in Subtropical Australia." *Soil Research* 53 (5): 475–484. <https://doi.org/10.1071/SR14227>.

Rashti, M. R., et al. 2017. "Assessment of N₂O Emissions from a Fertilised Vegetable Cropping Soil under Different Plant Residue Management Strategies." *Science of the Total Environment* 598: 479–487. <https://doi.org/10.1016/j.scitotenv.2017.04.086>.

Riches, D. A., et al. 2016. "Mitigation of Nitrous Oxide Emissions with Nitrification Inhibitors in Temperate Vegetable Cropping in Southern Australia." *Soil Research* 54 (5): 533–543. <https://doi.org/10.1071/SR15301>.

Rose, T. J., et al. 2018. "A Re-Evaluation of the Agronomic Effectiveness of the Nitrification Inhibitors DCD and DMPP and the Urease Inhibitor NBPT." *Agriculture, Ecosystems & Environment* 252: 69–73. <https://doi.org/10.1016/j.agee.2017.10.008>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Sambucci, O., J. M. Alston, and K. B. Fuller. 2014. *The Costs of Powdery Mildew Management in Grapes and the Value of Resistant Varieties*. Working Paper 1402. Davis, CA: Robert Mondavi Institute.

Sanz-Cobena, A., et al. 2016. "Soil Moisture Determines the Effectiveness of Two Urease Inhibitors to Decrease N₂O Emissions." *Mitigation and Adaptation Strategies for Global Change* 21 (7): 1131–1144. <https://doi.org/10.1007/s11027-014-9601-8>.

Scheer, C., et al. 2014. "Impact of Nitrification Inhibitor (DMPP) on Soil Nitrous Oxide Emissions from an Intensive Broccoli Production System in Sub-Tropical Australia." *Soil Biology and Biochemistry* 77: 243–251. <https://doi.org/10.1016/j.soilbio.2014.06.006>.

Scheer, C., et al. 2017. "Nitrification Inhibitors Can Increase Post-Harvest Nitrous Oxide Emissions in an Intensive Vegetable Production System." *Scientific Reports* 7: 43677. <https://doi.org/10.1038/srep43677>.

Soil Wealth and Integrated Crop Protection. 2023. *Nitrous Oxide Emissions from Vegetable Soils* (Factsheet). <https://soilwealth.com.au>.

Sok, J., and J. Hoestra. 2023. "Will Farmers Go Electric?" *Energy Research & Social Science* 102: 103180. <https://doi.org/10.1016/j.erss.2023.103180>.

Steenwerth, K., and K. M. Belina. 2008. "Cover Crops and Cultivation: Impacts on Soil Nitrogen Dynamics and Microbiological Function in a Mediterranean Vineyard Agroecosystem." *Applied Soil Ecology* 40: 370–380. <https://doi.org/10.1016/j.apsoil.2008.05.013>.

Storer, K. E., A. Coggan, P. Ineson, and A. Hodge. 2018. "Arbuscular Mycorrhizal Fungi Reduce Nitrous Oxide Emissions from N₂O Hotspots." *New Phytologist* 220: 1285–1295. <https://doi.org/10.1111/nph.15351>.

Suter, H., et al. 2021. "Opportunities to Improve Nitrogen Use Efficiency in an Intensive Vegetable System without Compromising Yield." *Journal of Environmental Quality* 50 (3): 791–798. <https://doi.org/10.1002/jeq2.20228>.

Swarts, N., et al. 2016. "Benchmarking Nitrous Oxide Emissions in Deciduous Tree Cropping Systems." *Soil Research* 54 (5): 500–511. <https://doi.org/10.1071/SR15247>.

Tullberg, J., et al. 2018. "Controlled Traffic Farming Effects on Soil Emissions of Nitrous Oxide and Methane." *Soil and Tillage Research* 176: 18–25. <https://doi.org/10.1016/j.still.2017.11.002>.

Vilarrasa-Nogué, M., et al. 2020. "Effect of Nitrogen Dose, Fertilisation Duration and Use of a Nitrification Inhibitor on Greenhouse Gas Emissions from a Peach Orchard." *Science of the Total Environment* 699: 134042. <https://doi.org/10.1016/j.scitotenv.2019.134042>.

Wang, F., et al. 2025. "Five-Year Controlled-Release and Stabilized Nitrogen Fertilization Reduces Field Nitrogen Loss without Increasing CO₂ Emissions in a Vegetable Rotation System." *Pedosphere* 35 (4): 741–750. <https://doi.org/10.1016/j.pedsph.2024.04.003>.

APPENDIX C.4: Priorities for Low Emissions Agricultural Solutions Investment

Wang, X., et al. 2024. "Effects of Long-Term Controlled-Release Urea on Soil Greenhouse Gas Emissions in an Open-Field Lettuce System." *Plants* 13 (8): 1071. <https://doi.org/10.3390/plants13081071>.

Wine Australia. 2023. *Safeguarding the Future for Australian Wine: An Emissions Reduction Roadmap*. Adelaide: Wine Australia. <https://www.wineaustralia.com>.

Wine Australia. n.d. *Cover Crops; National EcoVineyards Program; Under-Vine Cover Cropping Final Report (2023)*. <https://www.wineaustralia.com>.

Yang, T., et al. 2019. "Impact of Nitrogen Fertilizer, Greenhouse, and Crop Species on Yield-Scaled Nitrous Oxide Emissions from Vegetable Crops: A Meta-Analysis." *Ecological Indicators* 105: 717–726. <https://doi.org/10.1016/j.ecolind.2018.07.029>.

Zhao, Z., et al. 2017. "Nitrification Inhibitor Effects on Mitigating N₂O Emissions Were Weakened by a Urease Inhibitor in Calcareous Soils." *Atmospheric Environment* 166: 142–150. <https://doi.org/10.1016/j.atmosenv.2017.07.021>.