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Climate-smart agriculture

Australian sustainable farming practices enabled by plant science innovation

An independent technical review

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CROPLIFE AUSTRALIA

CropLife Australia is the national peak industry organisation representing the plant science sector in Australia.

CropLife's members are the world-leading innovators, developers, manufacturers, formulators and suppliers of organic and synthetic, chemical and biological crop protection products (pesticides) and crop biotechnology innovations. The plant science industry, worth more than $31.6 billion a year to Australian agricultural production, provides products to protect crops against pests, weeds and diseases as well as developing crop biotechnologies key to achieving global food and nutritional security by supporting the sustainable increased production of food, feed and fibre.

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FOREWORD

Australia's farmers have long been among the most resource-efficient growers and producers in the world. Operating in one of the most variable and challenging climates of any major agricultural nation, they have consistently adopted science-based innovations that lift productivity while safeguarding land, water and our unique biodiversity. Their success has been underpinned by science, innovation and stewardship: adopting new technologies and practices that drive yield gains, enhance resilience, improve sustainability and protect the environment.

This report, researched and authored by one of Australia's leading independent agronomists and agricultural academics, documents Australia's climate-smart agricultural achievements. It shows that integrating plant science innovations, including modern crop protection products, advanced genetics, crop biotechnology innovations and precision agriculture techniques, has played a decisive role in enabling Australian agriculture to produce more food, feed and fibre with a smaller environmental footprint.

Drawing on peer-reviewed scientific research, national datasets and industry case studies, this report provides clear scientific evidence that plant science innovations are a cornerstone of climate-smart agriculture, underpinning the long-term sustainability and productivity of Australian farming and global food systems.

When farmers have access to effective, safe and innovative technologies and products, they achieve higher yields and lower emissions intensity. Australia's cropping systems now rank among the lowest-emitting globally on a per-tonne basis. These outcomes have been supported by robust stewardship frameworks, science-informed and risk-based regulation and strong partnerships between industry, research and government.

The challenge for the farming sector is, however, only intensifying. Climate volatility, shifting market expectations and rising global competition mean Australia cannot stand still. Australia cannot maintain its competitive advantage without policy certainty and timely access to innovation. The sector's continued success depends on policies that safeguard access to modern technologies, incentivise ongoing R&D innovation and good stewardship, and recognise the essential role of plant science in achieving national and global climate goals and food security.

The evidence presented in this report provides a foundation for future policy. It reinforces that science-led innovation, supported by effective stewardship and regulatory clarity, is critical to maintaining Australia's position as a world leader in sustainable, productive and low-emissions agriculture.

Australian agriculture's track record shows what is possible. Our shared ambition is to build on that legacy so the sector continues to thrive profitably, productively and sustainably, in the coming decades and beyond.

Matthew Cossey
Chief Executive Officer
CropLife Australia

EXECUTIVE SUMMARY

As Australia faces climate change challenges, the capacity of Australian agriculture to adapt while sustaining productivity has become a defining national concern. To maintain Australia's farming success, policy makers, together with researchers and industry, must implement solutions to grow agricultural production, delivering more low-emissions food to support both global and national food security and a low-emissions future. To do this, Australia must lean into science, innovation and stewardship to deliver genuine climate-smart agriculture.

Australia's farming track record

- **World-leading efficiency and sustainability:**
  Australian agriculture is recognised globally for delivering more food with fewer resources. Despite operating in one of the most variable climates of any major exporter, the sector has maintained high productivity while protecting soil, water and biodiversity.
- **Demonstrated emissions reductions with increased productivity:**
  Since 1990, the agricultural sector has cut greenhouse gas emissions by around 20 per cent while increasing total output by more than 60 per cent.[1] This reflects decades of innovation, product stewardship and investment in science-based farming systems.
- **Lowest emissions intensity among major export nations:**
  Benchmarking data from ABARES shows that across a representative basket of commodities, Australia has the lowest farm-gate emissions intensity globally: up to 42 per cent lower than other major export nations. In cropping, Australia's grains industry has the lowest emissions per tonne among peer nations, demonstrating the sustainability of dryland production systems.[2]
- **Sustainable intensification achieved at scale:**
  Australian farmers have increased productivity without expanding land area, maintained output while reducing land use, improved water efficiency, and protected biodiversity through conservation tillage, improved genetics and modern agronomic practices.[3]

Plant science innovations driving climate-smart outcomes

- **Plant science innovations are central to climate-smart agriculture:**
  These innovations include modern crop protection products, crop biotechnology and advanced breeding techniques. They enable farmers to maintain yields, reduce input waste and improve resilience in a warming, more variable climate.
- **Precision and conservation practices:**
  Adoption of no-till and minimum-till systems, now used on over 90 per cent of Australian croplands, has increased soil carbon, reduced erosion and improved water infiltration.[4] Precision agriculture and controlled traffic farming systems minimise fuel and fertiliser use, thereby reducing emissions.[5]
- **Genetic innovations delivering measurable benefits:**
  GM Bt cotton has reduced insecticide use by 85 per cent since 1996, restoring beneficial insect populations and improving biodiversity.[6] GM canola varieties are herbicide-tolerant, providing improved weed control and higher yields, contributing to stable export supply and competitiveness.[7]

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1 "DISER | National Inventory Report Volume 1 - The Australian Government Submission to the United Nations Framework Convention on Climate Change."
2 "ABARES | International Farm Emissions Intensity Statistics."
3 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
4 Bellotti and Rochecouste, "The Development of Conservation Agriculture in Australia—Farmers as Innovators."
5 Robertson, Carberry, and Brennan, "The Economic Benefits of Precision Agriculture: Case Studies from Australian Grain Farms."
6 "CSIRO | Cotton Pest Management."
7 "OGTR | Snapshot of Genetically Modified (GM) Canola in Australia."

- **Improved water use efficiency:**
  - **Cotton:** 40 per cent improvement in water productivity over the past decade attributable to advances in plant breeding, producing 1.03 bales per megalitre, less than half the global average water requirement.[8]
  - **Grains:** the National Water Use Efficiency Initiative delivered a 60 per cent improvement in water use efficiency, generating a $5.60 return per dollar invested through better stubble management and weed control.[9,10]
- **Stewardship and safe use of crop protection products:**
  Risk-based regulation, through the APVMA, and industry stewardship programs ensures crop protection products are used safely and effectively, aligning with global best practice for human health and environmental protection.[11]

Sustaining agricultural productivity in a changing climate

- **Greater climate volatility:**
  Droughts, heatwaves, floods and storms are becoming more frequent and intense. Without further adaptation, profits are projected to contract by an additional 10 to 50 per cent by 2050.[12,13]
- **Expanding pest and disease threats:**
  Warmer temperatures and altered rainfall patterns are enabling invasive pests, weeds and disease to move into new regions, increasing management costs and putting yields at risk.[14]
- **Yield losses drive higher emissions:**
  Without access to next-generation crop protection products and improved genetics, yield gaps of 10 to 30 per cent have been documented across key crops under climate change stress conditions.[15] Lost yields drive higher emissions intensity per tonne of food produced, undermining sustainability credentials.
- **Export competitiveness at risk:**
  Australia exports 70 per cent of its agricultural output.[16] Even small reductions in productivity could translate to billions in lost export value, particularly as global buyers increasingly demand verified low-emissions, sustainably produced commodities.
- **Carbon leakage risk:**
  Reducing production without improving efficiency would shift demand to other nations with weaker environmental standards, leading to higher net global emissions: the very outcome climate action seeks to avoid.[17,18]

Climate change is already reshaping the conditions under which Australian farmers operate. Rising temperatures, shifting rainfall patterns, and escalating pests, weeds, and disease pressures are eroding productivity and threatening the gains achieved through decades of innovation and stewardship. Maintaining Australia's world-leading sustainability record requires decisive, proactive investment in science, technology and regulation to keep pace with accelerating climate risks.

Inaction carries tangible economic, environmental and social costs. To secure the future of a sustainable Australian agricultural sector, timely access to plant science innovations must be treated as a strategic national priority, enabling farmers to continue producing world-leading, low-emissions food, feed and fibre in an increasingly challenging environment.

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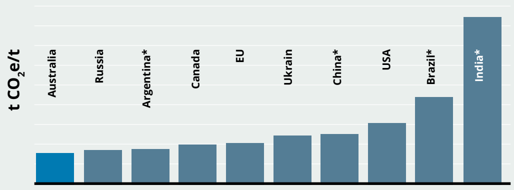
8 Roth et al., "Water-Use Efficiency and Productivity Trends in Australian Irrigated Cotton."
9 "GRDC | Investing in Water Use Efficiency Yields Results."
10 "CSIRO | Researching Water Use Efficiency for Increased Grain Yield."
11 "Australian Pesticides and Veterinary Medicines Authority."
12 "CSIRO | State of the Climate 2024."
13 Hochman, Gobbett, and Horan, "Climate Trends Account for Stalled Wheat Yields in Australia since 1990."
14 "IPCC | Sixth Assessment Report Chapter 5."
15 "IPCC | Sixth Assessment Report Chapter 5."
16 "ABARES | Snapshot of Australian Agriculture 2025 - Around 70% of Agricultural Production Is Exported."
17 Arvanitopoulos, Garsous, and Agnolucci, "Carbon Leakage and Agriculture."
18 Jakob, "Why Carbon Leakage Matters and What Can Be Done against It."

AUSTRALIA'S FARMING SUSTAINABILITY SCORECARD

Delivering more food with less land and resources – reducing agriculture's emissions intensity

Lowest Farmgate Emissions Intensity Among Major Exporters

- **Up to 42% lower emissions** than other major exporters.



Note: Excludes rice. * Indicates countries for which calculations of greenhouse gas emissions are based on Tier 1 default factors per the 2019 refinement to the 2006 guidelines

Up to 90% adoption

of minimal and no-till farming

Both minimal and **no-till farming** and **stubble retention** help maintain soil organic matter, reduce soil erosion and improve water retention.

20% Reduction

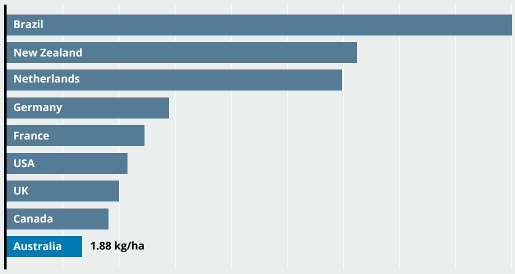
in GHG emissions since 1990 with 60% more output

7.4 million ha

of land for conservation or environmental protection purposes

Australian agriculture is a global leader in sustainable intensification.

Most sustainable pesticide use among major exporters



- Access to modern pesticides, coupled with **strong industry-led stewardship**, has resulted in relatively low pesticide usage in Australia.
- **1.88 kilograms per ha** – well below comparable export nations.

More water efficient

Grains:

- **Up to 60% improvement** in water use efficiency achieved through smarter farming practices.
- **$5.60 return** for every dollar invested.

Cotton:

- Water use efficiency has **improved by 40%** over the past decade.
- Achieving an **average of 1.03 bales** per megalitre; the global average is 2.07 bales per megalitre.

The adoption of GM Bt cotton has reduced insecticide use by 85% since 1996

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ABBREVIATIONS

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences (of the Australian Government Department of Agriculture, Fisheries and Forestry)
CAPAD	Collaborative Australian Protected Areas Database
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTF	Controlled traffic farming
ERF	Emissions Reduction Fund
GHG	Greenhouse gas
GM	Genetically modified
GRDC	Grains Research and Development Corporation
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
ISCC	International Sustainability and Carbon Certification
ISO	International Organization for Standardization
MOA	Mode of Action
Paris Agreement	Paris Agreement to the United Nations Framework Convention on Climate Change. *Also referred to as the Paris Accords or Paris Climate Accords*
R&D	Research and development
SOC	Soil organic carbon
VRN	Variable rate nitrogen
WUE	Water use efficiency

1. AUSTRALIAN FOOD PRODUCTION

Australia is home to just 0.3 per cent of the world's population, yet it produces enough food to feed tens of millions more people than its own. What makes Australia unique is not just the volume of food it grows, but the fact that most of it is exported. Around 70 per cent of Australian agricultural produce is sold overseas, accounting for approximately 3.5 to 4 per cent of global food exports.[19] Put simply, Australia's per-capita food exports represent an outsized contribution to global supply.

Each year, Australia's agricultural exports are valued at around $70 to 72 billion, with key commodities including wheat, barley, beef, lamb, canola, sugar, wool and dairy.[20] Grain alone represents a mainstay of this trade. In 2022–23, Australia produced 65.2 million tonnes of grain, of which 47.9 million tonnes were exported.[21]

Australia's role in global food security extends beyond scale. Its exports are trusted worldwide for quality, safety and sustainability.[22] This reputation is underpinned by robust regulatory frameworks, strict biosecurity laws, best-practice management of pests, weeds and disease, and clean, traceable supply chains.

Across its diverse and variable climate regions, Australia has developed globally renowned dryland cropping and grazing systems, making it among the most climate-adapted agricultural producers in the world. These practices, adapted to local conditions, highlight an important lesson for global agriculture: climate-smart farming is not a one-size-fits-all approach, but must be grounded in regional variability and focused on tangible outcomes for food security.

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19 "ABARES | Snapshot of Australian Agriculture 2025 - Around 70% of Agricultural Production Is Exported."
20 "ABARES | Agricultural Commodities and Trade Data - June Quarter 2025"; "ABARES | Snapshot of Australian Agriculture 2025 - Agricultural Production Is Growing."
21 "ABARES | Trade Dashboard"; "USDA Foreign Agricultural Service | Data and Analysis."
22 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."

2. AUSTRALIA'S COMMITMENT TO CLIMATE ACTION AND GLOBAL FOOD SECURITY

Australia signed the Paris Agreement on 22 April 2016, joining over 170 countries. In doing so, Australia reinforced that its climate-smart and sustainable agricultural practices are central to how it contributes to global climate action while safeguarding food security. The Paris Agreement explicitly states its goal is to:

> '*Increase the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production.'* Article 2.1(b) of the Paris Agreement (2016).[23]

In practice, this means prioritising innovations and farming systems that lower global emissions intensity and maintain reliable, high-quality agricultural outputs for export. To do so, and in the face of climate change challenges, will require improved on-farm productivity.

For Australia, climate variability and climate change – particularly the increased frequency of droughts and heatwaves – pose ongoing challenges for yield stability.[24,25,26] By aligning climate ambition with the imperative of global food supply, Australia can demonstrate how effective climate action in agriculture delivers measurable outcomes: fewer emissions per tonne of food (reduced emissions intensity), improved productivity and increased resilience across farming systems.

CASE STUDY

Crop trials to support stress tolerance and yield increase

Despite climate pressures, genetic improvements for Australian-specific crop varieties have contributed to wheat yield stability. Around half of Australia's 1.1 per cent per annum wheat yield gain is attributable to improved varieties in Australia. High-performing Australian-bred varieties from the Australian Wheat Institute and the GRDC pulse breeding program have improved traits such as disease resistance and heat tolerance.[27]

23 "UNFCCC | The Paris Agreement."
24 Hughes, Galeano, and Hatfield-Dodds, "ABARES | The Effects of Drought and Climate Variability on Australian Farms."
25 "IPCC | Sixth Assessment Report. Fact Sheet - Australasia: Climate Change Impacts and Risks."
26 "CSIRO | State of the Climate 2024."
27 Braidotti, "GRDC | New Ways to Select for Heat Tolerance in Wheat."

3. AUSTRALIAN AGRICULTURE'S SUSTAINABILITY CREDENTIALS

Australia's agricultural sector has made significant and measurable gains in resource efficiency, soil management and biodiversity conservation, demonstrating its ongoing transition towards more sustainable and climate-smart practices. Plant science innovations, including modern crop protection chemistry and biotechnology advances, have been central to these improvements, enabling farmers to produce more with fewer natural resources while protecting the environment. Importantly, sustainability encompasses not only environmental outcomes but also farm productivity and profitability, which are essential to the long-term viability of Australian agriculture and global food security.

Australian agriculture's sustainability achievements have been shaped by the highly variable climate conditions in which Australian farmers work. The contribution of plant science innovations in driving water use efficiency, soil carbon retention and improvement, and biodiversity gains – all while increasing productivity – must be interpreted in this context. This ensures that environmental performance assessments remain rigorous while reflecting on-ground conditions.

International comparisons of emissions intensity, therefore, require context-specific assessment rather than a universal approach. These metrics must be normalised for local agroecological conditions and production systems, accounting for variability across climate zones, soil types, and pest, weed and disease pressures.[28] Any reliable assessment must be grounded in these contextual parameters, recognising that sustainability is not universally defined, but must focus on outcomes and be contingent on local contexts.

To translate context-specific practices into legitimate sustainability credentials, independent third-party verification is required to underpin trust and transparency. Such verification provides assurance to both domestic and international markets and is increasingly necessary to ensure that sustainability claims are credible, comparable and accepted across diverse markets.

For example, more than 7,200 Australian grain farms participate in the International Sustainability and Carbon Certification (ISCC) Sustainable Grain Australia certification scheme. In 2021, this program verified over 1.7 million tonnes of grain as sustainably produced in line with international carbon and sustainability standards.[29] Certification criteria include declarations that farming operations meet ISCC sustainability requirements, on-farm audits to verify practices, environmental and social measures, GHG emissions, legal compliance and governance, and continuous improvements targets.

In the cotton sector, Australia's industry-led program MyBMP has been formally benchmarked against the internationally recognised Better Cotton Standard, allowing growers to market fibre as Better Cotton. Australian-derived and certified Better Cotton represented around 40 per cent of national cotton output in 2023-24.[30,31]

In addition to commodity-specific certification schemes, Australian agriculture is increasingly aligning with global sustainability frameworks that provide independent verification of climate-smart practices, which is particularly relevant for export-oriented producers. The Farm Sustainability Framework, developed by the Sustainable Agriculture Initiative Platform, is widely recognised by multinational food and agribusiness companies as a benchmark for on-farm sustainability across environmental, social and economic variables.[32]

Complementing this, many Australian agribusinesses adopt the International Organization for Standardization (ISO) Environmental Management Standards, which provide auditable, internationally consistent assurance of environmental performance.[33] Together with commodity-specific sustainability standards, these international verification systems reinforce the credibility of Australian agriculture's sustainability credentials and enable open access to discerning export markets.

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28 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
29 "GrainGrowers | Finding a Sustainability System That Fits Australian Grains."
30 "Cotton Australia & CRDC | Partnerships and Collaborations."
31 "Better Cotton in Australia (MyBMP)."
32 "SAI Platform | Farm Sustainability Assessment."
33 "ISO 14000 Family — Environmental Management."

3.1. Climate-smart agriculture requires both ecological and economic resilience

Sustainability is not just environmental: the economic sustainability of farms is equally essential if farming systems and food production are to endure. The Australian grains industry measures emission reduction by tracking decreases in emissions per unit of produce, an approach that exemplifies sustainable intensification.[34] This pathway enables farmers to meet rising food demand by producing more from existing farmland while simultaneously lowering emissions, protecting biodiversity, and maintaining economic resilience.

Australian agriculture has shown improvements in both farm-level profitability and sustainability practices over the past three decades. Indicators from the Australian Bureau of Agricultural and Resource Economics and Science (ABARES) reveal that broadacre farms have maintained strong cash incomes and rates of return, demonstrating their financial resilience despite seasonal variability (Figure 3.1).[35]

At the same time, adoption of climate-smart practices – such as stubble retention, reduced tillage and optimised inputs – have increased substantially (see Table 3.1: *Farm management practices across Australian agriculture businesses, 2021.*).[36] Evidence from the cotton and canola industries, such as yield gains and improved input efficiency, and high adoption rates of conservation tillage practices across Australia's grain and mixed-farming sectors, highlights the dual role of technological innovation in promoting environmental stewardship while maintaining the profitability necessary for long-term sector viability. These practices, supported by modern crop protection chemistry and innovative crop biotechnology solutions, have delivered demonstrable environmental benefits and strengthened the economic performance of Australian farms.

Australian farm cash income and productivity over time

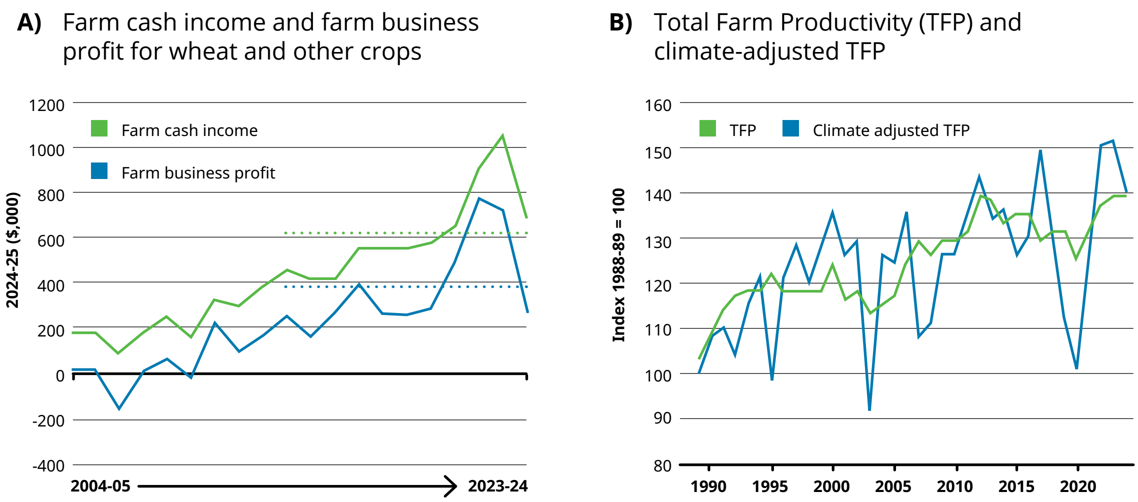


Figure 3.1. *Sustainability in farming encompasses not only environmental outcomes but also the long-term profitability and productivity that underpin farm viability. Improvements in efficiency and resource use are central to ensure Australian farms remain competitive while adopting sustainable land management practices (see Table 3.1 for adoption rates of practices). Panel **A** shows trends in farm cash income and farm business profit for crops (dashed line represents 10-year average to 2022-23), and **B** presents Total Factor Productivity (TFP) and climate-adjusted TFP for the broadacre sector, with increases in TFP and climate-adjusted TFP indicating improvements in profitability and international competitiveness. Together, these data underscore the interdependence of environmental sustainability and farm productivity and profitability in Australian agriculture.*[37]

34 Sevenster et al., "Australian Grains Baseline and Mitigation Assessment."
35 Topp, Ryder, and Smith, "ABARES | Financial Performance of Broadacre Farms 2022–23 to 2024–25."
36 "ABARES | Natural Resource Management and Drought Resilience — Survey of Farm Practices."
37 Topp, Ryder, and Smith, "ABARES | Financial Performance of Broadacre Farms 2022–23 to 2024–25."

3.2. Economic resilience for farm productivity and food security

Economic resilience is a central pillar of climate-smart agriculture, underpinning not only farmers' capacity to withstand shocks but also national and global food system stability. Resilient farm enterprises mean the steady supply of safe, affordable and high-quality produce to both Australia's domestic consumers and export markets. Furthermore, stable productivity is not only critical for farm incomes, but also for buffering consumers from price volatility that can otherwise exacerbate social and economic inequalities.[38,39]

Several interconnected factors drive this economic resilience. At the farm level, productivity must be maintained in the face of climatic variability; emerging pests, weeds and disease; and shifting global market conditions. At the consumer level, food must remain both affordable and consistently high-quality, ensuring confidence in domestic supply chains. At the national and international levels, resilience supports ongoing access to export markets that increasingly demand produce that meets strict quality, safety and sustainability standards. These layers form the foundation of food security, linking the financial viability of farm businesses with community wellbeing and market stability.

Climate-smart agriculture addresses these challenges by fostering adaptable, innovation-driven systems. Advances in agronomic practices, combined with the adoption of modern crop protection chemistry and crop genetics, have all contributed to stabilising yields, reducing crop failure risks, and enhancing product quality (discussed below under section *3.3. Australian agriculture's sustainability achievements*). Economic resilience is therefore not an ancillary benefit, but a core outcome of climate-smart agriculture, ensuring that productivity, food security and market competitiveness can be sustained well into the future.

3.3. Australian agriculture's sustainability achievements

Understanding Australia's current emissions profile is key to assessing agriculture's role in meeting national climate and emissions reduction goals. When emissions intensity indicators are adjusted for local realities, the results underscore Australian agriculture's performance. A 2023 ABARES report, which explicitly benchmarked Australia against international agricultural counterparts, clearly showed that sustainability is not new to Australian farming.[40]

Over the past three decades, the Australian agricultural sector has reduced its direct emissions by around 20 per cent, reflecting the long-standing role sustainability has played in helping Australian farmers adapt to one of the world's most variable climates.[41]

In 2024, Australian agriculture emitted an estimated 85 million tonnes of carbon dioxide equivalent, about 19 per cent of the nation's total greenhouse gas (GHG) output.[42] Yet it outperforms most comparable producers, generating roughly 42 per cent fewer emissions than comparable export nations (Figure 3.2).[43] Australia's agricultural GHG emissions intensity is notably low.

What does 'CO_2 equivalent' mean?

There are different types of greenhouse gases (GHGs). The main GHGs regulated and reported under international climate agreements are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2) and fluorinated gases (F-gases). Each gas has a different capacity to trap heat in the atmosphere, known as its 'global warming potential'.

Carbon dioxide equivalent (also CO_2-e) is a standard unit used to express the combined effect of all GHGs, allowing emissions to be compared by converting them into the amount of carbon dioxide that would produce the same warming effect over a specified time period.

38 "Price Volatility in Food and Agricultural Markets."
39 Harkness et al., "Towards Stability of Food Production and Farm Income in a Variable Climate."
40 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
41 Read et al.
42 "DCCEEW | Australia's Emissions Projections 2024."
43 "ABARES | International Farm Emissions Intensity Statistics."

International comparison of agricultural emissions, 2018 to 2020

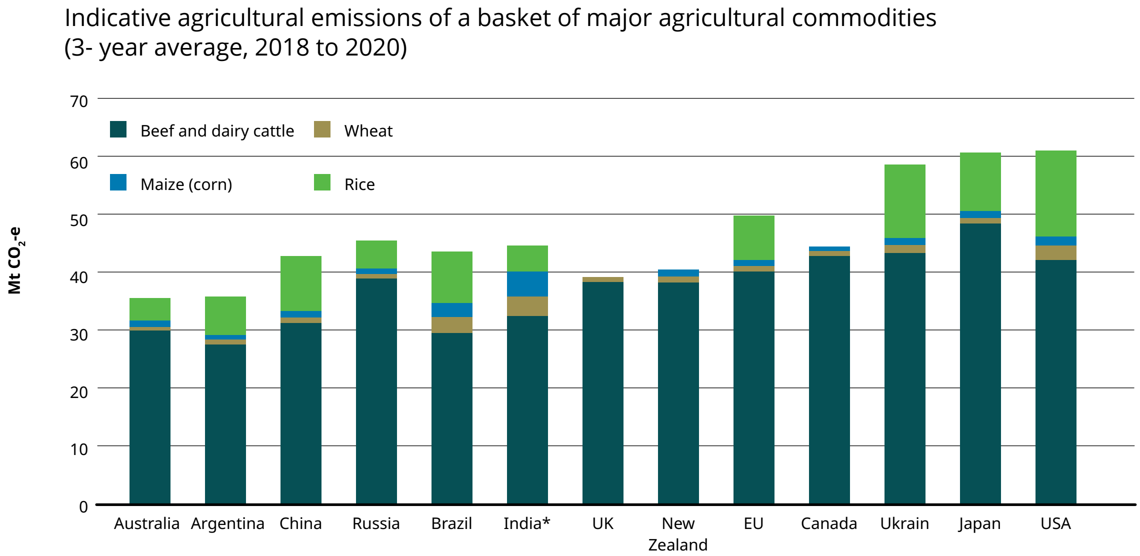


Figure 3.2. *Agricultural GHG emissions for a representative basket of major commodities across key producing and export nations (three-year average, 2018 to 2020). Australia records the smallest composite footprint among the countries compared, underscoring the sector's ability to deliver globally significant food and fibre with comparatively low emissions.*[44]

Within Australia's agricultural context, the grains sector stands out in demonstrating the nation's world-leading climate-adapted and sustainable agriculture efforts. In 2020, the grains sector's baseline emissions intensity was estimated to be 316 kilograms of carbon dioxide equivalent per tonne, accounting for 2 per cent of Australia's national emissions.[45] This value has decreased from 393 kilograms of carbon dioxide equivalent per tonne in 2005. When calculating for total net emissions – factoring in land use, land use change and forestry, including carbon removals through soil sequestration – the figure further reduces to 196 kilograms of carbon dioxide equivalent per tonne.[46]

When benchmarked internationally, Australia's grain sector demonstrates lower GHG emissions intensity than many global counterparts. Its cropping systems already operate at a high level of sustainability, which is particularly notable given Australia's variable climatic conditions. Further reductions in GHG emissions cannot be achieved without cutting production.[47]

The efficiency of the Australian grains sector provides a scalable model for low-emissions agricultural productivity.[48] Research by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) supports this pathway, showing that expanding production of low-emissions-intensity grain is one of the most sustainable strategies available for reducing global food-system emissions while bolstering domestic and export supply.[49]

For a nation that exports the majority of its agricultural output, producing less would simply shift demand to other jurisdictions, many of which do not share Australia's sustainability credentials, ultimately undermining environmental and food security outcomes. This phenomenon, known as 'carbon leakage', occurs when emissions reductions in one jurisdiction are negated by increases elsewhere through trade and production displacement to countries with weaker environmental regulations, eroding global sustainability gains and potentially amplifying total emissions.[50,51]

44 "ABARES | International Farm Emissions Intensity Statistics."
45 "GRDC | Greenhouse Gas Emissions."
46 Sevenster and Burrett, "CSIRO | Australian Grains GHG Account 2020."
47 Sevenster et al., "Australian Grains Baseline and Mitigation Assessment."
48 Sevenster et al.
49 Sevenster et al.
50 Arvanitopoulos, Garsous, and Agnolucci, "Carbon Leakage and Agriculture."
51 Jakob, "Why Carbon Leakage Matters and What Can Be Done against It."

Meeting Australia's ambition to reduce emissions by 62 to 70 per cent by 2035, on the way to net-zero by mid-century,[52] requires targeted abatement within agriculture where gains can be realised without undermining productivity.

Australian agriculture's strong sustainability credentials are no accident. They are the product of decades of investment into plant science research, developing innovations specific for Australian farming conditions and supporting adoption by primary producers. The Australian agriculture sector demonstrates that climate-smart, high-productivity farming is not only possible, but already being delivered at scale. The strength of these credentials is illustrated in the subsections below.

CASE STUDY

Genetically modified (GM) crops reduce GHG emissions

The adoption of GM seed, specifically herbicide-tolerant and insect-resistant varieties, has significantly reduced global GHG emissions.

These crop biotechnology innovations have multiple abatement benefits by lowering on-farm fuel use, enabling a shift from plough-based farming to minimal and no-till systems, reducing the need for multiple spray passes leading to fuel and chemical savings and mitigating land-use change. In 2020 alone, GM cropping delivered a net saving of 23.6 kilograms of carbon dioxide, equivalent to removing 15.6 million cars from the road for a year.[53,54,55,56]

3.3.1. Improved land management practices

Data from the Australian Agricultural Census show that farmers across the country have widely adopted improved land management practices that enhance productivity, strengthen farm resilience and deliver positive environmental outcomes.[57,58] As summarised in Table 3.1, adoption rates are consistently high across a range of practices that support soil health, water use efficiency and emissions reduction.

Stubble retention is the most widely practised method, implemented by 84 per cent of surveyed farms. This practice helps maintain soil organic matter, reduce erosion and improve water infiltration and retention.[59] Similarly, the widespread use of minimum or reduced tillage and optimisation of pesticide or fertiliser use (see Figure 3.4) reflect the sector's commitment to soil conservation and input efficiency.

52 "DCCEEW | Net Zero."
53 Brookes and Barfoot, "Environmental Impacts of Genetically Modified (GM) Crop Use 1996-2018."
54 Brookes, "Genetically Modified (GM) Crop Use 1996–2020."
55 Kovak, Blaustein-Rejto, and Qaim, "Genetically Modified Crops Support Climate Change Mitigation."
56 Sutherland, Gleim, and Smyth, "Correlating Genetically Modified Crops, Glyphosate Use and Increased Carbon Sequestration."
57 "ABARES | Australian Agricultural Census 2020–21 Visualisations."
58 "ABARES | Natural Resource Management and Drought Resilience — Survey of Farm Practices."
59 Llewellyn, D'Emden, and Kuehne, "Extensive Use of No-Tillage in Grain Growing Regions of Australia."

Practices that directly improve soil condition are also common. Approximately 64 per cent of farms surveyed report managing soil acidity, while a similar proportion have adopted measures to enhance soil water retention. More than half of Australian farmers surveyed (around 53 per cent) incorporate cover cropping, mulching, or maintaining perennial pastures. These practices strengthen soil structure, promote carbon retention and support biodiversity outcomes.[60]

The integration of plant science innovations, including precision agriculture application techniques, has further advanced improved land management practices. Precision application systems, underpinned by modern crop protection chemistry, allow farmers to apply inputs only where and when they are needed, minimising off-target impacts and maximising efficiency.

One example is controlled traffic farming (CTF), which uses GPS-guided autosteering to confine machinery to permanent wheel tracks. This precision system reduces fertiliser and pesticide input overlap by approximately 10 per cent, lowering fuel and chemical use and contributing directly to emissions abatement.[61] By preventing machinery from compacting the soil in cropping zones, CTF preserves soil structure, enhances plant root growth and improves water infiltration.[62,63,64] These outcomes collectively improve soil health, water use efficiency and overall farm productivity.

ABARES survey data show that nearly 40 per cent of Australian farmers now use CTF, with adoption particularly strong across grain-growing regions. While not yet universal, the steady uptake positions Australian farmers among the world's earliest and most advanced adopters of CTF and other precision land management practices.[65,66]

Through the combination of evidence-based agronomic practices and plant science innovations, Australian agriculture is achieving measurable sustainability outcomes while maintaining productivity and resilience under a changing climate.

SUMMARY | Improved land management practices

Role of plant science innovations:

- Precision agricultural technologies enable targeted application of pesticides and fertiliser, reducing wastage and off-target impacts.
- GPS-guided autosteering confines machinery to wheel tracks, minimising soil compaction, improving plant root growth and water infiltration. The system also results in reduced input overlap, thereby reducing fuel usage.
- Modern crop varieties and plant protection products are a key component to supporting advanced agronomic practices that maintain or improve productivity and conserve soil health.

Sustainability outcomes:

- Soil health: improved structure, organic matter and reduced compaction.
- Water use efficiency: better infiltration, retention and reduced irrigation demand.
- Emissions abatement: lower fuel and chemical use.
- Biodiversity: increased ground cover and perennial vegetation.
- Resilience: improved adaptation to climatic variability.

60 Dang et al., "Strategic Tillage in No-till Farming Systems in Australia's Northern Grains-Growing Regions."
61 Robertson, Carberry, and Brennan, "The Economic Benefits of Precision Agriculture: Case Studies from Australian Grain Farms."
62 Tullberg et al., "Controlled Traffic Farming Effects on Soil Emissions of Nitrous Oxide and Methane."
63 Antille et al., "The Potential of Controlled Traffic Farming to Mitigate Greenhouse Gas Emissions and Enhance Carbon Sequestration in Arable Land."
64 Tullberg, Yule, and McGarry, "Controlled Traffic Farming—From Research to Adoption in Australia."
65 Chamen, "Controlled Traffic Farming – From Worldwide Research To Adoption In Europe And Its Future Prospects."
66 McFadden, Njuki, and Griffin, "USDA | Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms."

Table 3.1. *Adoption of farm management practices across Australian agricultural businesses, 2021. Data show the proportion of farms using specific practices, the extent of adoption within farms, and the time of adoption. Results are based on a survey of over 2,300 farms, representing a population of nearly 82,000 agricultural businesses.*[67]

Farm management practices in Australia

Population
81,823

Sample farms surveyed
2,355

Practice	Used practice	All of the farm	Most of the farm	Some of the farm	Adopted less than 3 years ago	Adopted more than 3 years ago
Using technologies/tools to support climate related land management decisions	33%	56%	20%	24%	18%	82%
Using more water efficient crop or pasture varieties	40%	43%	28%	30%	16%	84%
Use of cover crops, inter-row crops, mulching or matting, or other ground cover	53%	42%	22%	36%	14%	86%
Setting a long-term minimum ground cover requirement	57%	58%	26%	15%	15%	85%
Retained stubble	84%	53%	27%	20%	9%	91%
Regrowth of native vegetation	51%	24%	16%	60%	12%	88%
Reducing long-term stocking rates	42%	54%	23%	23%	27%	73%
Planting or maintaining deep-rooted perennial pastures including fodder shrubs	44%	28%	25%	47%	15%	85%
Optimise pesticide or fertiliser use and reduce reliance	68%	61%	21%	18%	15%	85%
Minimising tillage or cultivation	65%	48%	27%	25%	12%	88%
Increasing on-farm water storage	54%	53%	17%	30%	18%	82%
Increasing fodder and grain storage	58%	47%	22%	30%	22%	78%
Incorporation of organic matter	50%	48%	23%	29%	13%	87%
Improving soil water retention	64%	56%	23%	20%	14%	86%
Improving soil acidity levels	64%	47%	22%	31%	14%	86%
Fallow	50%	39%	25%	36%	10%	90%
De-stocking early in low rainfall periods to preserve groundcover	68%	57%	26%	17%	17%	83%
Controlled trafficking	37%	62%	22%	16%	14%	86%
Cell, strip or rotational grazing	62%	52%	25%	23%	12%	88%
Carbon-farming/sequestration	12%	48%	24%	28%	18%	82%

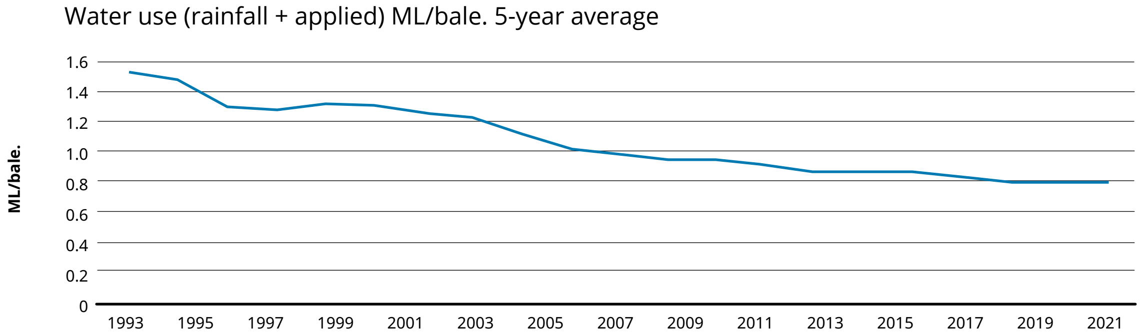
67 "ABARES | Natural Resource Management and Drought Resilience — Survey of Farm Practices."

3.3.2. Water use efficiency

Water use efficiency (WUE) has improved markedly across major cropping industries such as cotton, grains and horticulture, reflecting long-term investment in research and development for plant science solutions and best-practice management.

In the cotton industry, growers have improved productivity by 40 per cent over the past decade (Figure 3.3).[68] Australian cotton growers are recognised as global leaders, producing an average of 1.03 bales per megalitre, requiring less than half the water used in global production (an average of 2.07 megalitres per bale).[69]

Water use per bale of cotton in Australia has declined



Source: NSW DPI

Figure 3.3. *Trends in water use per bale of cotton in Australia, 1993 to 2021. Data represent the five-year average of total water inputs (rainfall and applied irrigation) required to produce one bale of cotton. Over this period, water use per bale has declined significantly, reflecting long-term improvements in water use efficiency achieved through advances in crop management, plant breeding, and the adoption of new crop biotechnology innovations.*[70]

Importantly, WUE calculations extend beyond the volume of water applied. WUE also reflects a crop's capacity to sustain growth, maintain fibre or grain quality, and deliver reliable harvest yields under variable climatic conditions. Accordingly, yield per unit of water is a critical indicator of overall efficiency.

In the Australian cotton industry, yield gains over the past decade can be attributed to advances in plant breeding, delivering varieties with improved drought tolerance and water-use responsiveness; the adoption of GM cotton varieties, which enable more efficient pest control and crop management to improve water efficiency; and implementing improved crop management practices, including precision irrigation scheduling, soil moisture monitoring and optimised nutrient management.[71] These innovations have allowed growers to maximise productivity while maintaining high fibre quality and yield stability under increasingly variable climatic conditions.

In the grains sector, the National WUE Initiative, a collaboration between CSIRO and the Grains Research and Development Corporation (GRDC), demonstrated that improved agronomic practices can lift productivity without increasing input costs. The initiative showed that effective summer fallow management, particularly through weed control and stubble retention, can deliver WUE improvements averaging 60 per cent, with an average return of $5.60 for every dollar invested.[72,73]

These outcomes demonstrate how integrated plant science innovations, combining crop genetics, crop protection and agronomy, enable farmers to adapt to increasing climate variability while producing more with less water.

68 Roth et al., "Water-Use Efficiency and Productivity Trends in Australian Irrigated Cotton."
69 "NSW DPI | Benchmarking Cotton Water Productivity."
70 "Cotton Australia & CRDC | Snapshot - Planet Water | Less Drops per Crop."
71 Roth et al., "Water-Use Efficiency and Productivity Trends in Australian Irrigated Cotton."
72 "GRDC | Investing in Water Use Efficiency Yields Results."
73 "CSIRO | Researching Water Use Efficiency for Increased Grain Yield."

SUMMARY | Water use efficiency

Role of plant science innovations:

- Plant breeding has developed crop varieties with enhanced drought tolerance and water use responsiveness.
- GM cotton has improved pest resistance and reduced crop stress, enabling better water allocation.
- Precision agronomy means optimised irrigation timing, soil moisture management and nutrient application.
- Herbicides have enabled weed control and stubble retention that improve summer fallow management and soil moisture retention.
- Research collaborations have translated science into practical on-ground tools for growers.

Sustainability outcomes:

- Water use efficiency (WUE):
  - Cotton: +40 per cent productivity gain in the past decade, with 1.03 bales per megalitre of water, compared to the global average of 2.07 bales per megalitre.
  - Grains: +60 per cent improvement in WUE through improved agronomic practices.
- Resource efficiency: higher yields per unit of water without increasing inputs.
- Economic returns: $5.60 per dollar invested in improved WUE.
- Resilience: improved crop performance under climate variability and water scarcity.
- Environmental benefits: reduced irrigation demand and improved soil moisture conservation.
- Global leadership: Australian cotton ranks among the most water-efficient cotton production systems in the world.

3.3.3. Soil organic carbon

Meaningful measurement of changes in soil organic carbon (SOC) depends on robust baseline data. The Soil Carbon Research Program (2009–2012) was a nationally coordinated initiative involving CSIRO, universities and state government agencies that established SOC baselines across Australian farming systems.[74,75] Over 20,000 soil samples collected from more than 4,000 sites now provide essential reference points to assess how land management practices influence SOC levels. These data confirm, for example, that no-till systems with stubble retention maintain higher SOC compared with conventional tillage.[76,77,78]

Since the 1990s, Australian farmers have rapidly adopted zero and no-till systems, which are now used in 80 to 90 per cent of Australian croplands.[79] This positions Australia as a global leader in conservation agriculture, reducing soil disturbance and biodiversity disruption (Figure 3.4).[80]

74 Rose, "CSIRO | The Soil Carbon Research Program (SCaRP)."
75 Baldock et al., "CSIRO | Australian Soil Carbon Research Program."
76 Page et al., "Organic Carbon Stocks in Cropping Soils of Queensland, Australia, as Affected by Tillage Management, Climate, and Soil Characteristics."
77 Chan et al., "Soil Carbon Dynamics under Different Cropping and Pasture Management in Temperate Australia."
78 Roper et al., "Under No-Tillage and Stubble Retention, Soil Water Content and Crop Growth Are Poorly Related to Soil Water Repellency."
79 Bellotti and Rochecouste, "The Development of Conservation Agriculture in Australia—Farmers as Innovators."
80 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."

Minimal- and no-till systems deliver measurable benefits: improved water retention and erosion control; yield gains of approximately 0.5 to 1.0 tonnes per hectare; enhanced productivity, adding around $100,000 to $140,000 for a typical 500-hectare operation;[81,82] and an estimated 4.3 million tonnes of carbon dioxide equivalent emissions avoided annually compared with conventional tillage, though the extent of these benefits remains contested in the literature.[83,84]

When combined with stubble retention, zero and minimal-tillage systems further improve soil structure, water infiltration, and nutrient cycling, leading to healthier soils and increased productivity.[85] These land management gains are underpinned by herbicide-enabled conservation tillage, which makes effective weed control possible without disturbing the soil.

Global adoption rates of conservation tillage practices

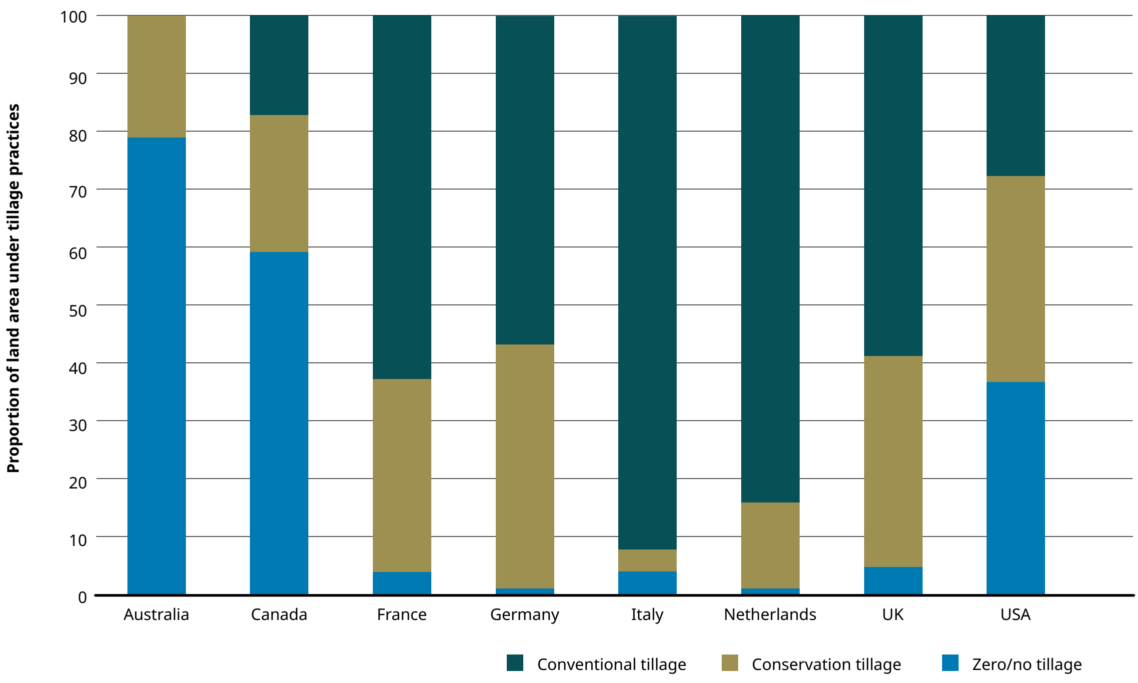


Figure 3.4. *Australia leads the world in the adoption of no-till practices, which minimise environmental and biodiversity disruption. Over 80 per cent of Australian croplands are managed using these best-practice systems, significantly higher than in comparable nations.*[86]

81 Wylie, P. and Moll, J. 1998. Opportunity Cropping (2nd edition). Conservation Farmers Incorporated, Toowoomba, Qld.
82 Thomas, G. A., Titmarsh, G. W., Freebairn, D. M. and Radford, B. J. 2007. No-tillage and conservation farming practices in grain growing areas of Queensland—a review of 40 years of development, *Australian Journal of Experimental Agriculture 47*(8), 887–898.
83 So et al., "Potential of Conservation Tillage to Reduce Carbon Dioxide Emission in Australian Soils."
84 Maraseni and Cockfield, "Does the Adoption of Zero Tillage Reduce Greenhouse Gas Emissions?"
85 Dang et al., "No-till Farming Systems for Sustainable Agriculture."
86 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."

SUMMARY | Soil organic carbon (SOC)

Role of plant science innovations:

- Herbicide-enabled agronomic practices have:
  - Facilitated effective weed management without soil disturbance.
  - Enabled and underpin no- and minimal-till systems.
- Modern crop varieties are compatible with conservation systems and stubble retention.
- The Soil Carbon Research Project provides robust baseline data to assess the impacts of these plant-science-enabled practices on soil carbon levels.

Sustainability outcomes:

- Higher SOC levels maintained under no-till with stubble retention compared with conventional tillage.
- Improved water infiltration, nutrient cycling, soil erosion control and soil structure, thereby protecting topsoil.
- Estimated 4.3 million tonnes of carbon dioxide equivalent emissions avoided annually through conservation tillage, supporting national abatement.
- Additional yield gains (0.5 to 1.0 tonnes per hectare) and improved farm profitability ($100,000 to $140,000 for a 500-hectare farm).
- Strengthening biodiversity through less disturbance to soil biota and habitat.

CASE STUDY
No-till systems in Australian agriculture

Reduced-tillage field trial results demonstrated both a significant reduction in erosion and a boost in available soil moisture, leading to an increase in yield. From the early 1990s, leading Australian farmers began trialling fewer tillage operations, progressing in many cases to direct seeding with no prior cultivation.[87] The demonstrated financial benefit incentivised farmers to take up no-till systems, delivering enormous environmental benefits in reducing soil erosion.

87 Rochecouste, J-F.G. and Crabtree, B. 2014, 'Conservation Agriculture in Australia', in Jat, R.A., Sahrawat, K.L. & Kassam, A.H. (Eds.) *Conservation Agriculture: Global Prospects and Challenges*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Food and Agriculture Organization (FAO), Publisher CAB International, UK.

3.3.4. Biodiversity outcomes

On-farm biodiversity indicators show that Australian agriculture contributes meaningfully to maintaining and enhancing ecological outcomes, while simultaneously supporting productive and profitable farming systems.

Data from the Australian Bureau of Statistics indicate that agricultural businesses collectively manage more than 7.4 million hectares of land specifically for conservation or environmental protection purposes, an increase of 7.3 per cent since the previous year in 2016-17.[88] The 2021 ABARES survey of on-farm practices also found that 51 per cent of farms have implemented practices supporting native vegetation regrowth (Table 3.1).[89]

Beyond land formally set aside for environmental conservation, a range of technology-enabled agricultural practices are delivering measurable biodiversity benefits. Adoption of integrated pest management (IPM), precision input optimisation, stubble retention, and reduced tillage create more stable and diverse agricultural ecosystems (see Table 3.1). These practices improve soil structure, habitat provision, and overall on-farm biodiversity.[90]

At the industry level, technological innovation has driven substantial ecological gains. In the cotton sector, adoption of GM Bt cotton, which provides in-plant protection against key insect pests, has reduced the use of insecticides by 85 per cent when combined with other IPM strategies.[91] This dramatic decline in broad-spectrum insecticide applications has allowed populations of beneficial insects, including predators and parasites of crop pests, to recover. Their return supports sustainable pest control and helps maintain a healthier, more balanced farm ecosystem (Figure 3.5).[92]

Through the integration of biotechnology, precision agriculture and ecologically informed management, Australian farmers are achieving measurable biodiversity outcomes alongside productivity and resilience gains.

SUMMARY | Biodiversity outcomes

Role of plant science innovations:

- GM Bt cotton provides in-plant insect pest resistance, dramatically reducing the need for broad-spectrum insecticide application.
- Integrated pest management (IPM) systems combine biological, agronomic, chemical and biotechnological tools for targeted, ecosystem-friendly control.
- Precision input optimisation technologies enable targeted application of pesticides and fertilisers, minimising non-target impacts.

Sustainability outcomes:

- 85 per cent reduction in broad-spectrum insecticide use in the cotton industry, leading to recovery of beneficial insect populations.
- Enhanced ecosystem services for natural pest regulation and pollination.
- 7.4 million hectares of agricultural land managed for conservation or environmental protection.
- 51 per cent of farms actively supporting native vegetation regrowth, contributing to improved biodiversity and ecological resilience.
- Improved soil health, habitat diversity, and co-benefits for productivity and environmental performance.

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88 "ABS | Land Management and Farming in Australia, 2016-17 Financial Year."
89 "ABARES | Natural Resource Management and Drought Resilience — Survey of Farm Practices."
90 "ABARES | Natural Resource Management and Drought Resilience — Survey of Farm Practices."
91 "CSIRO | Cotton Pest Management."
92 Wilson et al., "IPM in the Transgenic Era."

Adoption of GM cotton has significantly reduced insecticide application rates

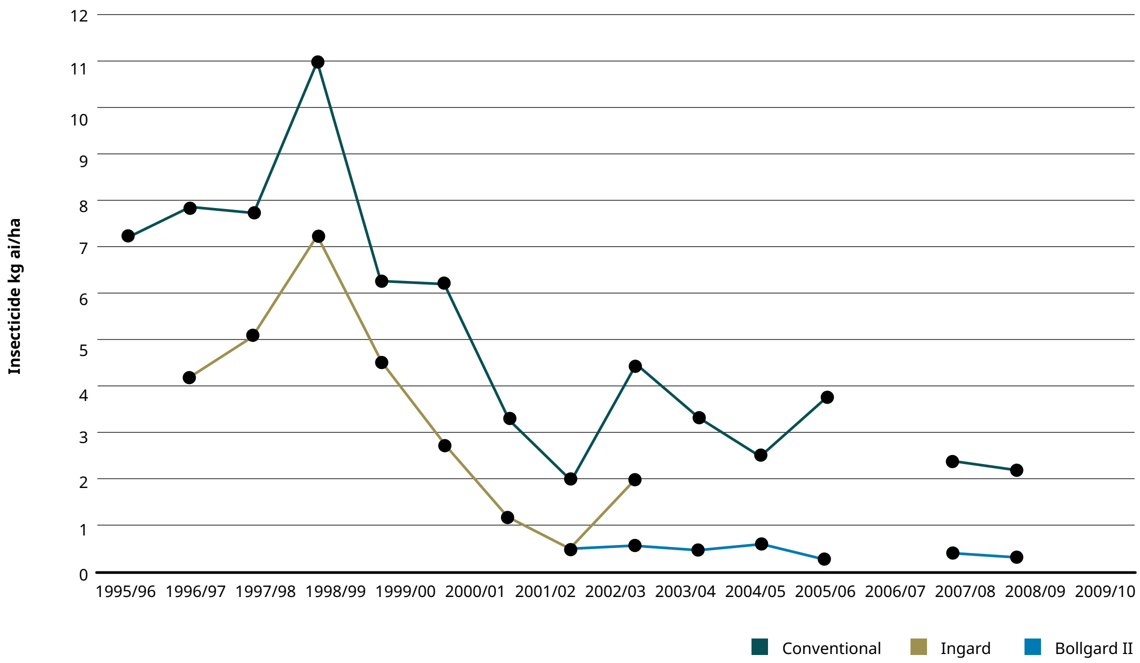


Figure 3.5. *Insecticide use patterns in Australian cotton production, 1995 to 2006. Data show the amount of insecticide applied (kilograms of active ingredient per hectare) for all pests under conventional cotton, first-generation Bt cotton (Ingard), and second-generation Bt cotton (Bollgard II). The introduction of Bt cotton in 1996 to 97 is associated with significant reductions in insecticide use relative to conventional cotton farming systems. No sampling occurred in 2007/08, as drought limited cotton production.*[93]

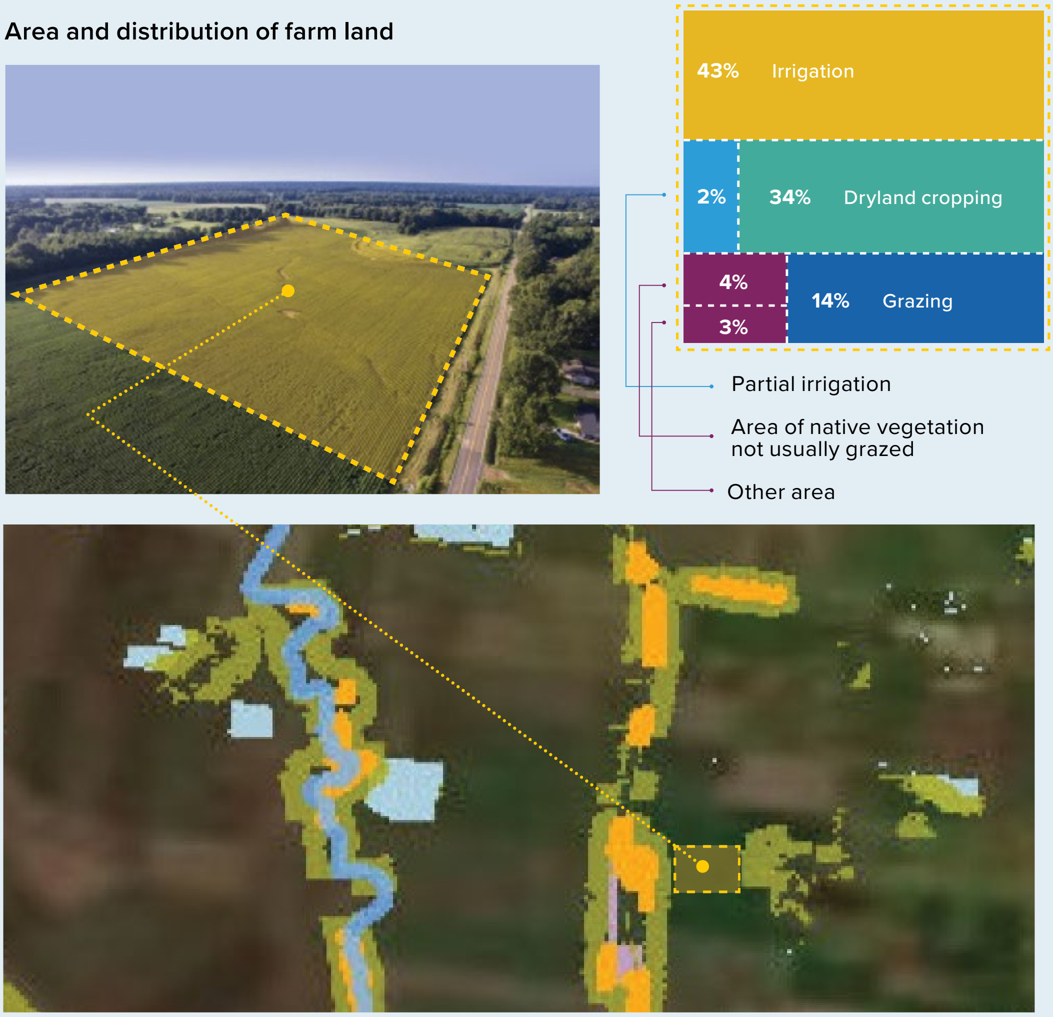
93 Wilson et al., "IPM in the Transgenic Era."

CASE STUDY

Mapping biodiversity corridors in cotton landscapes

Cotton Australia and the Cotton Research Development Corporation are using satellite imagery to map biodiversity corridors in cotton landscapes. The approach will help to identify threatened and iconic regional species, prioritise management practices and find pragmatic ways to measure change in biodiversity condition at industry scale.[94]

Area and distribution of farm land



In the future, satellite maps could be used to map biodiversity condition, plan priority actions and areas across the cotton landscape, and guide collaborative work to improve regional biodiversity.

94 "Cotton Australia & CRDC | Plant Biodiversity: Benefiting from Biodiversity."

3.3.5. Sustainable intensification

Australian agriculture demonstrates a long-standing commitment to sustainability through its track record of decoupling agricultural productivity from land use.[95] Since the start of the Green Revolution more than 50 years ago, enabled by plant science innovations, Australian food production has more than doubled, while at the same time being produced on 28 per cent less land, which is returned to nature conservation (Figure 3.6).

This capacity to produce more on existing farmland, while delivering positive environmental and social outcomes, is the essence of sustainable intensification.[96]

Land area under cultivation has declined in Australia

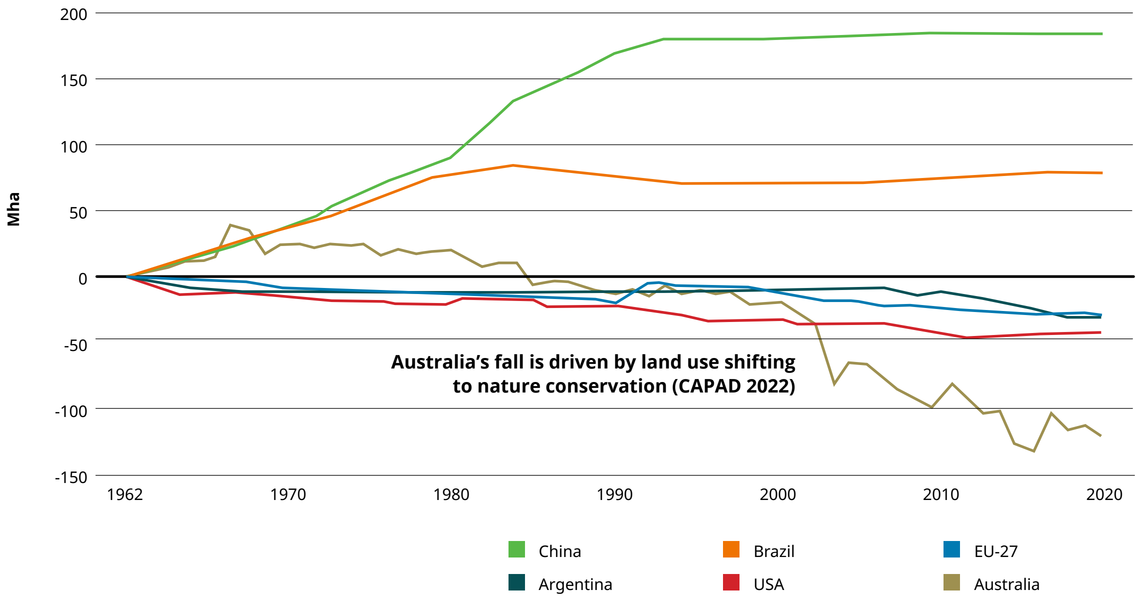


Figure 3.6. *Australia has curtailed the area devoted to agriculture by designating more land for conservation, even as farm productivity and total output have continued to climb.*[97]

Sustainable intensification is underpinned by continual advances in, and the adoption of plant science innovations. Modern crop genetics, targeted crop protection chemistry, and data-driven agronomic practices lift yields and thereby sever the traditional link between higher output and ever-expanding farmland.

Australia's ability to increase wheat production is an example of sustainable intensification. In the early 1900s, average wheat yields in Australia were around 0.7 to 1.0 tonnes per hectare.[98] The development and commercial release of locally bred wheat cultivars (such as Federation, which was specifically bred for local adaptation) and steady improvements in cultivation techniques saw the national average finally break 1 tonne per hectare in the 1940s. Since the 1980s, this trend has continued upward at roughly 1.1 per cent per year.[99] Despite marked year-to-year swings driven by drought and heat stress, average yields over the past two decades have hovered between 1.8 and 2.5 tonnes per hectare.[100,101]

95 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
96 Donovan, "CIMMYT | What Is Sustainable Intensification?"
97 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
98 "ABS | Release of Historic Agricultural Data and an Update on Future Agricultural Data."
99 Fischer, "Chapter 2 - Farming Systems of Australia."
100 "ABS | Feature Article - A Hundred Years of Agriculture."
101 Ritchie, Rosado, and Roser, "Data Page: Wheat Yields."

Detailed attribution studies indicate that about half of modern yield gain comes from genetic improvement (notably semi-dwarf, water-efficient cultivars with better disease and heat tolerance). The other half stems from complementary land management technologies: conservation tillage made possible by glyphosate-based weed control, earlier sowing windows, precision nitrogen management, improved pest-management chemistry and decision-support tools that help farmers plan more effectively.[102,103]

Sustainable intensification plays a critical role in reducing pressure on ecosystems. Around 80 per cent of global deforestation is linked to agricultural expansion.[104] Rising demand for food, driven by population growth, urbanisation and changing dietary preferences, has historically been met through farmland expansion, often at the expense of forests and other natural ecosystems. This expansion not only accelerates biodiversity loss but also contributes significantly to the rise of global GHG emissions.[105]

Australia's efforts in sustainable intensification align with global efforts to decouple agricultural production from land expansion. Without the productivity gains achieved through plant science innovations, meeting today's cereal demand at 1961 yield levels would have required an additional 1.58 billion hectares of cropland, an area almost the size of Russia, more than tripling the area currently used for cereals (Figure 3.7).[106]

Australia's experience underscores how science-led agricultural intensification delivers not only food security and economic resilience but also emissions abatement and land-sparing benefits. This aligns well with the Paris Agreement Article 2.1(b).[107]

SUMMARY | Sustainable intensification

Role of plant science innovations:

- Modern crop genetics, including locally bred, semi-dwarf, water efficient, disease- and heat-tolerant cultivars, have driven steady yield improvements in key crops such as wheat.
- Approximately 50 per cent of yield gains can be attributed to genetic improvements, and the remainder to modern crop management and technology adoption.
- Advances in crop protection chemistries have enabled conservation tillage, supporting earlier sowing and improved soil health.
- Precision agronomy and decision-support tools allow targeted fertiliser and pest management.
- Local breeding programs have developed crop varieties adapted to Australian-specific soils and climate.

Sustainability outcomes:

- Land sparing: higher yields reduce need for farmland expansion, thereby protecting biodiversity and natural ecosystems.
- Rising yields despite decline in cultivated land area, thereby mitigating deforestation and associated GHG emissions.
- A reduced agricultural footprint, with more land transitioned to conservation or natural habitats, supports biodiversity and carbon sequestration.
- Demonstrated alignment with the Paris Agreement Article 2.1(b) by increasing production while reducing emissions and land pressure.

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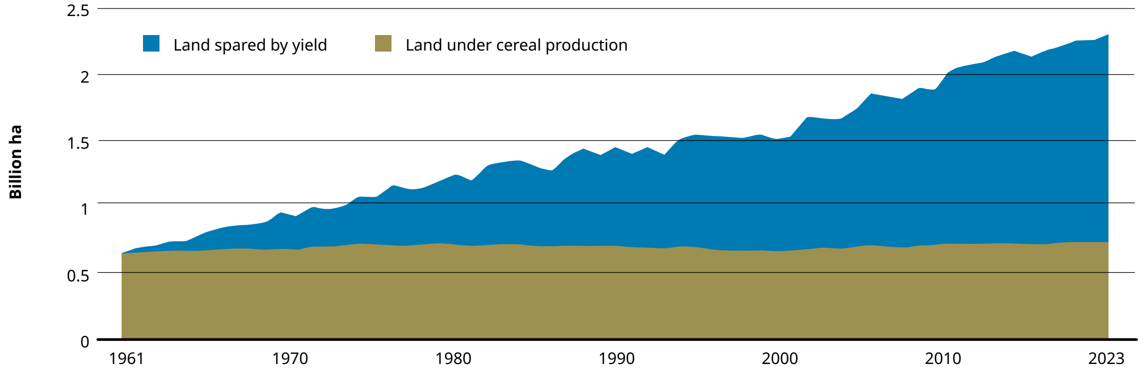
102 Richards et al., "Yield Improvement and Adaptation of Wheat to Water-Limited Environments in Australia—a Case Study."
103 "ABS | Feature Article - A Hundred Years of Agriculture."
104 "COP26: Agricultural Expansion Drives Almost 90 Percent of Global Deforestation."
105 "CSIRO | Transforming Australian Food Systems: Shaping a More Equitable, Healthy and Sustainable Future for Australian Food."
106 Ritchie, "Yields vs. Land Use."
107 UNFCCC | The Paris Agreement.

Global land spared as a result of cereal yield improvements



Source: Food and Agriculture Organization of the United Nations (2025)

Figure 3.7. *Land sparing is calculated as the extra hectares that would have been required to meet each year's global cereal output, had yields remained static at 1961 levels. Yield gains have cumulatively spared about 1.6 billion hectares of cropland, while the physical cropping footprint has stayed close to 700 million hectares over the same period.*[108]

3.3.6. Right inputs, right place: evidence of low-impact pesticide use

Crop losses due to pests, weeds and disease occur at every stage of the supply chain, from production to retail, and contribute to raising the emissions intensity per unit of food consumed. Globally, food loss and waste accounted for an estimated 8 to 10 per cent of GHG emissions between 2010 to 2016.[109] A large share of those emissions arise from production inputs to crops that are never consumed. Annually, this equates to 40 per cent of global crop production lost to plant pests and disease.[110]

The judicious use of crop protection products plays a crucial role in lowering the GHG emissions intensity of food systems by preventing avoidable yield losses. The safe use of pesticides effectively mitigates yield losses from pests, weeds and diseases, ensuring that a greater proportion of harvest biomass reaches consumption rather than being lost across the supply chain.

Continued advances in modern chemistry have led to the development of products that are more selective, safer and reduce off-target effects, such as improving outcomes for beneficial insects. Australian farmers adopted these technologies under robust stewardship frameworks, integrating them into IPM systems. This science-based approach enables Australian farmers to maintain high productivity while safeguarding biodiversity and soil and water health.[111]

Meaningful assessment of production inputs requires metrics that normalise chemical use to local production, climate and pest dynamics, rather than applying uniform benchmarks. Generalised or aggregate figures can otherwise obscure legitimate regional variations in production systems facing persistent pest, weed, and disease pressure, such as cotton, cereal, potato, and fruit-tree sectors, where judicious pesticide use remains an essential IPM component.[112]

Australia's national pesticide application rates are significantly lower than those of comparable export-orientated nations (Figure 3.8). This reflects a risk-based regulatory system combined with a mature stewardship culture where science-driven input management delivers both economic and environmental benefits.[113,114]

108 Ritchie.
109 "UNFAO | Food Loss and Waste: Regional Technical Platform on Green Agriculture."
110 "UNFAO | Plant Production and Protection."
111 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
112 Crop Consultants Australia and IPM Technologies Pty Ltd., "A Review of Integrated Pest Management (IPM) in Australian Cotton."
113 Read et al., "ABARES | Environmental Sustainability and Agri-Environmental Indicators – International Comparisons."
114 Ritchie, Rosado, and Roser, "Data Page: Total Pesticide Use per Area of Cropland."

Pesticide use per hectare of land, 2022

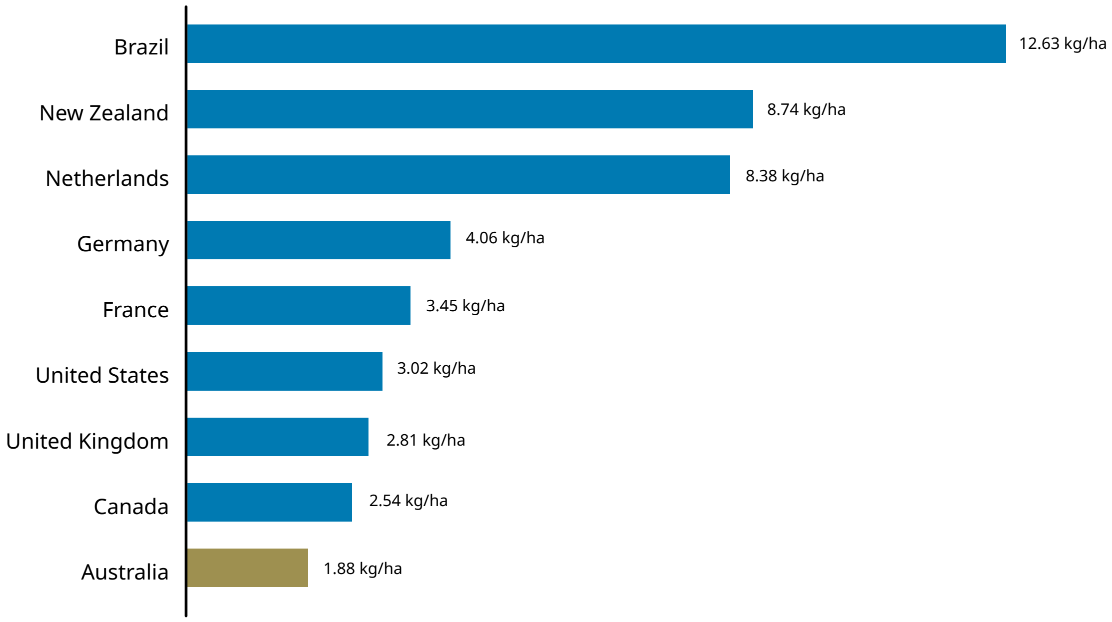


Figure 3.8. *Pesticide application rates on cropping land across selected countries in 2022. Across a set of major agricultural exporters, Australia recorded the lowest average pesticide application (1.88 kilograms per hectare), substantially below peers. This comparatively modest input intensity reflects Australia's integrated pest-management practices and the need to tailor chemical use to its predominantly dryland, variable agroecological zones.*[115]

SUMMARY | Right inputs, right place

Role of plant science innovations:

- Development and adoption of modern crop protection products, that are more selective, safer and have reduced off-target effects, supports beneficial insect populations.
- Integration of precision application technologies, IPM and science-based label guidance to ensure judicious use.

Sustainability outcomes:

- Yield preservation and reduced crop losses ensure a greater share of harvest biomass reaches consumption, lowing GHG emissions intensity.
- Ecosystem protection from the use of modern chemistries and precision application technologies.
- Maintained ecosystem integrity through minimised off-target impacts and lower pesticide use rates compared with other export-oriented nations.
- Improved resource efficiency, through evidence-based management of fertiliser, water and crop protection inputs, delivering both economic and environmental benefits, including enhanced biodiversity support with IPM frameworks.

115 Ritchie, Rosado, and Roser.

3.3.7. Integrating innovation, regulation, and best-practice product stewardship

Australia's approach to judicious pesticide use combines rigorous regulation, ongoing R&D and best-practice farm management. This integration ensures environmental protection, agricultural productivity and long-term sustainability.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) regulates the registration of pesticide products, including approval of labels that specify active ingredients, application rates, safety precautions, withholding periods and environmental risk mitigation measures. The APVMA operates as a risk-based, independent regulator, ensuring that pesticide approvals in Australia are grounded in robust scientific evidence, underpinning public confidence in the regulatory system.[116]

Plant science innovations, including modern pesticides, are the result of decades of research-intensive development. These tools are designed with precise modes of action, undergo extensive toxicological and environmental testing and are accompanied by clear stewardship pathways.

The stringent R&D and regulatory processes ensure that label instructions are not arbitrary but reflect rigorous science, guiding safe and effective use. For example, Australia is the first country to require the inclusion of Mode of Action (MOA) information on pesticide product labels. This initiative enables farmers to make informed product rotation decisions, supports resistance management strategies and promotes responsible pesticide use. By clearly identifying MOA groupings, this system helps prevent over-reliance on single chemistries and preserves product efficacy. This foundation allows Australian farmers to access world-leading innovations and, importantly, to deploy them in ways that support climate-smart agriculture by reducing losses, optimising inputs and sustaining yields.

Complementing rigorous regulation, Australia's plant science industry exemplifies best-practice product stewardship. It emphasises product selection based on efficacy and environmental safety; strict adherence to label requirements, reflecting extensive R&D; precision technologies to target applications and reduce drift; IPM integration that combines chemical, biological, cultural and mechanical pest control methods;[117] safe handling, storage and disposal of used or obsolete products; and resistance management strategies, developed by industry partnerships with research organisations, provide guidance on rotating chemistry with different modes of action to slow resistance in pests, weeds and disease.[118,119] The outcome is a national pattern of effective yet low overall pesticide use (Figure 3.8).

These measures demonstrate that Australia not only has access to advanced plant science innovations, but also possesses the regulatory rigour, scientific capability and on-farm stewardship culture to ensure their safe, effective and sustainable use delivering tangible climate-smart agricultural outcomes.

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116 "Australian Pesticides and Veterinary Medicines Authority."
117 *UNFAO | Pest and Pesticide Management - Integrated Pest Management.*
118 "CropLife Australia | Resistance Management."
119 "Cesar Australia | About Cesar Australia."

SUMMARY | Integrating innovation, regulation and best-practice product stewardship

Role of plant science innovations:

- Modern pesticide chemistries, developed through decades of R&D with precision MOA and robust safety testing, are enabling targeted and effective pest control.
- Best-practice chemical stewardship means correct product choice, timing, rate and application method, all tailored to local pest pressures and climatic conditions.
- MOA labelling in Australia is a world-first initiative that enables informed decision making to support sustainable pesticide use.
- R&D driven label guidance reflects rigorous toxicological and environmental science.
- Support from science-based regulation from the APVMA, which ensures product approvals, label instructions and use conditions are evidence-driven and risk managed.

Sustainability outcomes:

- Climate-smart agriculture practices reduce yield loss, optimise input use and lower emissions intensity.
- Resistance management practices, supported by MOA labelling.
- Environmental protection through targeted, safe and compliant applications, which minimise off-target effects.
- Long-term agricultural productivity by preserving the efficacy of crop protection tools.
- Knowledge transfer through label-based education empowers growers to make science-informed decisions.
- Stewardship excellence through science-based product application, compliance and disposal.

CASE STUDY

High-tech precision application

Advances in application technology like drone spraying and AI-guided booms, combined with GPS systems, improve efficiency and reduce off-target drift. Colour sensing (RGB, red-green-blue) camera systems enable site-specific herbicide application to distinguish between crops, weeds and bare soil in real time, resulting in less herbicide use and better targeting.

Green-on-brown herbicide application, where weeds are controlled in fallow paddocks before crop establishment, has long been a cornerstone of conservation tillage and sustainable farming systems. By targeting weeds before sowing, it preserves soil moisture, improves seeding conditions and reduces weed pressure in the following crop.

The next frontier is green-on-green application, where advanced machine vision and AI-enabled sprayers can distinguish weeds from crops in real-time. This allows for precise, in-crop targeting of herbicides, dramatically reducing chemical use, lowering input costs and minimising environmental impacts, while also helping to slow the development of herbicide resistance.

Green-on-brown application shown. Image: John Deere

4. THE CHALLENGE AHEAD FOR AUSTRALIAN AGRICULTURE

Australia's agricultural production base already operates under a markedly harsher climate than in the early 20th century. Since 1920, average land temperatures have risen by 1.51 °C, driving a six-fold increase in the frequency of extremely hot days. In 2019, Australia recorded 40 days when the national average temperature was hotter than 99 per cent of days in the historical record.[120]

Meanwhile, drought exposure and irrigation risk have increased, with winter rainfall declining by about 16 per cent in south-western Australian and 9 per cent in the south-east. Streamflows have also declined at most monitoring gauges since 1970.[121] These climatic trends have already translated into measurable productivity losses across many cropping regions, with parts of Western Australia and New South Wales experiencing more than a 20 per cent decline in climate-adjusted productivity between 2000–01 and 2014–15 (Figure 4.1).[122]

The effect of climate change on cropping productivity in Australia

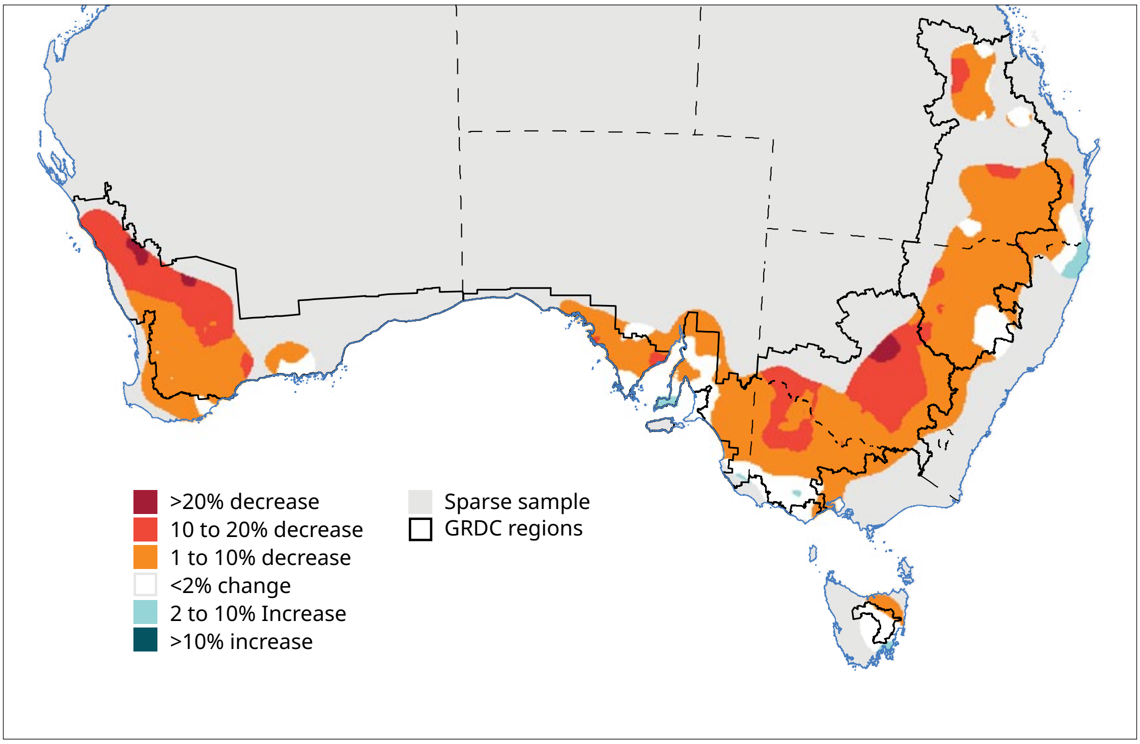


Figure 4.1. *Map of average climate effect on productivity levels since 2000–01, (relative to the 1914–15 to 2014–15 average conditions). Across much of southern Australia, climate conditions have reduced productivity between 10 and 20 per cent or more relative to the long-term baseline, reflecting the influence of hotter and drier conditions.*[123]

120 "CSIRO | State of the Climate 2024," 20.
121 "CSIRO | State of the Climate 2024."
122 Hughes, Lawson, and Valle, "ABARES | Farm Performance and Climate: Climate-Adjusted Productivity for Broadacre Cropping Farms."
123 Hughes, Lawson, and Valle.

Projecting ahead, more extreme weather events such as heatwaves, bushfires, storms, floods and droughts are expected. Southern regions are likely to see drier winters and springs, while northern Australia can expect more intense and variable rainfall.[124] ABARES modelling suggests that these climatic shifts have already eroded profitability, attributing a 23 per cent drop in average broadacre farm profits between 2001–2020 (about $29,200 per farm) to hotter, drier conditions.[125] The same ABARES modelling forecasts that, without further adaptation, profits could contract by a further 10 to 50 per cent by 2050.

Looking ahead, Australian agriculture faces the dual challenge of sustaining productivity and profitability while managing intensifying climatic pressures. Maintaining the sector's resilience will depend on continued innovation, adaptive management and long-term planning that aligns economic performance with environmental stewardship.

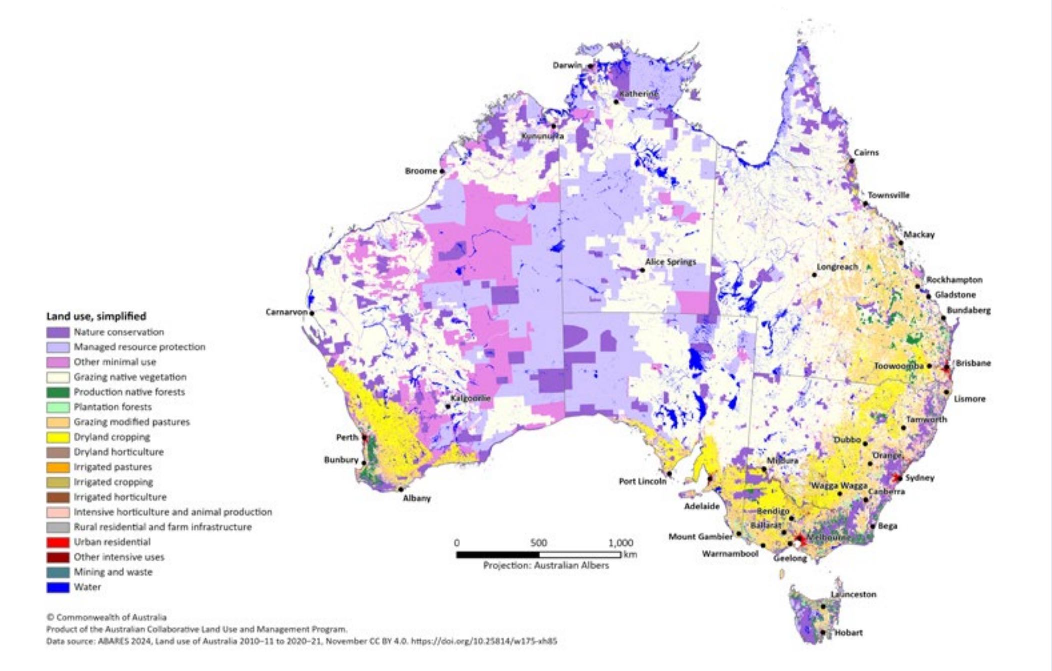
CASE STUDY

Australian wheat productivity is threatened by the consequences of climate change

The historical extent of Australia's wheat-growing zone broadly aligns with Goyder's Line, a climatic boundary delineating regions receiving less than 250 millimetres of average annual rainfall, beyond which cropping becomes unreliable. Within these marginal zones, wheat productivity has historically been constrained by low rainfall and high temperatures, while conditions improve progressively toward cooler, wetter coastal regions, where yields are typically higher.

Recent climate data indicate that many of Australia's traditional wheat-growing areas have experienced significant warming and declining rainfall over recent decades. As shown in the temperature anomaly maps (1910-2024), these shifts have intensified heat and moisture stress across key production zones. Consequently, some areas now face temperature and rainfall conditions approaching or exceeding the thresholds once considered uneconomic for cropping, posing challenges for long-term viability and yield stability.

Land use in Australia, 2020-21



Land use across Australia in 2020-21, showing major categories including grazing, conservation, cropping and urban areas.[126]

124 Hochman, Gobbett, and Horan, "Climate Trends Account for Stalled Wheat Yields in Australia since 1990"; Williams, "Impact of Climate Change on Wheat Yields in Australia."

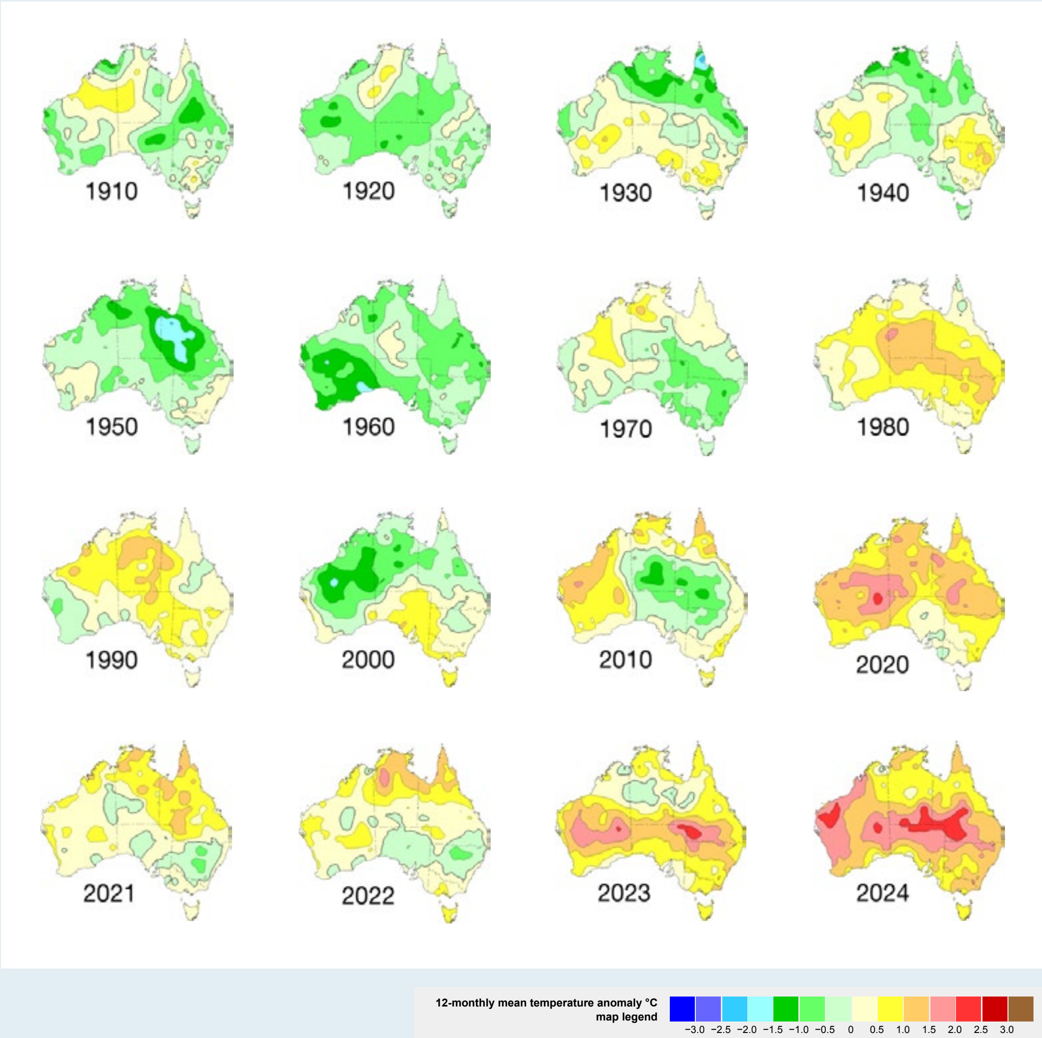
125 Hughes and Gooday, "Climate Change Impacts and Adaptation on Australian Farms."

126 "ABARES | Land Use of Australia 2020-21."

CASE STUDY (continued)

Australian wheat productivity is threatened by the consequences of climate change

Progressive warming of Australia, 1910-2024



Observed changes in average temperature across Australia from 1910 to 2024.[127]

127 "BOM | Australian 12-Monthly Mean Temperature Anomalies since 1911."

4.1. The status quo is not enough

Australia's sustainable contributions to global food security will only endure if farmers can continue to adapt to the intensifying impacts of climate change. Continued adaptation and productivity enhancements will be essential for sustaining competitiveness in global markets.[128]

Australian farmers are already experiencing more frequent and severe droughts, heatwaves, floods and shifting weeds, pest and disease pressures compared to the early climate records from 1910.[129,130,131,132] The IPCC projects that a 2 °C rise in global mean temperature could impose cumulative economic losses on Australia of about USD 115 billion (approximately AUD 176 billion) over 2022–2032.[133] This eroding productivity threatens the viability of rural communities.

4.2. The pressure on Australia's biodiversity and natural landscapes

Beyond agriculture, invasive pests, weeds and disease also threaten Australia's unique biodiversity, with climate change expected to accelerate their spread and increase their competitiveness.[134] Australia now harbours more introduced plant species than native ones, making invasive weeds a leading driver of ecosystem decline.[135] They threaten about 45 per cent of assessed native species, ranking second to habitat loss as a cause of biodiversity decline.[136] Since 1960, invasive plants have taken an estimated $200 billion from the national economy through productivity and control costs.[137]

Farmers and environmental land managers depend on modern pest-management chemistry as one of the few effective tools to control invasive species and safeguard fragile ecosystems.[138] Climate change is intensifying these pressures by driving ecological shifts and enabling insects, invasive plants and diseases to expand into new areas. Warmer, wetter conditions are likely to increase their range and impact severity, heightening the need for more robust IPM strategies. The magnitude of this challenge is already evident; weeds alone cost Australia's grain producers about $4.3 billion each year, an average of $203 per cropped hectare.[139]

Australian research organisations, state agencies, CSIRO and Commonwealth departments have developed models to predict how climate change may affect the spread, timing and risk of pest, weed and disease outbreaks (Figure 4.2).[140,141] These studies consistently show that warmer temperatures and altered rainfall patterns will expand the geographic range of several high-priority pests and diseases and allow them to multiply faster. For example, the NSW Department of Primary Industries found that the Queensland fruit fly (*Bactrocera tryoni*) is increasingly likely to thrive in southern horticulture regions, with conditions allowing more generations per year.[142] Similarly, national CLIMEX models show that fall armyworm (*Spodoptera frugiperda*) is expected to stay active for longer periods and spread further across grain and horticultural areas.[143]

The implications for agricultural innovation are clear. Expanded pest ranges and longer activity seasons will place greater pressure on existing control strategies, increasing the need for new traits (such as pest- and disease-resistant varieties) and modern crop protection chemistry.

128 Hughes and Gooday, "Climate Change Impacts and Adaptation on Australian Farms."
129 "CSIRO | State of the Climate 2022."
130 "DAFF | National Statement on Climate Change and Agriculture."
131 "CSIRO | Weeds under Climate Change."
132 Fitzgerald, "GRDC | Grain Production in a Changing Climate - Elevated CO2, Heat and Moisture Stress."
133 Lawrence et al., "2022: Australasia. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," 11.
134 "Chapter 5."
135 "Key Findings | Australia State of the Environment 2021."
136 Coutts-Smith and Downey, "Impact of Weeds on Threatened Biodiversity in New South Wales."
137 Bradshaw et al., "Detailed Assessment of the Reported Economic Costs of Invasive Species in Australia."
138 Low, "Glyphosate: A Chemical to Understand."
139 "GRDC | Impact of Weeds on Australian Grain and Cotton Production."
140 "CSIRO | Catalysing Australia's Biosecurity."
141 Camac et al., "Forecasting Trade and Biosecurity Risk under Climate Change."
142 "NSW DPI | Climate Vulnerability Assessment Queensland Fruit Fly Results Report."
143 Maino et al., "Regional and Seasonal Activity Predictions for Fall Armyworm in Australia."

Modelling shifts in pest geographic distribution

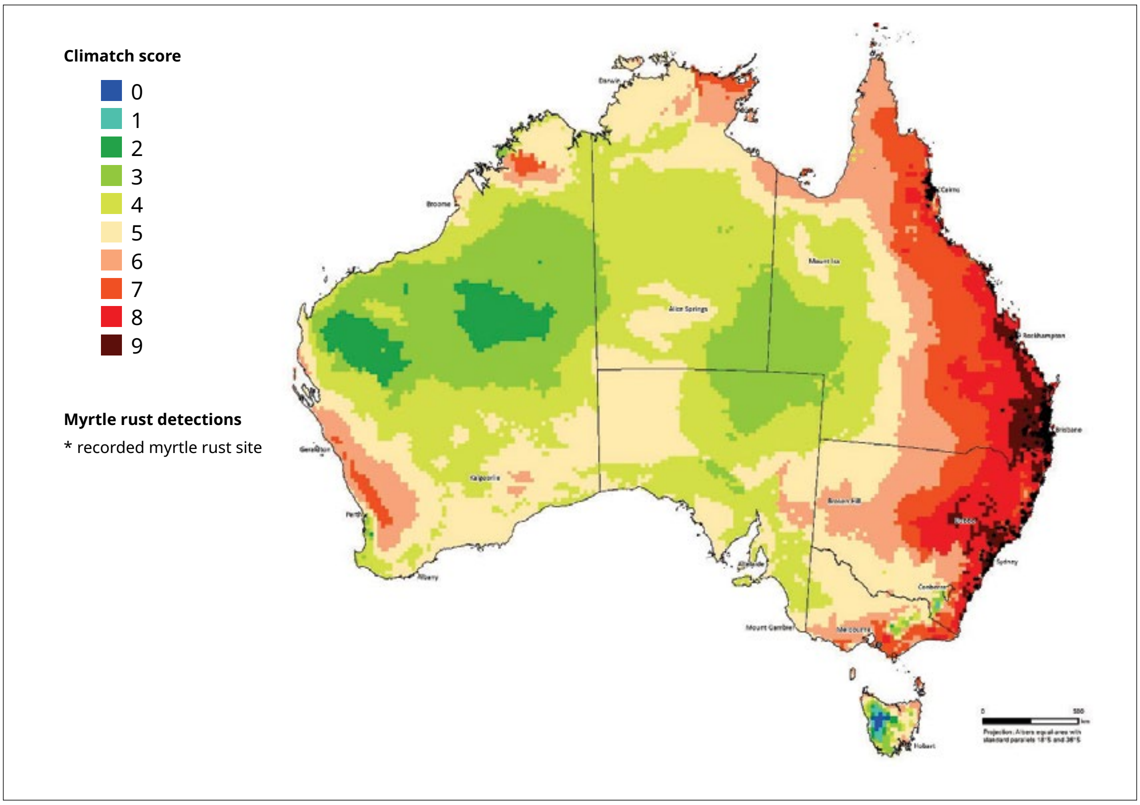


Figure 4.2. *Potential geographical distribution of myrtle rust in Australia based on Climatch modelling. This compares climate conditions at known detection sites with other regions and has been used to map the potential threat of myrtle rust.*[144] *Climatch scores below 5 correspond to no detection of myrtle rust.*

4.3. Science and technology driving transformation

Innovation-led efficiency has long been central to how Australian farmers operate. ABARES modelling shows that adopting new technological innovations that enable outcomes-focused agronomic practices has been critical to helping Australian farmers adapt to a changing climate.[145]

Between 1989 and 2020, the Australian cropping sector's adoption of innovations, such as plant breeding advances, precision input management, no-till systems and IPM, enabled a 68 per cent increase in farm productivity (Figure 3.1B).[146] Australian farmers have adapted to challenging climatic conditions before and the industry can do so again. Yet, the challenges of climate change will require Australian agriculture to accelerate and scale up these solutions, doubling down on improving genetics, access to modern chemistry, the adoption of precision agricultural technologies and water use efficiency to mitigate the negative effects of climate change.

In its recent report, the Australian Academy of Science highlighted the central role of innovation in meeting future national challenges, identifying science and technological transformation as one of three overarching priorities.[147] Within this, the Academy explicitly recognises the growing demand for precision agriculture, climate adaptation and climate-smart agriculture technologies as critical pathways for reducing the emissions intensity of agricultural systems. Agricultural science itself is projected to be one of the top eight science capability areas in demand by 2035. This national framing highlights the central role of agricultural science, technology and R&D, including plant science, in maintaining productivity, competitiveness and environmental performance under a changing climate.

144 Singh, Senarath, and Read, "ABARES | Climatic Suitability of Australia's Production Forests for Myrtle Rust."
145 Hughes and Gooday, "Climate Change Impacts and Adaptation on Australian Farms."
146 Hughes and Gooday.
147 "Australian Academy of Science | Australian Science, Australia's Future: Science 2035."

Climate adaptation in Australian farming means adjusting farming practices, crops and technology adoption to stay productive under changing climatic conditions. A 2019 report from ABARES indicated a 22 per cent reduction in farm profits during 2000–2019 could be attributed to climate change.[148] Modelled climate scenarios forecast further declines if adaptation is limited.

The Australian Government's recently released Agriculture and Land Sector Plan recognises that the sector has already made valuable contributions to national emissions reduction goals.[149] It acknowledges that Australia's primary producers are world leaders in low-emissions food and fibre production, and therefore does not impose mandated sectoral targets. Instead, the plan emphasises that continued progress will rely on supporting innovation, research and investment in productivity and sustainability outcomes. By focusing on commercially viable abatement options and enabling technologies, the plan charts a pathway that maintains Australia's competitive advantage in global markets while contributing meaningfully to the national 2035 emissions reduction target. This approach aligns with the evidence presented in this report: targeted innovation, not production cuts, is key to further reducing emissions intensity while sustaining output and profitability.

Future advances in plant science innovations hold substantial potential to deliver measurable emissions reduction, productivity gains and resilience, further ensuring the continuation and expansion of Australia's climate-smart agricultural trajectory. Figure 4.3 illustrates the significant yield gap between current and attainable production levels in Kenya, highlighting both the risks posed by climate change and the opportunities available to mitigate this through innovation.[150] Current average yields sit at just 1.4 tonnes per hectare, and under extreme climate scenarios could decline further to around 1.1 tonnes per hectare, a 25 per cent reduction. In contrast, with access to improved seeds, modern technologies and best-practice agronomy, yields of up to 4.2 tonnes per hectare are achievable. This 2.8-tonne gap underscores both the vulnerability of agricultural productivity to climate change pressures and the transformative potential of science and technology to close yield gaps and enhance resilience. A few notable examples of technology-driven opportunities are discussed below.

Current and attainable maize yields in Kenya under climate change

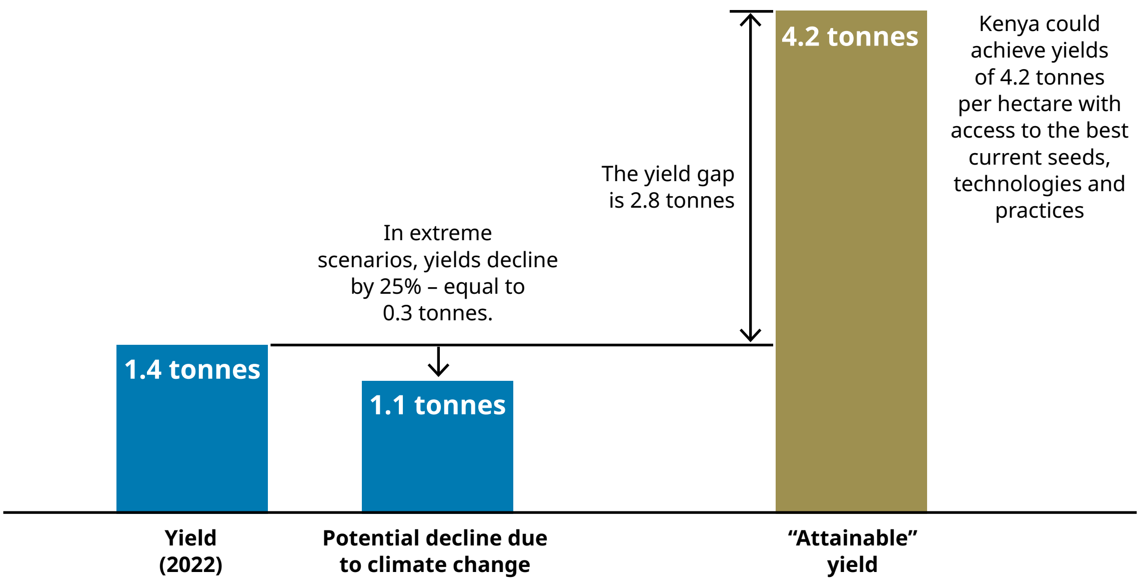


Figure 4.3. *Comparison of observer maize yields with modelled attainable yields, illustrating the yield gap, in Kenya under future climate change projects. Average yields in 2022 face potential decline under extreme climate scenarios. However, adoption of improved seeds, advanced technology and best agronomic practices could lift yields significantly.*[151]

148 Hughes and Hatfield-Dodds, "Climate Change since 2000 Has Cut Farm Profits 22%."
149 "DAFF | Agriculture and Land Sector Plan."
150 Ritchie, "How Will Climate Change Affect Crop Yields in the Future?"
151 Ritchie.

4.3.1. The escalating challenge of crop protection

Climate change is reshaping the agricultural pest and disease landscape, increasing the need for crop protection products at the very time when their efficacy is also being challenged. The IPCC notes that a warmer climate expands the geographical and ecological boundaries of pests, weeds and disease, directly increasing the need for pesticide use to maintain yields and food security.[152] Warmer conditions accelerate pest lifecycles and broaden survival ranges, allowing previously marginal organisms to establish and intensify in new regions.

At the same time, higher atmospheric carbon dioxide levels and rising temperatures undermine the effectiveness of herbicides. Research shows that elevated carbon dioxide reduces herbicide absorption and efficacy in weeds, weakening chemical control and forcing farmers to apply higher doses or more frequent treatments.[153]

Climate change also exacerbates the evolution of herbicide resistance. One study found that high carbon dioxide concentrations and elevated temperatures increased resistance to the herbicide cyhalofop-butyl in multiple-resistant awnless barnyard grass (*Echinochloa colona)*, a weed of global significance.[154]

Climate change creates a triple threat to crop protection: (1) expanding the geographical ranges of pests, weeds and disease; (2) reducing the efficacy of crop protection products under elevated carbon dioxide and heat; and (3) accelerating the development of resistance. These interlinked pressures underline the urgency of investment in innovation and best-practice product stewardship. Without effective adaptation, including IPM, new MOA and biotechnological solutions, farmers will face increasing difficulty in safeguarding yields, sustaining productivity and reducing emissions intensity under climate stress.

4.3.2. The role of GM crops in mitigating climate change

GM crops can significantly reduce agricultural GHG emissions by increasing yields and limiting land-use change.[155] Modelling shows that if the European Union adopted GM maize, soybean, cotton, canola and sugar beet at levels comparable to the US, GHG emissions could fall by 33 million tonnes of carbon dioxide annually, equivalent to 7.5 per cent of the EU's agricultural emissions in 2017. Most of these savings arise from land spared from conversion of natural ecosystems such as forests and grasslands to agricultural land.

The study also highlights that increased GM uptake would reduce dependence on soybean imports from regions such as Brazil, where deforestation drives high emissions. Evidence shows that GM crops deliver yield gains and higher farm profitability; in some cases, they also reduce pesticides use and improve soil carbon storage. As new traits for drought and heat tolerance emerge, the study's authors argue that the climate mitigation potential of GM crops will expand even further.

In Australia, the widespread adoption of GM cotton and canola has demonstrated clear agronomic and economic advantages, enhancing resilience to pests and weeds, reducing input costs and helping maintain competitiveness in export markets. Over 99 per cent of cotton grown in Australia is now GM cotton, which has substantially lowered insecticide use while preserving yield and export viability.[156] Within Australia's canola industry, nearly half (46 per cent) of all production now comes from herbicide-tolerant GM varieties, offering economic and environmental gains through improved weed control and operational flexibility.[157]

152 "IPCC | Sixth Assessment Report Chapter 5"
153 Ziska, "The Role of Climate Change and Increasing Atmospheric Carbon Dioxide on Weed Management."
154 Refatti et al., "High [CO2] and Temperature Increase Resistance to Cyhalofop-Butyl in Multiple-Resistant Echinochloa Colona," 2.
155 Kovak, Blaustein-Rejto, and Qaim, "Genetically Modified Crops Support Climate Change Mitigation."
156 "OGTR | Genetically Modified (GM) Cotton in Australia."
157 "OGTR | Snapshot of Genetically Modified (GM) Canola in Australia."

4.3.3. Life cycle assessment for the climate-smart role of modern pest management

A recent ISO-compliant life cycle assessment by the University of Arkansas highlights the significant environmental costs of removing modern crop protection tools.[158] The US study modelled maize, soybean and cotton under four scenarios, showing that eliminating herbicides and insecticides substantially increased GHG emissions, energy use, land occupation and water consumption per unit of output. Soybean emissions rose by 258 per cent without insect control and by 127 per cent without weed control. For cotton and maize, emissions were about double when pest control was removed: 105 per cent and 93 per cent, respectively.

Increases in emissions due to removing crop protection tools stems from yield losses, additional field operations and reduced capacity to maintain conservation tillage systems. Although transport and processing were not major drivers of emissions, significant yield losses at the farm level amplified emissions that carried over into later stages, resulting in lower productivity.

In Australia, crop protection products enable sustainable intensification and support practices such as conservation tillage. Despite their central role, crop protection products account for only about 7 per cent of the grains sector's already markedly low GHG emissions profile (see section 3. *Australian agriculture's sustainability credentials*).[159] The continued use therefore makes both environmental and economic sense.

4.3.4. Precision application technologies as climate adaptation and mitigation tools

Precision application technologies provide both adaptation and mitigation benefits by enabling farmers to reduce input use, protect soils and sustain and increase yields. These technologies also further mitigate the direct drivers of agricultural GHG emissions and emissions intensity: fertiliser, fuel and soil gases. By sustaining yields with few inputs, these tools secure productivity gains in a warmer, drier and more variable world.

Controlled traffic farming (CTF) will become increasingly valuable under projected climate variability. As stated above (see 3.3.1. *Improved land management practices*), CTF preserves soil porosity and water infiltration, reducing water logging and the conditions that drive nitrous oxide emissions. An Australian multi-site field study estimated that CTF reduced combined soil emissions (nitrous oxide and methane) by 30 to 50 per cent.[160] As intense rainfall events become more common, this mitigation potential will likely become more significant.

Optical spot-spraying technologies use sensors and cameras to detect weeds in real-time and apply herbicide where weeds are present, rather than broadcasting chemical application across the entire paddock. This technology already allows Australian farmers to reduce herbicide use in fallow periods by 70 to 90 per cent per pass, with strong financial returns.[161] Emerging platforms that integrate high-resolution satellite imagery with machine learning can separate weed detection from herbicide application, with potential to deliver reductions in chemical use of up to 80 per cent.[162] Such innovations will be particularly valuable as shorter spray windows in a hotter climate demand more targeted, efficient applications.

Variable-rate nitrogen (VRN) and decision-support tools offer another critical pathway. Climate change is projected to exacerbate both drought years (when applied nitrogen may be unused and wasted), and increased periods of rainfall, which drive nitrous oxide emissions. VRN systems adjust fertiliser rates to soil and seasonal conditions, reducing excess application and associated emissions. Australian research has shown that emissions factors for nitrous oxide vary with climate and nitrogen application rate, underscoring the potential for precision nitrogen management to deliver significant abatement.[163] A recent GRDC comparison found that optimised nitrogen management produced just 0.6 tonnes of carbon dioxide equivalent per hectare, compared with 2.5 to 3.7 tonnes of carbon dioxide equivalent per hectare under conventional fertiliser application practices.[164]

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158 Thoma et al., "Life Cycle Assessment of Impacts of Eliminating Chemical Pesticides Used in the Production of U.S. Corn, Soybeans, and Cotton."
159 "GRDC | Greenhouse Gas Emissions."
160 Tullberg et al., "Controlled Traffic Farming Effects on Soil Emissions of Nitrous Oxide and Methane."
161 "GRDC | Optical-Spot-Spraying Case Study."
162 "GRDC | WeedSAT Turning Your Conventional Boom into a Spot Sprayer Using Ultra High Resolution Satellite Imagery."
163 Xing et al., "Modelling the Response of N2O Emission Factor to Nitrogen Application Rates and Inter-Annual Climate Variability."
164 "GRDC | Greenhouse Gas Emissions."

4.3.5. Breeding resilience: genetic solutions for crops in a changing climate

Climate change is reshaping crop production in Australia and beyond. Rising temperatures and reduced rainfall are directly affecting crop productivity and yields. Crop genetic improvements have historically demonstrated their effectiveness in increasing yields, both in Australia and globally. This was most notably evident during the Green Revolution. Today, genetic improvement is again emerging as a critical solution to counteract the adverse impacts of climate change, enabling farmers to maintain productivity under increasingly variable and challenging conditions.

Modelling studies illustrate both the promise and limits of current approaches. By adapting sowing dates and selecting suitable Australian wheat varieties, yields could increase by 4.6 per cent in future climate scenarios through reduced crop failure.[165] However, these adjustments alone may not be sufficient to fully offset the risks posed by climate change, calling for more efficient farming practices and the development of new drought-tolerant varieties.[166] This highlights the dual challenge of optimising existing genetic potential while investing in transformative breeding innovations.

A wide range of genetic traits are under investigation to improve resilience in Australian farming systems. One example is the CAIGE project, a collaboration between Australian university researchers, industry, state governments and international research institutions to develop Australian-adapted wheat and barley varieties with disease resistance and stress tolerance. This work is intended to help farmers maintain yields in the face of a changing climate.[167]

Another avenue of research focuses on enhancing photosynthetic efficiency – which, despite being fundamental to plant growth, is recognised as one of the least efficient biological processes on Earth. Work undertaken through the Earlham Institute, as part of the International Wheat Yield Partnership, suggests that it may be possible to improve elite wheat lines by identifying genetic markers and genes associated with greater photosynthetic capacity. Such advances could enhance energy conversion efficiency and ultimately deliver significant yield gains.[168]

Researchers at the University of Adelaide's Waite Research Institute used genetic and molecular biology techniques to study barley varieties and identify genes that improve fertility and hybrid vigour, making the plants more tolerant of weather extremes.[169,170] Other research groups are exploring ways to make plants grow more strongly in hot, dry conditions, focusing on traits like better seedling establishment, faster growth and more efficient use of nutrients and water.[171]

In addition to agronomic traits, pest and disease resistance are also an area of focus for crop improvement. For example, blackleg disease (*Leptosphaeria maculans*) is the most economically significant disease affecting canola in Australia, typically causing 5 to 30 per cent yield loss and, in severe epidemics, up to 95 per cent. Developing genetic resistance is the most effective control method.[172] Recent advances in canola breeding have delivered lines with improved blackleg resistance.[173,174]

While conventional breeding remains an important pathway for developing resilient crop varieties, the process can be relatively slow, particularly in the face of rapidly intensifying climate pressure. Advances in genetic modification and genetic engineering therefore provide complementary and accelerated avenues to introduce traits that enhance stress tolerance, pest and disease resistance, and resource-use efficiency. By aligning breeding innovations with modelling insights, Australian agriculture can secure yield stability in a warmer, drier world while simultaneously reducing vulnerability to climate extremes. Crop genetic improvement represents a powerful and indispensable solution to counteract the adverse impacts of climate change.[175]

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165 Collins and Chenu, "Improving Productivity of Australian Wheat by Adapting Sowing Date and Genotype Phenology to Future Climate."
166 Wang et al., "Modelling Biophysical Vulnerability of Wheat to Future Climate Change."
167 "CAIGE – CIMMYT Australia ICARDA Germplasm Evaluation."
168 "Earlham Institute | Improving Photosynthesis to Increase Wheat Yield."
169 Selva et al., "HvSL1 and HvMADS16 Promote Stamen Identity to Restrict Multiple Ovary Formation in Barley."
170 "University of Adelaide | Cracking the Code for Better Barley - and More of It!"
171 Rebetzke et al., "Breeding 'Systems Resilience' for Reliable Crop Production with Changing Climates."
172 McCallum et al., "GRDC | Fungicide Resistance in Blackleg Disease in Canola."
173 Vasquez-Teuber et al., "Breeding and Management of Major Resistance Genes to Stem Canker/Blackleg in Brassica Crops."
174 Amas et al., "Status and Advances in Mining for Blackleg (Leptosphaeria Maculans) Quantitative Resistance (QR) in Oilseed Rape (Brassica Napus)."
175 He et al., "Genetic Solutions through Breeding Counteract Climate Change and Secure Barley Production in Australia."

5. SECURING AUSTRALIA'S CLIMATE-SMART AGRICULTURAL FUTURE

Australian agriculture must adapt to intensifying heat, water scarcity and profit volatility or risk ceding productivity, competitiveness and rural livelihoods to a changing climate. It cannot rest on its current hard-won sustainability credentials: it must look ahead, balancing risks and economics while recognising that true sustainability requires continual adaptation and long-term planning. The sector must relentlessly pursue higher productivity while driving ever-greater environmental gains.

Australian agriculture already operates with some of the lowest on-farm GHG emissions intensities of any major exporter, a record built on rigorous chemical input stewardship and science-based regulation. Yet meeting increasing sustainability expectations in a hotter, drier and more variable climate demands another step-change in efficiency. The ability to meet Australia's sustainability and global food security goals depends on continued access to innovative tools and technologies from the plant science sector. These innovations reduce input-related emissions, safeguard yields under intensifying climate conditions and keep Australia at the forefront of climate-smart, high-value agricultural production.

The data in this report demonstrate that Australian farmers are already among the world's most efficient and sustainable food producers. Their ability to grow more with less land, water and inputs underpins the sector's exceptionally low emissions intensity – the result of decades of investment into Australian-specific plant science solutions. These gains exemplify the principles of climate-smart agriculture: food, feed and fibre production that is environmentally responsible, economically viable and socially equitable through affordable supply. This is only possible due to the effectiveness of evidence-based policy and the central role of science in supporting productivity, competitiveness and environmental outcomes.

Beyond meeting domestic needs, Australia carries a moral responsibility to contribute to global food security. By strengthening its sustainability credentials, Australian agriculture can continue to support local prosperity while helping to nourish a growing world population.

Modern crop protection products and advanced plant breeding – including biotechnology – are central to sustainable intensification. They enable farmers to maintain high yields while conserving soils, reducing emissions and building resilience to drought, heat, pests and disease. Precision application technologies enhance input-use efficiency, reduce GHG emissions and make best use of every hectare farmed. Together, these tools represent the essential infrastructure of a resilient and competitive agricultural sector in a decarbonising global economy.

Delays or restrictions in accessing plant science innovations impose clear costs on productivity, emissions and export competitiveness. Bringing a new biotechnology trait to market now costs USD 115 million and takes around 16.5 years, with nearly 40 per cent of that time spent in regulatory processes.[176] Crop protection products face even longer timelines: over 12 years at a cost of USD 301 million.[177] Each year of delay reduces farmers' ability to capture yield gains and forces reliance on less efficient practices that can lead to higher emissions per tonne of output. As a majority export industry, even modest productivity losses could translate to billions in lost revenue and diminished sustainability credentials for the Australian agricultural sector.

The intensifying impacts of climate change demand a new level of ambition. Shifting pest and disease pressures, growing resource competition and tightening sustainability standards will make farming ever more challenging. Past success is no guarantee for future resilience. To sustain and enhance its sustainability credentials, Australia must secure timely access to the full suite of plant science innovations that underpin modern, climate-smart agriculture.

176 AgbioInvestor, "Time and Cost to Develop a New GM Trait."
177 AgbioInvestor, "Time and Cost of New Agrochemical Product Discovery, Development and Registration."

To maintain a successful trajectory in agricultural productivity, Australia's policy and regulatory settings must evolve. Regulatory pathways for both crop protection products and biotechnology traits must become more agile, transparent and internationally aligned to ensure farmers can access safe, effective technologies that are already available to their competitors overseas. Delays in granting access to new technologies already cost the sector billions in lost productivity and export earnings. Removing or constraining access to modern crop protection tools could double or triple emissions per tonne of output, eroding Australia's hard-won sustainability gains and forcing expansion into new land to maintain production, leading to devastating consequences for biodiversity.

The risks of inaction are clear. ABARES modelling projects that, without continued adaptation, farm profits could fall by up to 50 per cent by 2050.[178] Without the tools and innovations of the plant science industry, Australia risks losing the sustainability gains that make its agriculture a global benchmark.

The path forward must be one of partnership between government, industry and research. With coordinated action, Australia can continue to lead the world in sustainable, climate-smart agriculture. Productivity, profitability and environmental stewardship are not competing objectives, but mutually reinforcing pillars of a prosperous agricultural future.

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