FERTILIZER AUSTRALIA

Executive Summary of the key information in the White Paper titled:

Nitrogen Fertiliser Use and Greenhouse Gases - An Australian Assessment: Challenges and Opportunities

Cover image credit (middle): Webber Chivall Fertilisers

Fertilizer Australia commissioned a White Paper to inform stakeholders about nitrogen use in Australia, provide an understanding of N losses in the Australian context, focussing on GHG emissions, and provide some recommendations on future policy options that could be considered.

This Executive Summary is an overview and readers are encouraged to refer to the White Paper for more detailed explanations and commentary.

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Preamble

The Albanese Labor Government has committed to reduce greenhouse gas emissions to 43% below 2005 levels by 2030.

A large source of emissions from agriculture comes from the use of nitrogen fertilisers, and several countries have placed restrictions on the quantity of nitrogen fertiliser, in an effort to reduce emissions.

In all examples, this has had a detrimental effect on agricultural output and put the prosperity of those countries at risk.

Fertilizer Australia commissioned the drafting of this white paper to assist the Australian government in reaching its targets without the perverse outcomes that might result from a mandate that reduces the use of fertiliser, particularly nitrogen. There are more nuanced methods of achieving these outcomes.

A reduction, such as was attempted in Canada, may not have a significant effect on emissions in Australia, but it will drastically slash Australian agricultural production, put regional communities at risk and potentially remove the surplus that Australia exports, damaging Australia's prosperity.

Furthermore, Australia's soils are very old, and the soil carbon is heavily influenced, in a positive way, by the application of fertilisers, particularly nitrogen. The reduction in nitrogen could damage soils, potentially in an irreversible way.

The white paper provides the government with an Australian perspective on nitrogen fertiliser use and a baseline for the government from which to measure changes in emissions.

Australia has a unique agricultural system, with much of it broadacre and in arid climates. Australia's emissions from such enterprises are very low.

While some enterprises in higher rainfall areas produce more emissions, there are solutions to these, using technology and farming practices, rather than reducing fertiliser input.

These technologies and farming practices aim to ensure that the amount of nutrients that go into the plants are maximised and the amount lost to the environment is minimised. This is called Nutrient Use Efficiency and can, in certain circumstances, reduce the amount of fertiliser applied.

The white paper provides several recommendations that can assist the government in developing a nuanced and well-considered response to emissions from nitrogen fertilisers while maintaining Australia's position as a prosperous country that feeds and clothes the world.

Fertilizer Australia would like to thank Dr Rob Norton, Dr Cameron Gourley and Professor Peter Grace, as well as our very own Jeff Kraak, for their expertise and input that went into drafting this white paper.

Stephen Annells
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Glossary

Term	Definition
C	Carbon
GHG	Greenhouse Gases
Ha	Hectare
Mt. CO_2E	Metric tonnes of carbon dioxide equivalent
N	Nitrogen
N_2	Dinitrogen
NBI-N	Nutrient Balance Intensity (kg N/ha)
NH_3	Ammonia
NH_4^+	Ammonium
N_2O	Nitrous Oxide
NO_3^-	Nitrates
NUE	Nitrogen Use Efficiency
PFP	Partial Factor Productivity (grain per kg/N)
SOM	Soil Organic Matter

Challenges and Opportunities

Agricultural Use of Nitrogen

Nitrogen (N) is an essential element required in large amounts. It is the most common nutrient limitation for plant growth.

Fertilisers supplement the N supply to plants that comes from the soil and manures, composts and legumes, to enhance crop and pasture production.

N fertilisers have made it possible to sustain the growing world population, sparing millions of hectares of natural and ecologically sensitive systems that otherwise would have been converted to agriculture.

In Australia, N use is fundamental to the productivity and sustainability of its agricultural industries but it is characterised by insufficiency in some areas and an excess in others.

The N challenge is balancing the benefits in productivity from using N inputs while minimising the N losses and the impact of those losses.

The use of N in various industrial, agricultural, and other activities can result in N leakage with environmental consequences such as pollution of water bodies and emission of greenhouse gases.

On the other hand, underusing N can result in reduced food production, the loss of soil organic matter (SOM), degradation of soil quality and increased erosion.

The opportunity is provided by efficiency-improving technologies and practices that improve productivity and reduce nitrous oxide (N_2O) emissions.

Land managers, supported by technology and appropriate policy settings, can address the N challenge where reduced N losses and improved nitrogen use efficiency (NUE), across all sectors, provide the foundation for a Greener Economy to, simultaneously, produce more food and energy while reducing environmental pollution.

Nitrogen Fertiliser Manufacturing

N fertiliser manufacture uses fossil fuels such as natural gas and coal, which have a large embedded carbon footprint.

The challenge is that while it is technically feasible to manufacture N fertiliser with a low carbon footprint, it is currently not economical as farmers are, typically, not prepared to pay a premium for N fertiliser manufactured to have a low carbon footprint.

The opportunity is to position Australian agriculture to take advantage of changes in consumer demand for produce with a low carbon footprint.

This may cause a change in farmers' responses to market signals and technology improvements that lower the cost of N fertiliser with a lower carbon footprint.

Policy settings that aid this transition should be considered.

Background information

What is nitrogen and why is it important?

- N is an essential nutrient to plants and forms the source of protein in our food.
- Although it is abundant in the atmosphere as dinitrogen (N_2), plant available forms of N are often the most limiting nutrient in natural and agricultural ecosystems.
- N in soil is mainly present in organic matter, which is transformed to plant-available N through biological activity and soil micro-organisms.
- Too little N leads to low crop yields and declining soil health, conversely, too much N can lead to environmental damage through losses to air, land and water.
- The global production of synthetic N fertilisers using the Haber-Bosch process has enabled food production to support an estimated 40% of the world's population.
- The amount of N cycling through our systems has dramatically increased since the Industrial Revolution and the "Green Revolution".
- While N is vitally important for farm profitability, food production and a healthy diet, losses of N from production systems can result in environmental damage at a local and global scale.
- The European Nitrogen Assessment and "Our Nutrient World" identified that leakages from the N cycle have negatively impacted water quality, air quality, greenhouse gas balance, ecosystems and biodiversity, and soil quality.

The Nitrogen Cycle

- N is a reactive element that cycles through soils, plants, animals and the atmosphere.
- As N cycles from the air to soil and into plant products, ammonia (NH_3) volatilisation, nitrate (NO_3^-) leaching and nitrification/denitrification can result in environmental impacts.
- NH_3 and N_2O emissions can be derived from all N sources, including manures, composts, crop residues, biological fixation and fertilisers.

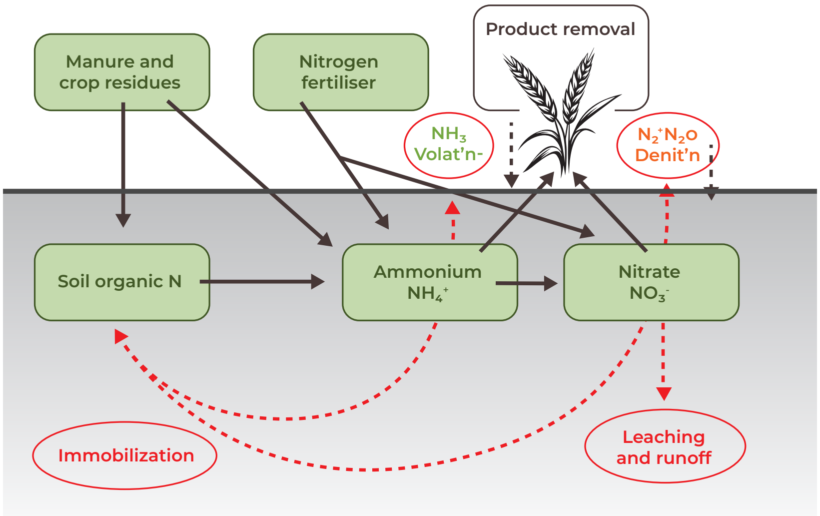

Figure 1
A simplified nitrogen cycle showing the inputs and pools of nitrogen, along with loss and transfer pathways in red (IPNI). (Volat'n = volatilisation; Denit'n = denitrification). Gaseous N can be redeposited.

Nitrogen Use Efficiency

- NUE is the ratio of the sum of N removed in agricultural production outputs and the sum of N added as inputs.
- NUE can be measured in many ways depending on the purpose of the assessment.
- The most common and practical NUE assessment is the 'removal to use' ratio, called a partial nutrient balance. N input minus N removal also estimates N balance on an area basis. These indices are simple to calculate, scalable and applicable for agricultural and environmental assessments.
- Improved field, farm and industry fertiliser use information will assist in assessing and bench-marking N use efficiency.

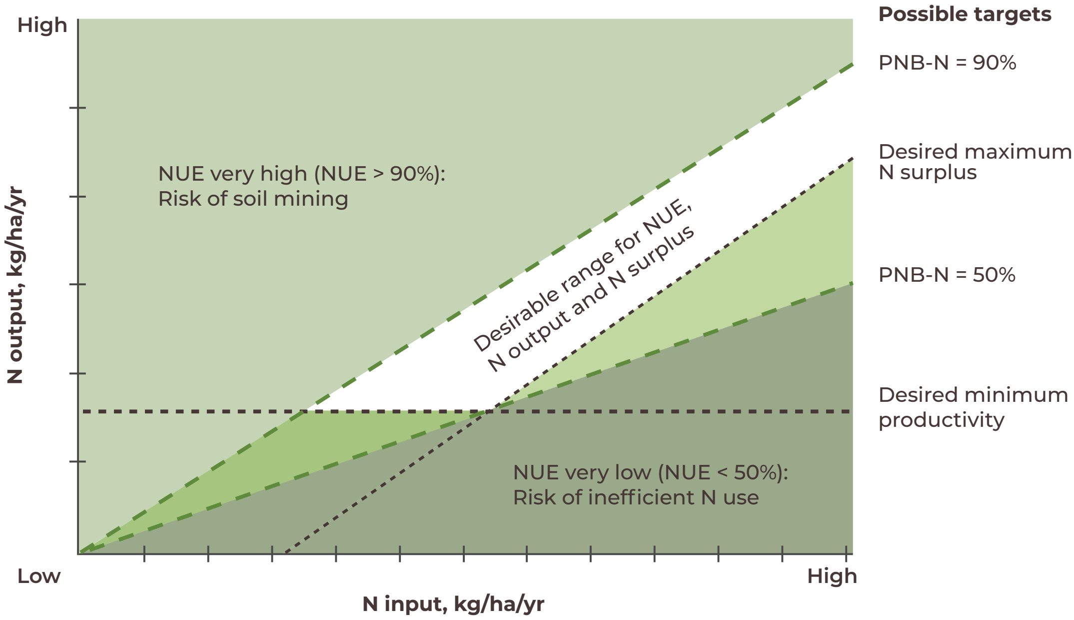

Figure 2
One of several frameworks proposed for interpreting PNB-N to include scaling of N use. The values are only indications, as target PNB-N values are industry and region-specific.

Image Credit: Yara Australia

Fate of N not removed in agricultural products

A consequence of the transfers between N pools in the soil and then into crop or pasture plants or the SOM pool, is that some N is lost through a range of pathways. Below is a summary of those pathways.

I. Losses of N as gases

- Four N gases are released from the soil in appreciable quantities. These are N_2, NH_3, nitric oxide (NO) and N_2O.
- Denitrification is the principal process where NO_3^- is biologically reduced by removing one or more of its oxygen atoms to create N_2, NO or N_2O, depending on soil conditions.
- NH_3 gas is produced when ammonium (NH_4^+) from manures or fertilisers decompose.

II. Losses of N through water

- NH_4^+ is not mobile in the soil, but the NO_3^- form of N can move through the soil, potentially into subsurface and surface waters.
- N in water can lead to algal blooms and eutrophication in water bodies.
- Secondary N_2O emissions can be derived from NO_3^- transferred to water.

III. Losses of N to and from organic matter

- N can be released from, or incorporated into, organic matter depending on the Carbon (C)-to-Nitrogen ratio of the material added.
- Cultivation, residue burning and long fallows reduce SOM levels.
- Low SOM can result in poor soil structure, reduced fertility and declining soil health.

Importance of N for food security and soil health

I. N for soil health

- Organic N from SOM is critical to support the soil's physical, chemical and biological fertility.
- Balanced nutrition with conservation farming practices, including adding supplementary N from inorganic or organic N fertilisers, helps maintain SOM levels and soil health.

II. N for food and fibre production

- Organic N - whether from soil or recycled organic materials - cannot sustainably supply enough N to support highly productive $90 billion AUD agricultural production systems.

III. Balancing role of N fertilisers

- Australian farms use around 1.5 Mt of elemental N annually, less than 1.5% of global consumption.
- N fertilisers help replace the N lost in crop products and maintain soil productivity.
- There is a sizeable water-limited yield gap in the Australian grains industry due to sub-optimal N management practices.

Context and operating environment

Nitrogen and Greenhouse Gas Emissions

N_2O emissions, like all GHG, are reported as being derived from three sources described in the table below:

Scope 1	Direct emissions from the activities undertaken. In the case of agriculture, this includes cultivation, residue burning, and use of N fertilisers, soil ameliorants and fossil fuels. For 2020-2021, the National Greenhouse Gas Inventory reported 76.3 Mt CO_2e for agriculture.
Scope 2	Indirect emissions - created by the production of energy used on the farm, such as electricity. Scope 2 emissions for agriculture are estimated at 1.28 Mt CO_2e, out of 163.3 Mt CO_2e.
Scope 3	Indirect emissions – meaning those not produced on the farm itself – they differ from Scope 2 as they cover those produced by customers using the company's products or those produced by suppliers that the company uses. Typical Scope 3 emissions for agriculture are fertiliser manufacture, storage and irrigation infrastructure. Scope 3 emissions are not reported under the National Greenhouse Gas Inventory.

- Agriculture produces around 15% of Australia's greenhouse gas emissions, and N_2O represents about 15% of the emissions from agriculture or 8.1 Mt carbon dioxide equivalent (CO_2e).
- Direct (Scope 1) N_2O emissions from agriculture are derived from fertilisers (30%), decomposition of crop residues and organic materials (30%), the direct deposition of dung and urine (35%) and where animal manure is stored and land applied (5%).
- Revised N_2O emission factors (EF) for various industries have been recently published, which provide higher confidence (Tier 2/3) estimates of GHG production from applied fertilisers.
- There are additional GHG emissions embedded in N fertiliser (Scope 3) as a consequence of manufacture.

N_2O is a potent greenhouse gas contributing to climate change. It has a much higher global warming potential than CO_2, although its atmospheric concentration is much lower.

The White Paper focuses on Scope 1 emissions - those directly derived from agricultural activities on farm, although Scope 3 emissions associated with fertiliser manufacture are significant.

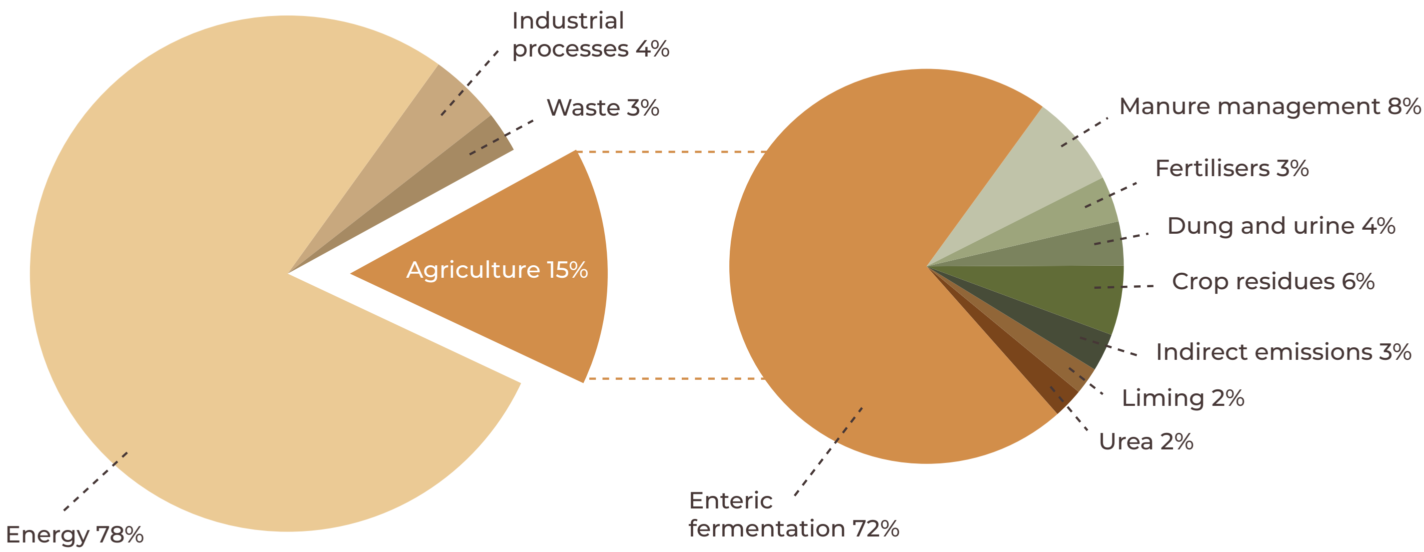

Figure 3
Total Australian Greenhouse Gas emissions for Australia by United Nations Framework Convention on Climate Change, net of Land Use, Land Use Change and Forestry sector (left) and the breakdown of agricultural emissions by IPCC source.

The agricultural sector contributes around 79% of Australia's N_2O emissions. The National Inventory report indicates that N_2O emissions are derived from direct emissions from inorganic fertilisers (2.46 Mt CO_2e), urine and dung deposited by grazing animals (2.61 Mt CO_2e), crop residue decomposition (4.38 Mt CO_2e) and indirect emissions due to N leaching and runoff (2.38 Mt CO_2e). Other agricultural sources of GHG are methane from enteric fermentation, manure management and rice cultivation, and CO_2 released from liming and burning fuels for activities like irrigation, machinery operation and processing. There are additional GHG emissions from urea fertilisers due to the 20% carbon content, released as CO_2, not N_2O. The GHG inventory estimates this adds 1.76 Mt CO_2e.

Estimating Scope 1 nitrous oxide emissions in agriculture

As N_2O emissions can vary significantly due to on-farm management and environmental conditions, generalised emission factors (EF) are often used to estimate the amounts emitted.

We also use the term ‘tiers’ to describe the type and quality of data used to calculate emissions. Tiers are based on the system used by the International Panel for Climate Change. The Tier of data increases as the data improves, so Tier 1 is lower quality and Tier 3 is the highest quality.

The 2019 Intergovernmental Panel on Climate Change (IPCC) indicated a Tier 1 N_2O emission factor (EF) based on 1% N fertiliser use. This EF indicated that for each 100 kilograms of N fertiliser, one kilogram of N is released as N_2O. This assumes a direct and linear relationship between N fertiliser use and N_2O emissions.

In collaboration with the fertiliser industry and farmer organisations, federal and state agencies have undertaken field research across industries since 2003 to develop Tier 2 and Tier 3 EF values and strategies to mitigate emissions.

The Cooperative Research Centre for Greenhouse Gas Accounting (1999-2006), Nitrous Oxide Research Program (NORP, 2009-12), the National Agricultural Nitrous Oxide Research Program (NANORP, 2012- 16), the National Adaptation and Mitigation Initiative (NAMI, 2009-12) and outputs from multiple projects funded through the Action on the Ground Program (2012- 16) have all provided a public, high-quality data set to support agriculture across all industries and regions.

The most recent summary of this research has drawn the following conclusions:

- An average EF for all N sources was 0.57%.
- EF ranged from 0.17% (non-irrigated pastures) to 1.77% (sugar cane).
- EF were independent of topsoil organic carbon content, soil bulk density and pH but increased with rainfall for every 100 mm over 300 mm.

Estimating Scope 3 emissions for N fertiliser

Significant GHG emissions are embedded in the production of N fertilisers, although the amount varies depending on the place of manufacture and the different N sources. For example, when urea fertiliser was produced in Australia, it had a GHG 'cost' of 3.3 t CO_2e per tonne N, while urea produced in China, using coal-derived energy, has twice this GHG 'cost'.

NH_3 is the basic building block for most N fertilisers. Haber-Bosch is the industrial process of forming ammonia. It directly combines N from the air with hydrogen, under high pressure and temperature.

While producing NH_3 with a low or no carbon footprint is technically feasible, the financial cost for this process is currently greater than the Haber Bosch process, which uses energy from fossil fuels such as natural gas.

There is significant global interest and investment in decarbonising N fertiliser production using green energy, new production technologies and carbon capture and storage initiatives (Green Ammonia). The International Fertilizer Association estimates that the production of Green Ammonia could total almost 80 Mt by 2028.

In Australia, there is also interest in producing Green Ammonia, however, most of the proposed projects target exporting NH_3 as an energy source. Several of these projects have received evaluation funding from the Australian Renewable Energy Agency (ARENA).

As Australia is currently highly reliant on importing N fertilisers, sourcing N fertilisers with a low carbon footprint would reduce Scope 3 emissions for agriculture.

Using Australia's clean energy sources to produce Green Ammonia would be a better method of reducing Scope 3 emissions.

However, N fertiliser with a low carbon footprint will likely carry a price premium.

Nitrogen use in Australia - types, sources, regional and industry use patterns.

I. Types and sources of N for agriculture

- In general, Australian agriculture is based on extensive (Broadacre) rather than intensive land use.
- Most Australian agricultural production comes from approximately 66 million hectares, which have generally low N inputs.
- Rainfed crops are the primary users of N fertiliser.
- Urea is the most common N source, comprising 68% of the N applied nationally.

II. N fertiliser use by the agricultural industry

- The grains industry uses around 60% of national N fertiliser annually, while other industry sectors use less than 10% each.
- Both the prices paid for fertilisers and prices received for produce in Australia, are determined by global prices.

III. Efficient and effective N use on Australian farms.

- Fertiliser use, in agriculture, is an economic decision by growers in the light of seasonal risk and input price and commodity prices.
- Those decisions vary among industries based on the likely yield responses to supplied N fertiliser and the environments where those industries operate.

IV. Australian N fertiliser use in the global context

- By global standards, N use in Australia is low.
- Both the rate used and any surplus of removal overuse are small, so nutrients are generally used effectively.

Total N fertiliser consumption by country & industry

Australia uses less than 1.5% of the total elemental fertiliser N consumed globally and is ranked the 17 largest consumer out of 117 countries reporting N use.

The largest consumers are China (21%), USA (18%) and India (11%), with the top 20 countries consuming 82% of all N fertiliser.

Over 50% of the fertiliser N applied globally is urea. This is a result of its cost, ease of transport and application.

In Australia, around 70% of the N is supplied as urea, with another 12% applied as ammoniated phosphates (MAP and DAP).

Nitrogen-UE and NBI-N for selected cereal production systems

By global standards, Australian farmers are modest users of N fertiliser. This is mainly driven by seasonal conditions, with little market distortion by commodity support or subsidy schemes.

As a result, there are sizeable annual variations in N use and therefore NUE. Single-year data on crop NUE and PFP does not account for the rotational systems in which Australian crops are grown. More complex calculations are required when animals are involved in the production system, as estimates of manure nutrient recycling and pasture N cycling are likely important in these systems.

Table 1 is a summary of the comparative N use and performance indicators (NUE, PFP-N and NBI) for cereal production for the 20 major N fertiliser users, for the year 2018 (which is the audit period for the IFA Fertiliser-Use-By-Crop data).

While the data in Table 1 has several assumptions embedded in it, a comparison across countries shows that Australia, with low yield and low fertiliser input, still manages a good return on N (PFP), although the nutrient balance indicates efficiencies that can be made.

The fate of the modest surplus of 6 kg N/ha per year is not able to be assessed from these types of evaluation. While it may contribute to N pollution, equally, that surplus may also be carried over from year to year, either as mineral N or sequestered into organic matter.

Country	Cereal Area (kha)	Cereal Prod'n (kt)	Mean Cereal Yield (t/ha)	N Applied (kg N/ha)	NUE (kg grain N/kg N%)	PFP-N (kg grain/ kg N)	NBI (kg N/ha)
Argentina	15,111	70,591	4.67	63	116	74	-10
Australia	16,633	33,861	2.04	38	83	53	6
Bangladesh	12,275	58,812	4.79	91	83	53	16
Brazil	21,483	103,260	4.81	70	107	68	-5
Canada	15,002	58,727	3.91	98	63	40	37
China	99,932	612,122	6.13	170	57	36	74
Egypt	2,592	17,564	6.78	283	38	24	177
EU27	52,324	273,885	5.23	118	69	44	36
India	98,094	321,556	3.28	118	43	28	67
Indonesia	17,058	89,454	5.24	97	85	54	15
Iran	9,081	18,651	2.05	105	31	19	73
Mexico	9,426	36,068	3.83	104	58	37	44
Pakistan	13,736	39,658	2.89	150	30	19	105
Russia	41,989	109,839	2.62	34	119	76	-7
Thailand	12,016	37,867	3.15	83	59	38	34
Türkiye	10,871	34,396	3.16	88	57	36	38
Ukraine	14,258	69,112	4.85	67	114	72	-9
United Kingdom	3,106	21,084	6.79	166	64	41	59
United States	53,646	439,708	8.2	144	90	57	15
Vietnam	8,605	48,924	5.69	133	0.67	43	43

Table 1
Cereal area and mean cereal yield, mean N fertiliser application rate, and the performance indicators of Nitrogen Use Efficiency (also referred to as Partial Nutrient Balance kg nutrient removed/kg nutrient applied), Partial Factor Productivity (PFP-N t yield/kg nutrient applied), and Nutrient Balance Intensity (NBI-N kg N/ha). The Partial Nutrient Balance is based on a weighted cereal grain N content of 1.58% (as is basis). Data is for the audit period 2018, and for the twenty largest N users. Data derived from the FAO CropStat database and fertiliser use from IFA Fertiliser-Use-By-Crop dataset.

Recommendations

Our recommendations incorporate technological advancements and practice change. None are stand-alone, and combining these recommendations is important to achieving our emissions reduction goal.

Consider policies encouraging the widespread use of nitrification inhibitors to improve NUE and reduce N_2O emissions.

Formally assess the effectiveness and risks of N inhibitors and slow-release technologies.

Encourage greater adoption of objective tools like N budgets, soil and plant testing, which follows Fertcare® stewardship principles, to guide fertiliser use.

Encourage greater adoption of precision agriculture tools that assist in spatially and temporally targeting inputs where and when they are most needed.

Incentivise the Australian manufacture of N fertilisers with a low carbon footprint and N inhibitors.

Engagement of industry bodies, research organisations and state and federal governments in sharing of data on inputs, NUE and N_2O emissions.

Avoidance of free market disruption with taxes, levies or quotas on N fertilisers.

Encourage widespread use of N inhibitors and slow-release technologies with assistance from government policy and support.

Scientific advancements will continue to play a vital role in developing solutions and options for reducing N losses. Some specific technologies, such as nitrification inhibitors, have proven effective at improving NUE and reducing N_2O emissions but at present, are typically not cost-effective for growers to implement.

It would be far more efficient and cost effective for government to engage in a pre-farm aggregation of N_2O abatement, whereby a limited number of fertiliser manufacturers engage directly with the government to precoat fertiliser products like urea, at an agreed price per tonne.

This payment would then be passed onto growers in the form of a reduced price for treated N fertiliser. Therefore, adoption by the farming community would be increased significantly, as the product would be sold at a similar unit cost as standard urea, depending on the value of the N_2O abatement payment.

We also understand from Fertilizer Australia that their members are not looking for a profitability outcome from this mechanism, just the credential of supplying a more benign form of fertiliser (reduced N_2O emissions associated with the end use of fertiliser) but at no loss of profitability to their core business.

We recommend that the Minister for Climate Change and Energy work with Fertilizer Australia and its members to develop this pre-farm treated fertiliser aggregation payment to reduce emissions from N fertiliser use on Australian farms.

Formally assess the effectiveness and risks associated with inhibitors and slow-release technologies before widespread use.

The Australian Industrial Chemicals Introduction Scheme (AICIS) assesses the risks of importing or manufacturing (introducing) industrial chemicals and promoting their safe use.

Not all the inhibitor products currently available on the Australian market are listed in the AICIS inventory.

Agricultural chemicals that claim to control weeds, pests and diseases must be reviewed by the Agricultural Pesticides and Veterinary Medicines Authority (APVMA) before being released. Inhibitors and slow-release fertiliser products do not require regulatory approval for use on Australian agricultural land.

If there were to be widespread use of inhibitors and slow-release formulations, some formal review may be of value to consider issues such as:

- the level of effectiveness of a product to reduce N loss, e.g., N_2O emissions
- the operator's occupational health and safety issues associated with applying inhibitors (both the active ingredient and solvents/carriers) to fertiliser and the safety of those who apply treated fertiliser to soil
- plant safety to assess the potential for phytotoxicity
- consumer safety and international trade implications resulting from ingestion/use of food and fibre crops treated with inhibitors, slow-release formulations, and/or unintended consequences resulting from widespread use of these products. For example, the hygiene of common bulk transport and handling equipment for food, e.g. grain and treated fertiliser
- implications of widespread use of inhibitors and slow-release fertilisers on soil microbial health
- risks to the broader environment, e.g. the water quality of deep drainage or surface water runoff from treated fields.

New Zealand is introducing an agricultural use registration process for inhibitors, including establishing maximum residue limits for agricultural produce under the Codex Alimentarius Commission (CAC). The CAC is the central part of the Joint FAO/WHO Food Standards Programme and was established by FAO and WHO to protect consumer health and promote fair practices in food trade. Australia could consider a similar approach.

Encourage greater adoption of objective measures like N budgets, soil and plant testing to guide nutrient inputs.

Through the Fertcare® stewardship program, the fertiliser industry endorses objective measures such as N budgets, soil and plant testing and appropriate analysis and interpretation methods to provide evidence-based, site-specific nutrient management recommendations. This is based on meeting crop nutrient demand from existing soil nutrient availability, supplemented where necessary by applied fertiliser and other nutrient sources, e.g. animal manures or compost. Minimising N surplus to crop requirements will significantly reduce the potential for offsite nutrient impacts such as NO_3^- and emissions.

There is a need for greater use of soil and plant testing by growers to guide nutrient inputs. Whilst many factors contribute to crop and pasture responses to nutrient inputs, soil and plant tests have proven to help guide nutrient inputs.

Policies encouraging greater grower adoption of soil and plant testing as the basis for nutrient inputs should be considered.

Encourage greater adoption of precision agriculture tools.

Minimising N surplus to crop requirements at a sub-paddock scale will help optimise farmers' financial return on nutrient inputs and reduce the potential for off-site impacts.

Variable-rate fertiliser application technologies have been available for some time, though adoption is generally low. However, the ability to gather and interpret agronomic and economic data and spatially apply varying rates of inputs, such as fertiliser, is challenging for many growers. Others with specialist skills are often needed to implement precision agriculture pragmatically.

Policies that make precision agriculture knowledge and skills more widely available and demonstrate the benefits to growers should be considered.

Incentivise the Australian manufacture of N fertiliser with a low carbon footprint and N inhibitors.

The production of "green" NH_3, as a feedstock to N fertiliser manufacture, is an evolving technology. Using renewable energy sources in manufacturing can reduce N fertilisers' Scope 3 carbon cost.

Fertiliser businesses are yet to see any material demand from farmers for low- carbon fertiliser footprint, including the price premium reflecting the increased cost of manufacture. Since this impedes the development of "green" NH_3 projects for fertiliser use, the government may need to consider adjusting policy settings to stimulate this development.

N inhibitors and their ingredients are largely imported, which may lead to supply chain insecurity. Policy settings which support local manufacture of inhibitors to secure supply of existing and emerging inhibitors that are under development in Australia should be considered.

Compared to other parts of the world, Australian manufacturing is commonly expensive. Government policy settings which support development of Australian manufacturing employing new technologies which result in low-carbon N fertilisers should be considered.

Encourage greater levels of data sharing:

The research effort in developing N best management practices will need to continue as farming systems evolve and new technologies are available. The various commodity research and development corporations and the fertiliser industry hold high-quality data on fertiliser use and management practices. The ongoing high-quality research undertaken across industries provides more complete estimates of N_2O emissions, which will affect the Australia Greenhouse Gas inventory. There would appear to be an opportunity for more active data sharing among these groups on N use and N_2O emissions. This will better quantify N budgets, and N use efficiencies across applications and scales.

Avoidance of free market disruption with taxes, levies or quotas on N fertilisers

A suite of national policy approaches can support continued improvement in N management. Australian agriculture is fully exposed to the global market when purchasing inputs and marketing produce. A recent ABARE report notes that agricultural support interventions such as direct restrictions, tariffs, taxes and levies can influence production decisions, farming practices and the use of inputs such as fertilisers by changing the relative costs and returns of using resources in agriculture.

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