1st China–Australia Symposium on Crop Stress & Climate Adaptation, 10–15 March 2026, Launceston, Australia

Manage Reactive Nitrogen for Sustainable Food Production and Environment

Deli Chen (AO, FAA)

Redmond Barry Distinguished Professor

Leader, Soil and Environment Research

Director, ARC Research Hub for Smart fertilizers

The University of Melbourne and China Agricultural University

ARC Research Hub for Smart Fertilisers

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The University of Melbourne

Established in 1853, Rank #14-37 in the World

A large and productive research team in UoM
(50-60 people, 3 highly Clarivate™ cited researchers)

- Fundamental soil C, ***Nitrogen*** and P cycling (molecular to field/catchment to national and global scale)
- Real-time and large-scale gaseous fluxes (CO_2, N_2O, CH_4, NH_3) in agro-ecosystems
- Novel fertilisers ARC Research Hub
- Recycle and reuse agricultural waste
- Modelling, data analytics and decisions support systems

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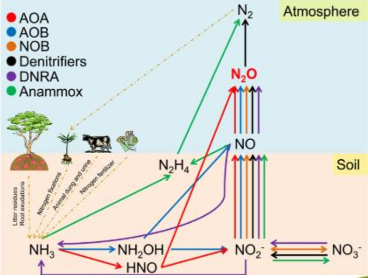
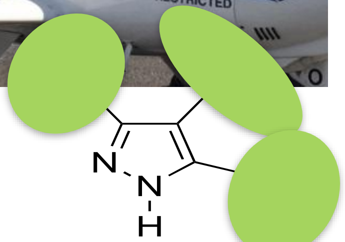
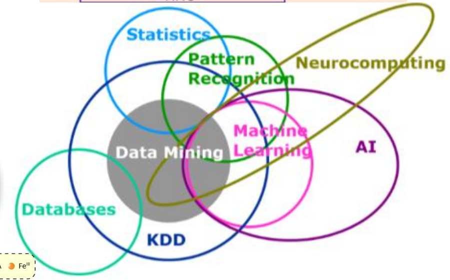
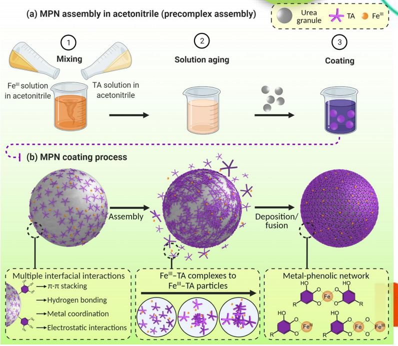
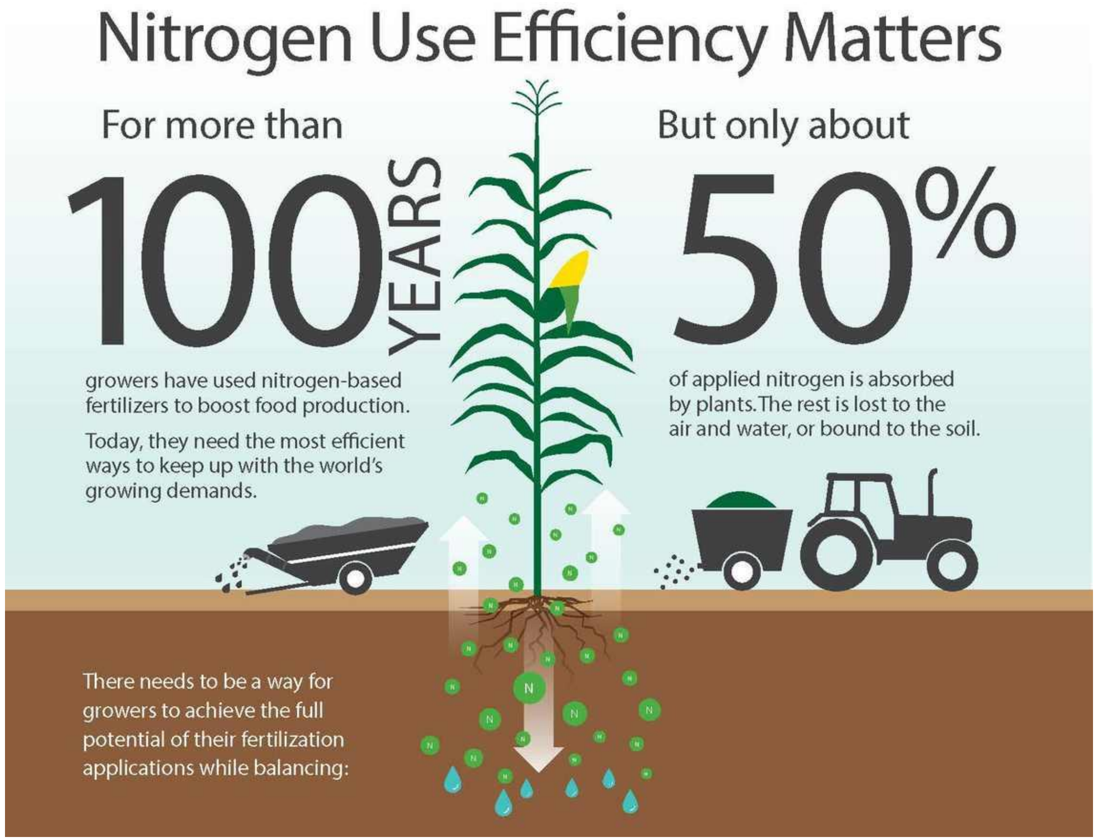




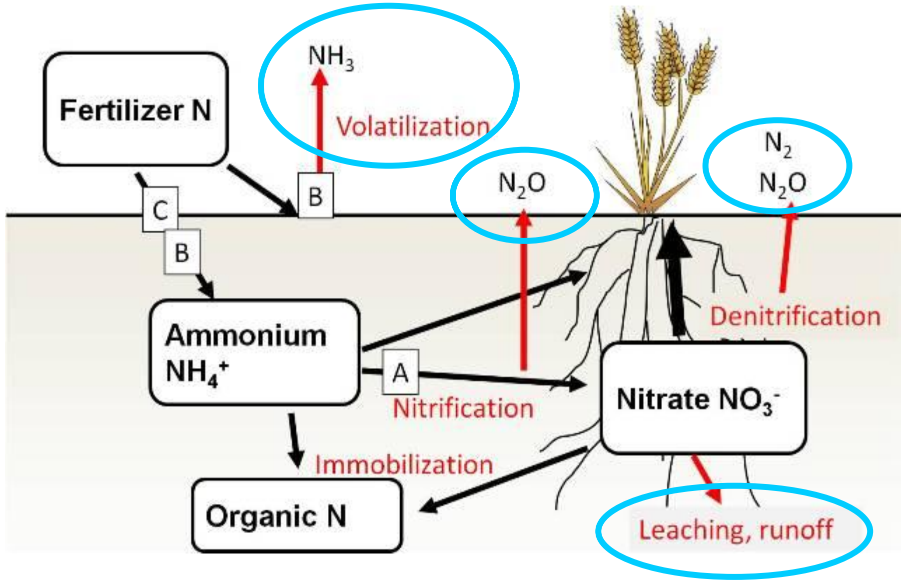




Low N use efficiency

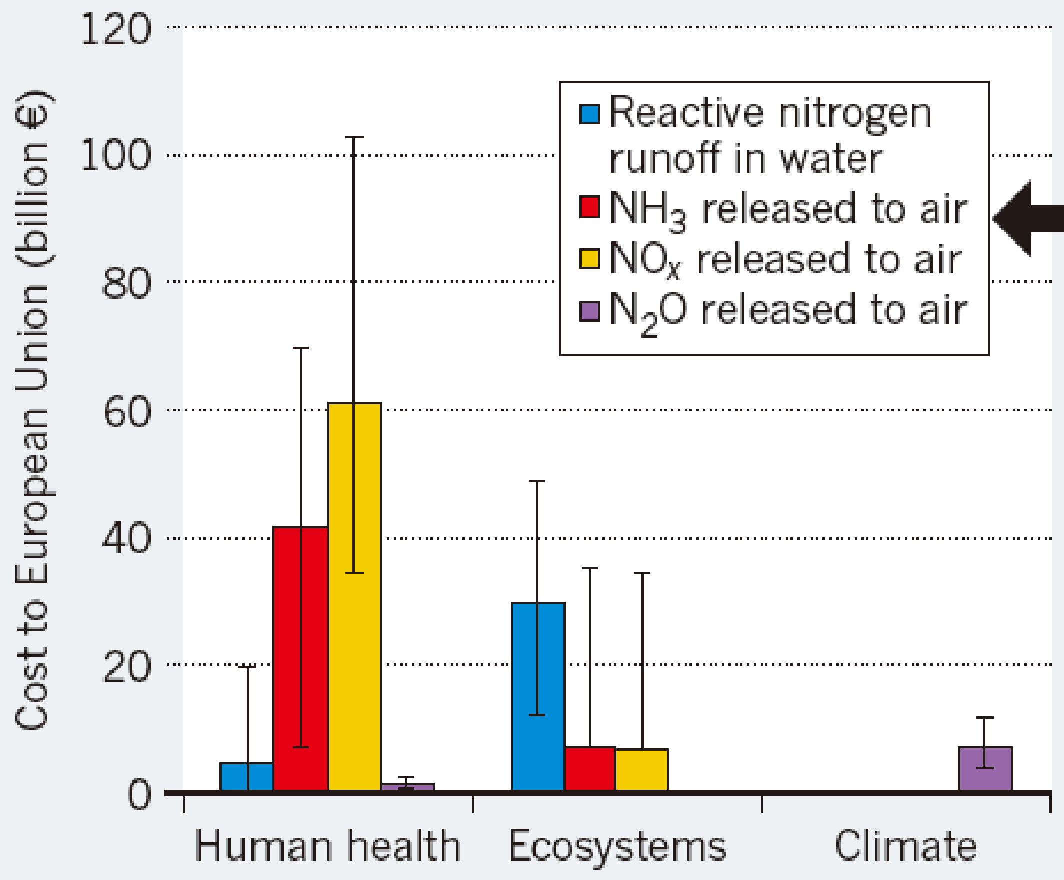


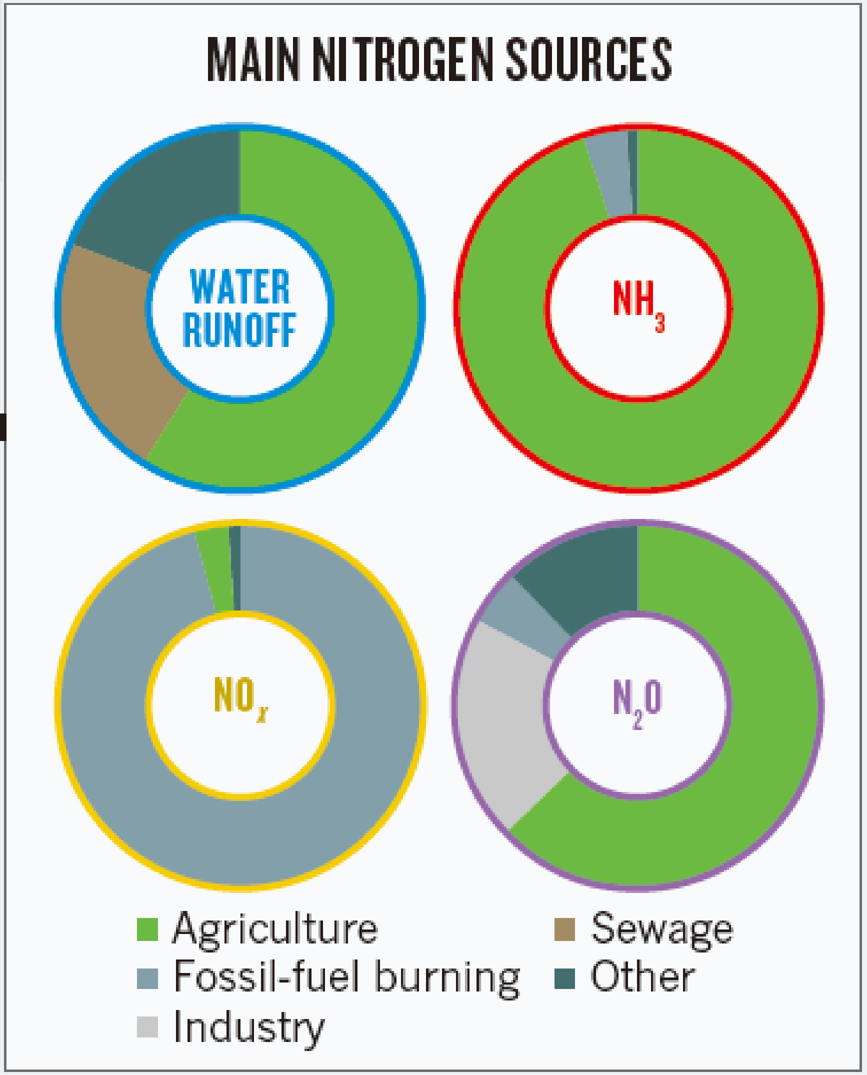
- 2% world energy
- >$200b/year
- Societal cost is a magnitude higher



Enormous damage costs of N pollution

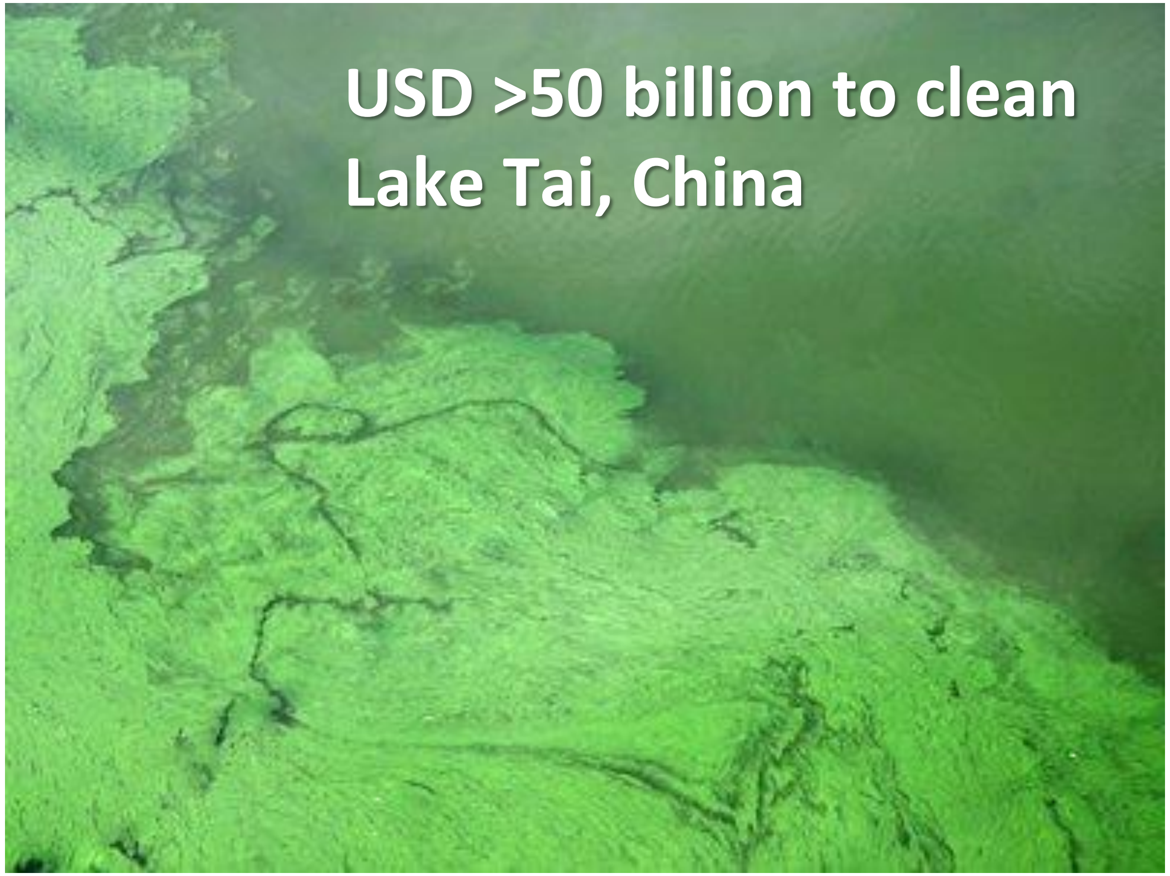
€70b to € 320b (per year) in EU

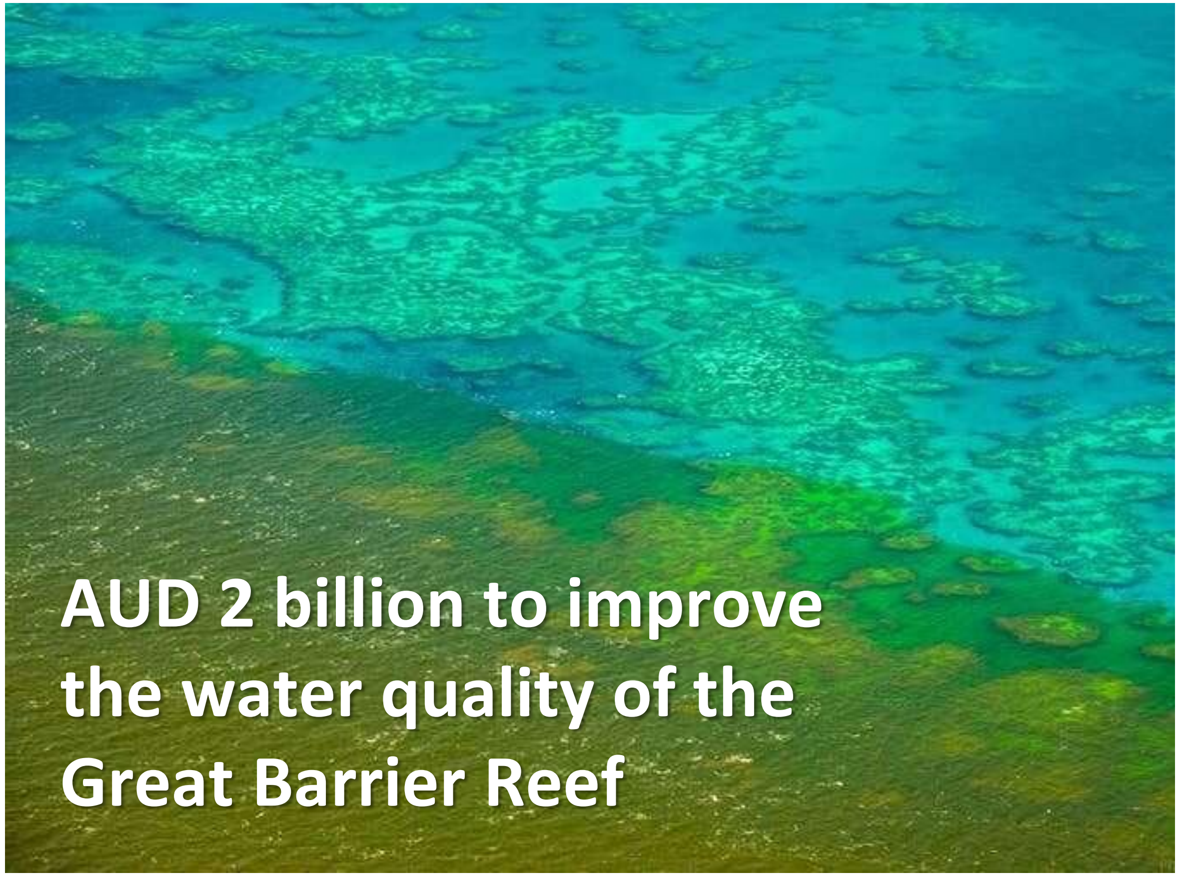




Sutton et al. 2011

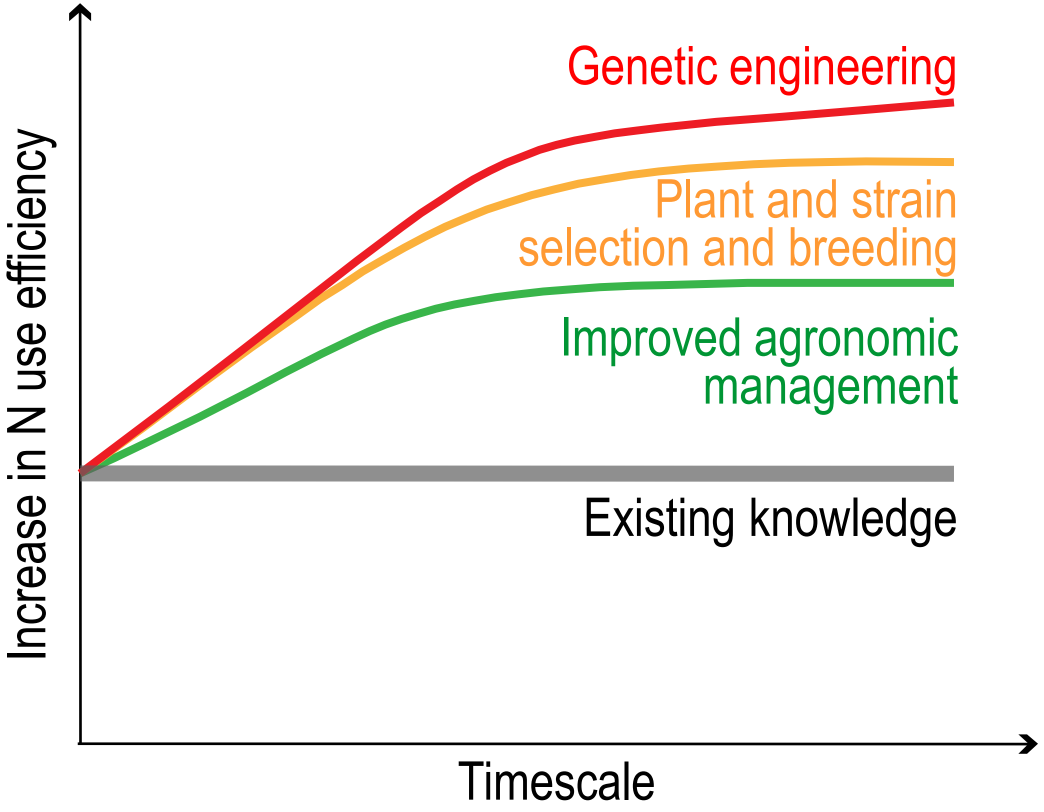
Cost on prevention is much lower than remediation





Improving N en use efficiency: where will progress come from?

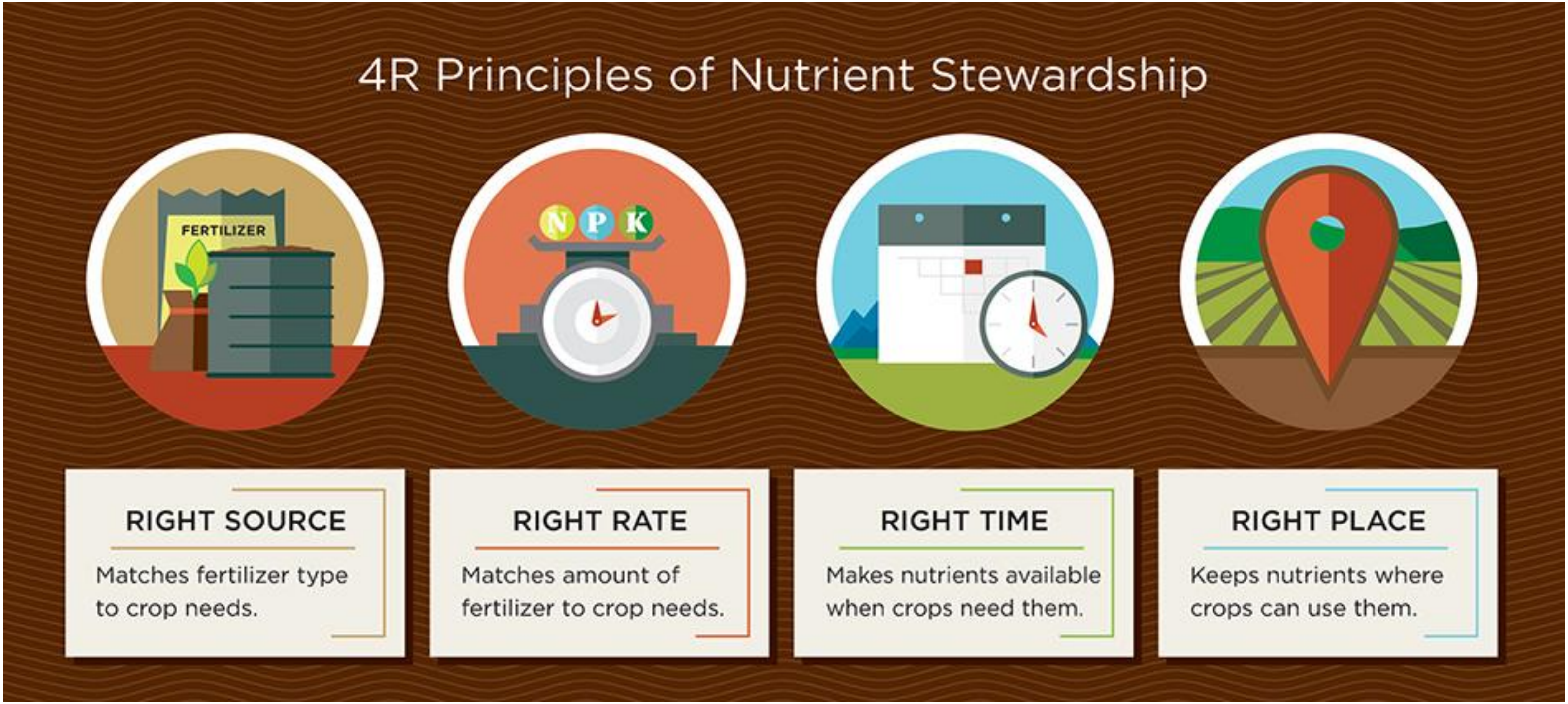
Biotech vs Agronomy



- In the short and medium term, most of the gain in nitrogen use efficiency is expected to come from improved agronomic practices
- Biotechnology is seen contributing only in the long term, and relatively modestly (less than 'conventional' breeding)

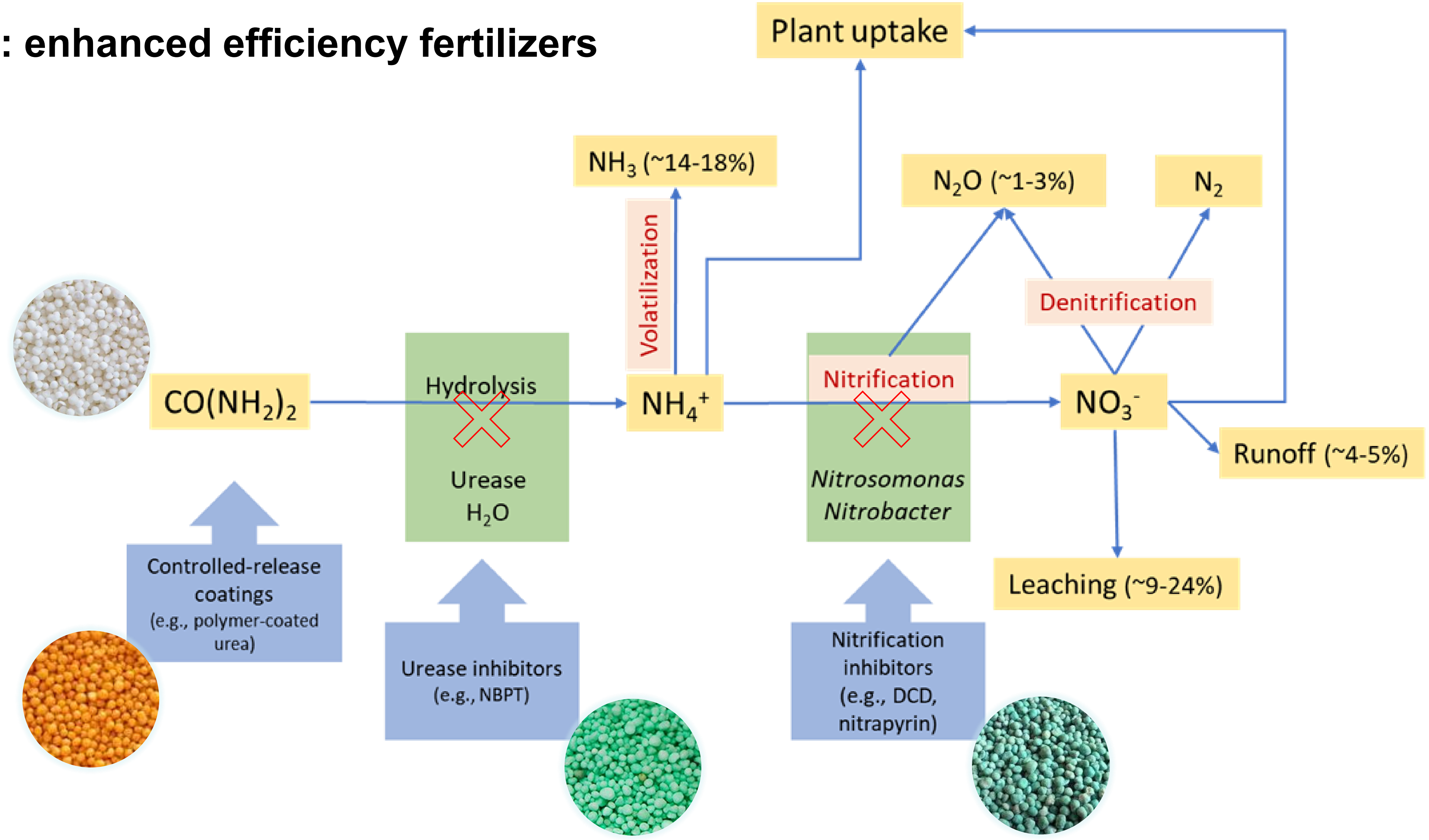
| Source: Giller *et al.*, 2004

Fertilizer management



Use of EEFs to reduce N losses

EEFs: enhanced efficiency fertilizers



ARC (Industrial Transformation) Research Hub for Smart Fertilisers

(2021-2026, $17 million)

Australian Government
Australian Research Council

THE UNIVERSITY OF MELBOURNE

LA TROBE UNIVERSITY

Incitec Pivot Fertilisers

Elders

Faculties of Veterinary and Agricultural Sciences,
Science, Engineering and IT

Improve efficiency of N use by up to 20%

ARC Research Hub for Smart Fertilisers

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Theme 1. Fertilisers with engineered coatings

Theme 2. Urease and nitrification inhibitors

Theme 3. Plant-soil microbiome interactions

Theme 4. Agronomic, environmental and social benefits

Theme 5. Maximising sector wide value

ARC Research Hub for Smart Fertilisers

Australian Government
Australian Research Council

nature food

PERSPECTIVE

https://doi.org/10.1038/s43016-022-00542-7

Check for updates

Next-generation enhanced-efficiency fertilizers for sustained food security

Shu Kee Lam[1,2], Uta Wille[2,3], Hang-Wei Hu[1,2], Frank Caruso[2,4], Kathryn Mumford[2,4], Xia Liang[1,2], Baobao Pan[1,2], Bill Malcolm[1,2], Ute Roessner[2,5,8], Helen Suter[1,2], Geoff Stevens[2,4], Charlie Walker[2,6], Caixian Tang[2,7], Ji-Zheng He[1,2] and Deli Chen[1,2] ✉

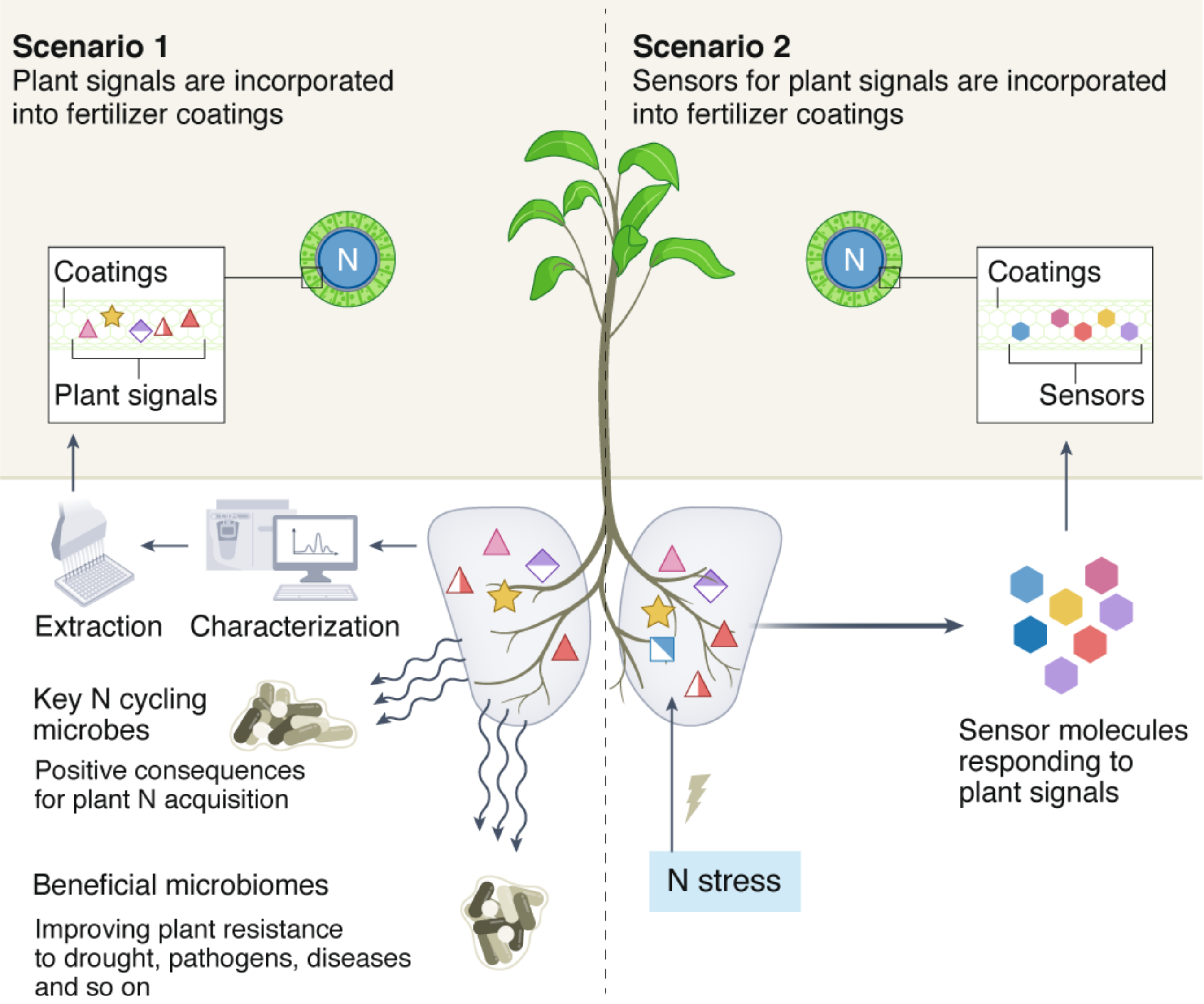
Plant-oriented fertilizer coatings

Scenario 1 (left)

- Include into coatings the plant signalling molecules that can recruit beneficial microbiomes to improve plant N acquisition and promote plant resistance to environmental stresses

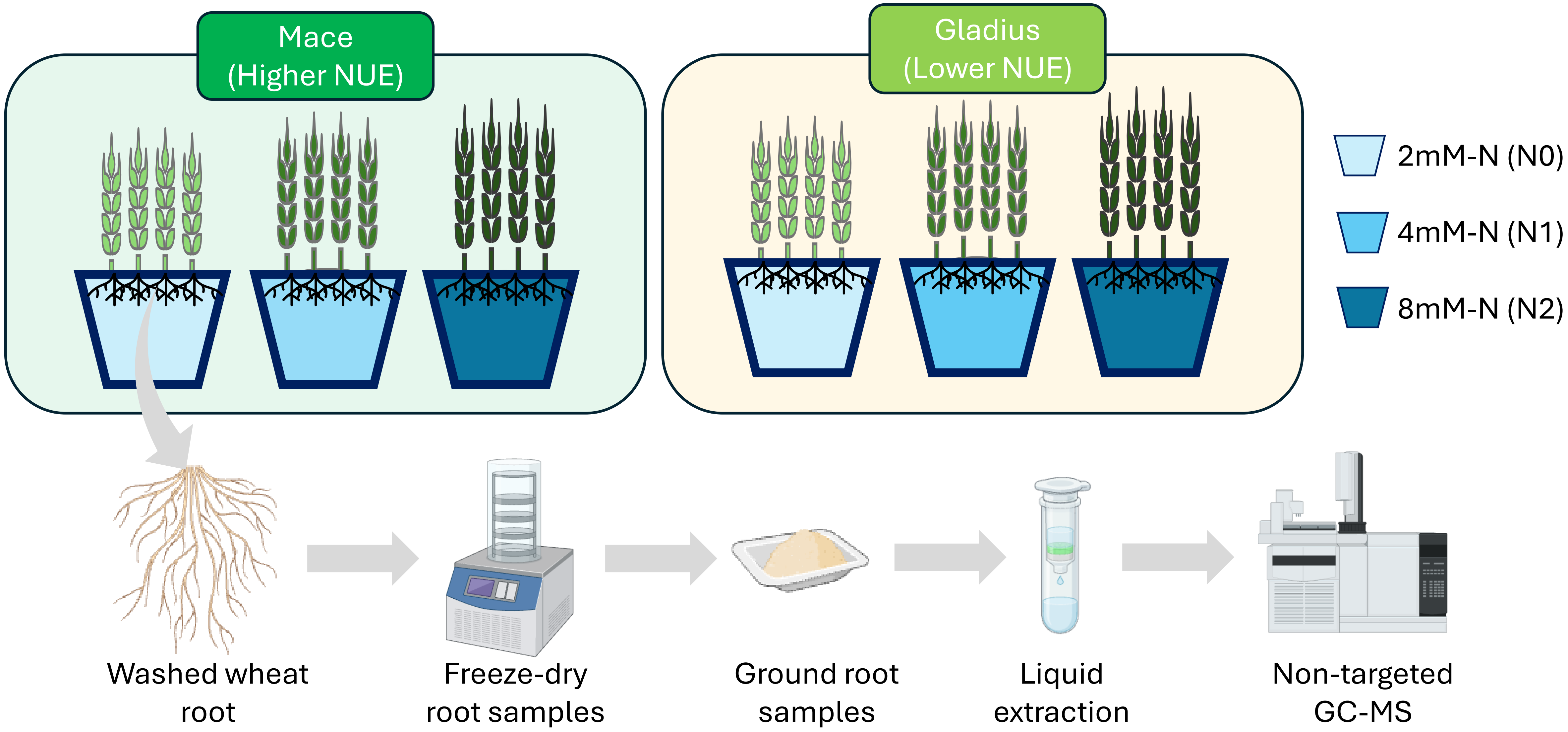
Scenario 2 (right)

- Coatings release fertilizers when exposed to signalling molecules that are produced by plants under N stress conditions



Lam et al. 2022, *Nature Food* 3: 575-580

Hydroponic experiment for root metabolite detection



Metabolite profile of wheat under different N availability

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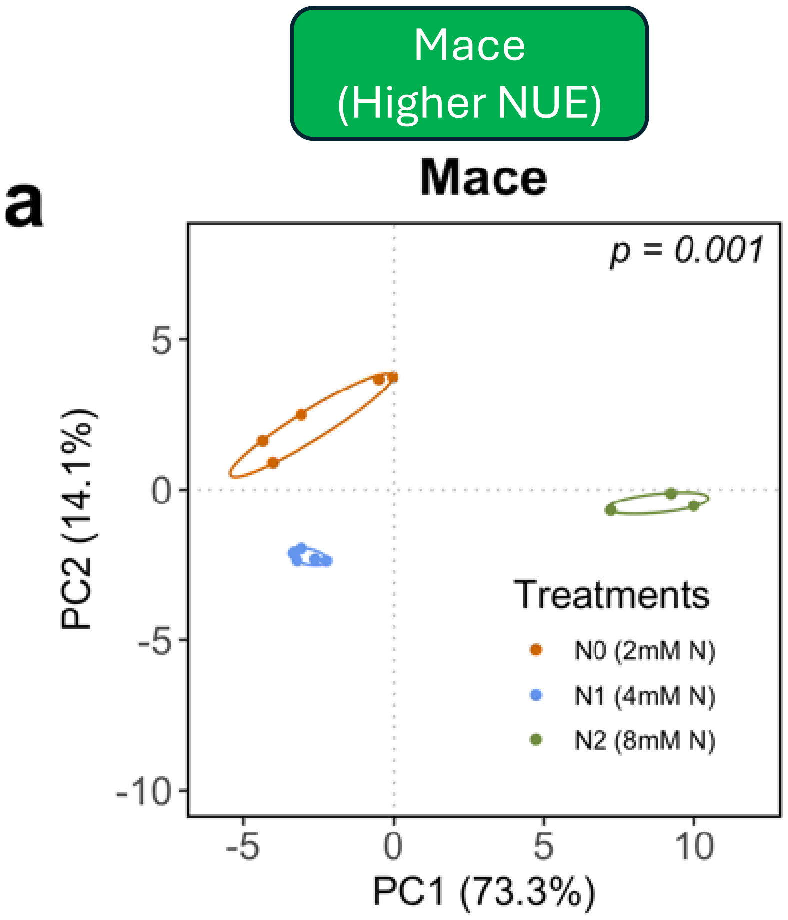
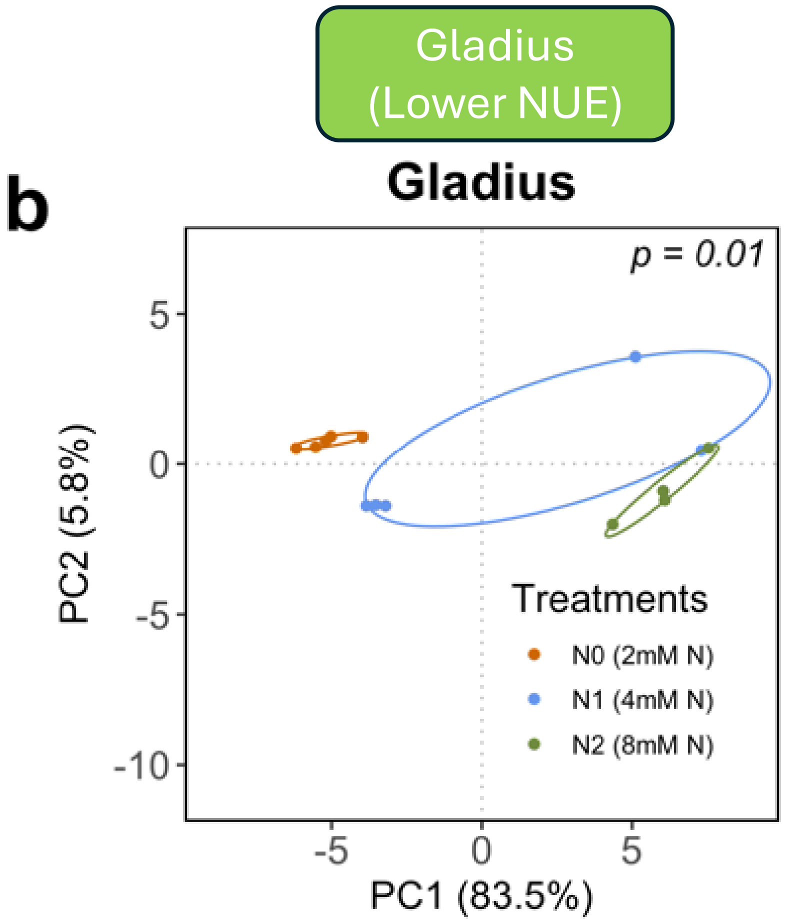
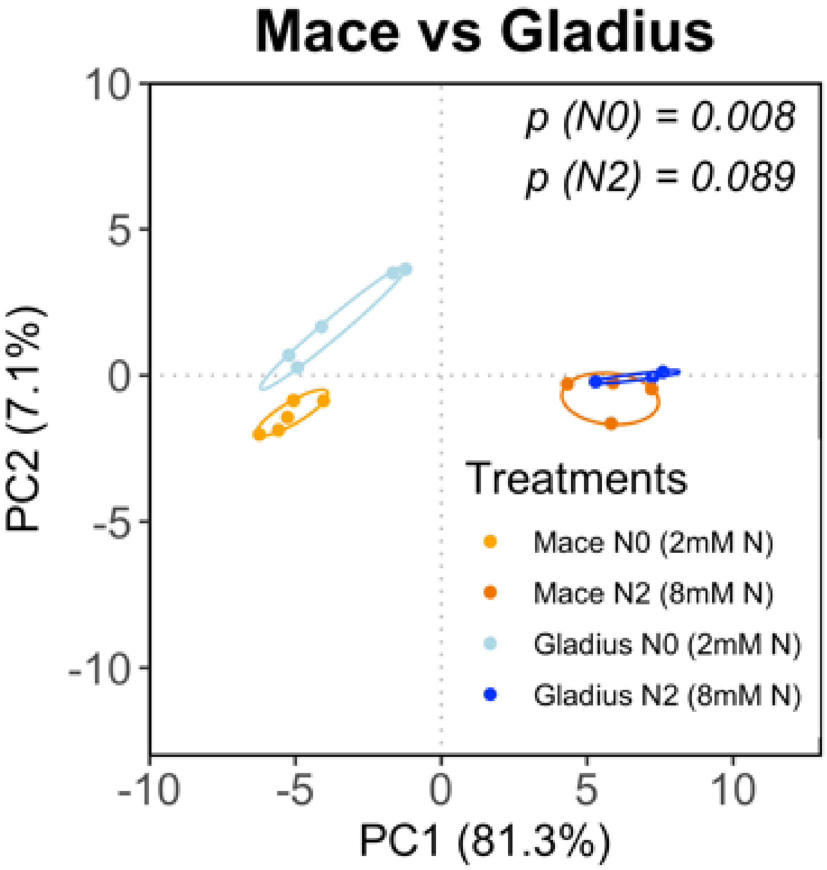




Chan et al. (2024) Cultivar-specific wheat-associated bacterial communities and metabolites in response to nitrogen deficiency. (Plant and Soil)

Stearic acid response in Mace under N deficiency



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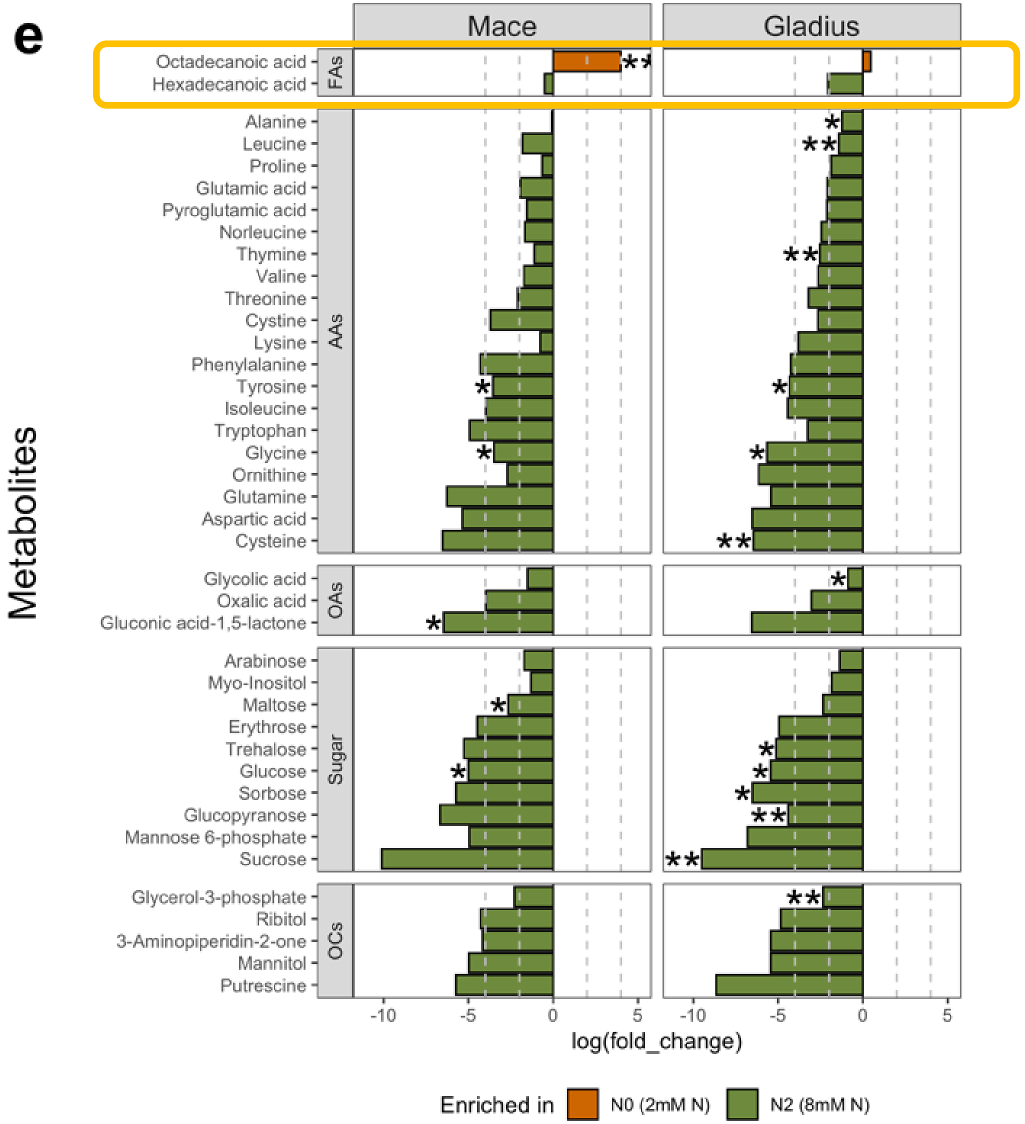
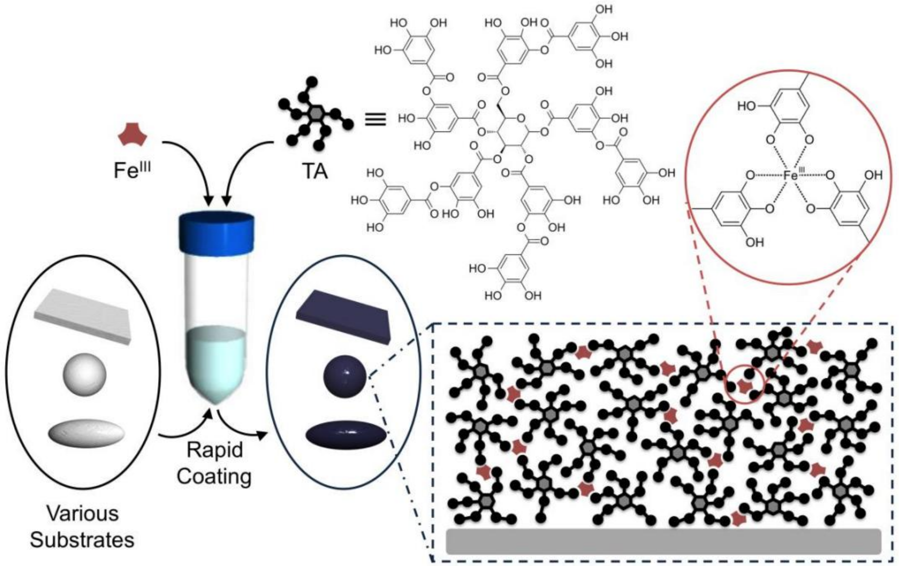
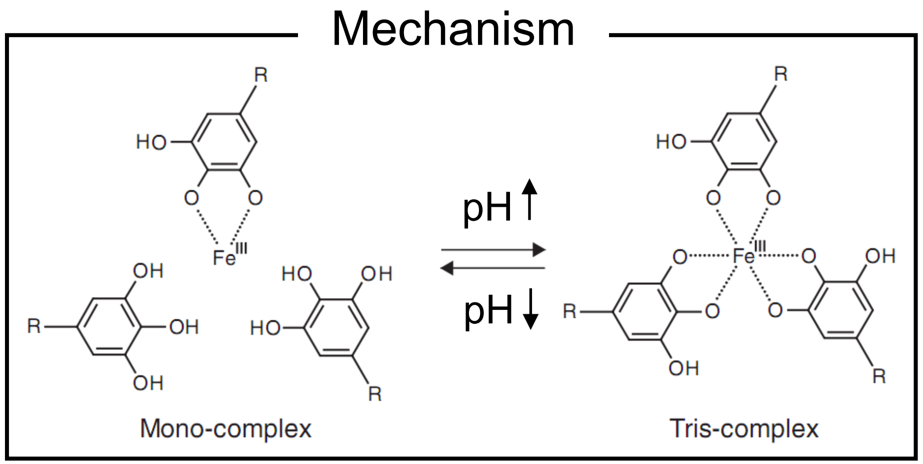


Chan et al. (2024) Cultivar-specific wheat-associated bacterial communities and metabolites in response to nitrogen deficiency. (Plant and Soil)

Metal-Phenolic Networks (MPNs)



Formation of a MPN - based on coordination between natural polyphenol (e.g. tannic acid, TA) and metal ions (e.g. Fe^{3+}) developed by the research team at the University of Melbourne. This team will bring exclusive expertise from the University to this project. Prof Frank Caruso is world-renowned and a key player in our project team

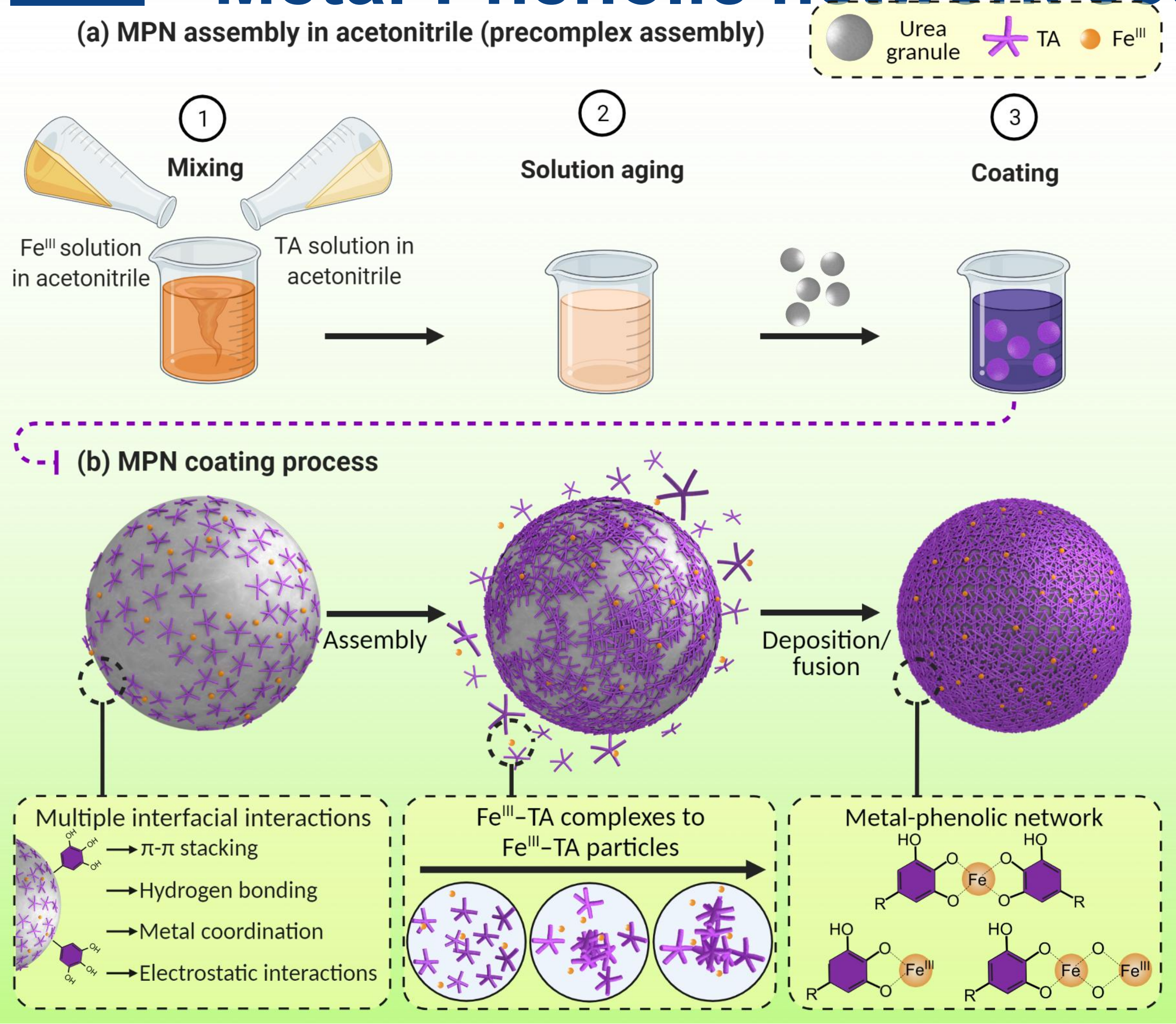


Ejima et al. *Science* **2013**, *341*, 154

Features

- *Metal-Phenolic Coordination*
- *pH-Dependent Disassembly*
- *Triggered Cargo Release*
- *Multifunctionalities*

Metal-Phenolic network coatings on urea granules



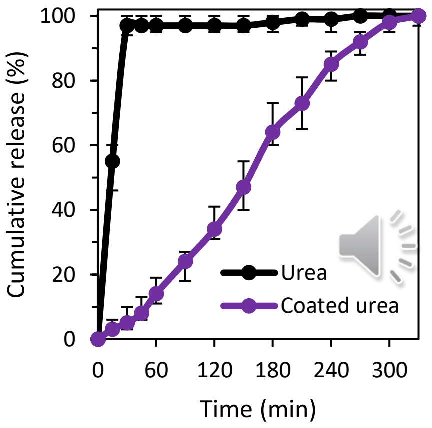
Urea granules

MPN coating

Coated Urea granule

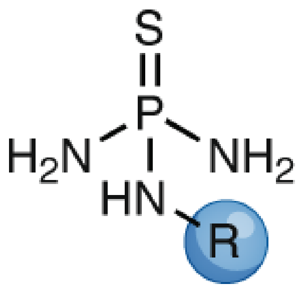
- ✓ Stimulus-responsiveness
- ✓ Fast processable
- ✓ Recyclable
- ✓ Self-healing

Urea release profile in water

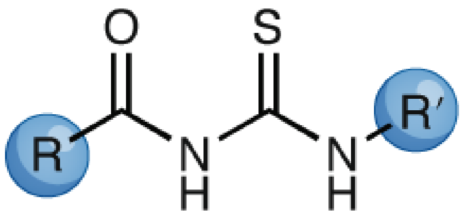


New design of urease and nitrification inhibitors

- Structural modifications of selected current urease and nitrification inhibitors to improve their efficiency under various agricultural settings.

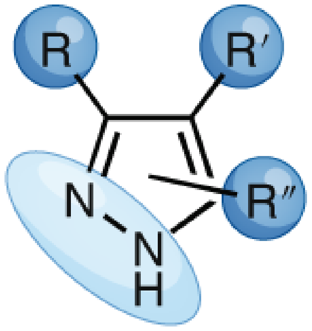


NBPT analogues



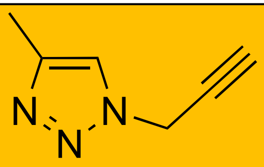
N,*N*′-disubstituted acylthioureas

Structural variations
- Cyclic/acyclic
- Heteroatoms
- Polarity



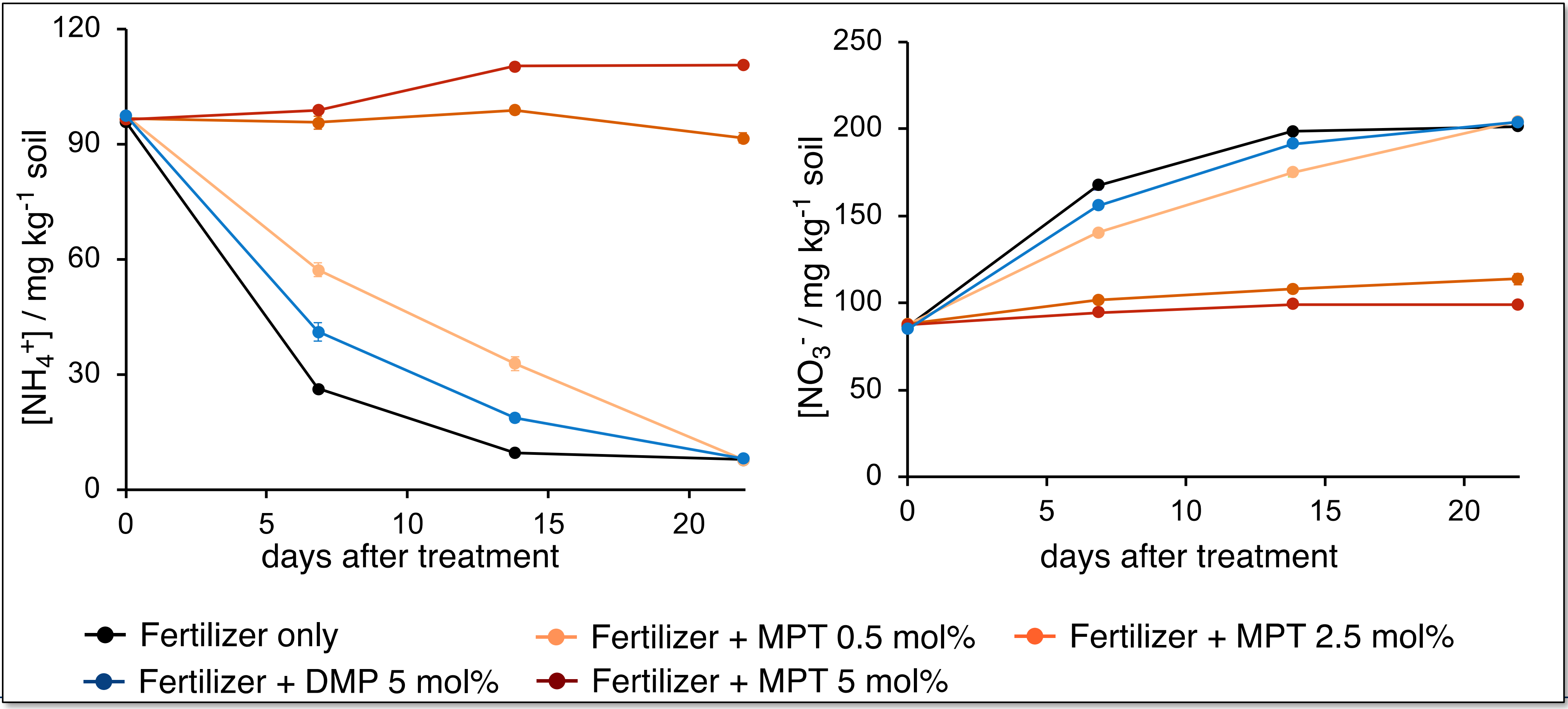
DMP analogues

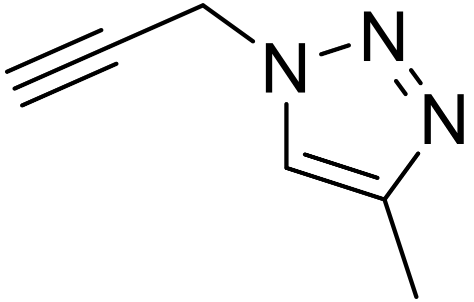
Soil Incubations (pH 5.9)



4-methyl-1-(prop-2-yn-1-yl)-*1H*-1,2,3-triazole
MPT

$$NH_3 \underset{}{\overset{H^+}{\rightleftharpoons}} NH_4^+ \xrightarrow{\textit{nitrosomonas}} NO_2^- \xrightarrow{\textit{nitrobacter}} NO_3^-$$





MPT

The best candidate for a new NI

- **MPT outperforms DMP** in suppressing NO_3^- formation and N_2O emission
- **MPT is far more stable than DMP** on urea granules
- **Dosage** for field application **still needs to be adjusted**

ARC Research Hub for
Smart Fertilisers

Price comparison

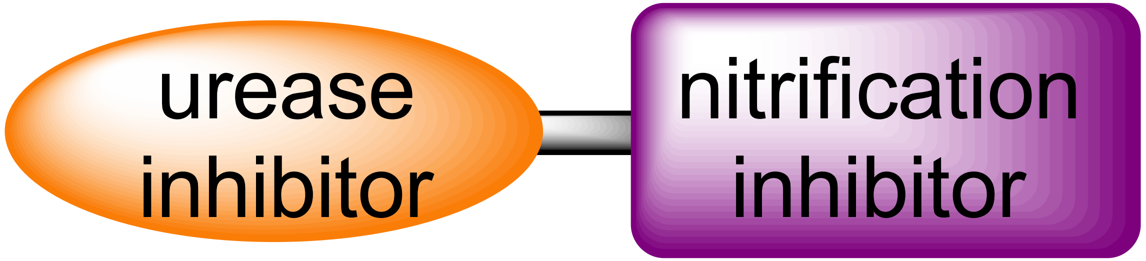
DMP	MPT
$13–20	$200–250

We should negotiate a better deal

Dual action inhibitor

Problem:
DMPP and NBPT cannot be used together, because acidity of DMPP promotes hydrolysis and inactivation of NBPT.

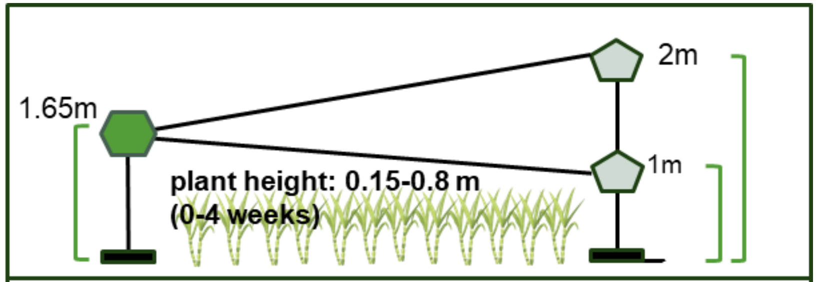
Strategy:
Developing a dual action inhibitor which controls both urea hydrolysis and nitrification.



First model systems have been synthesised and are currently being tested in soils.

Queensland sugarcane field trial (dual inhibitor)

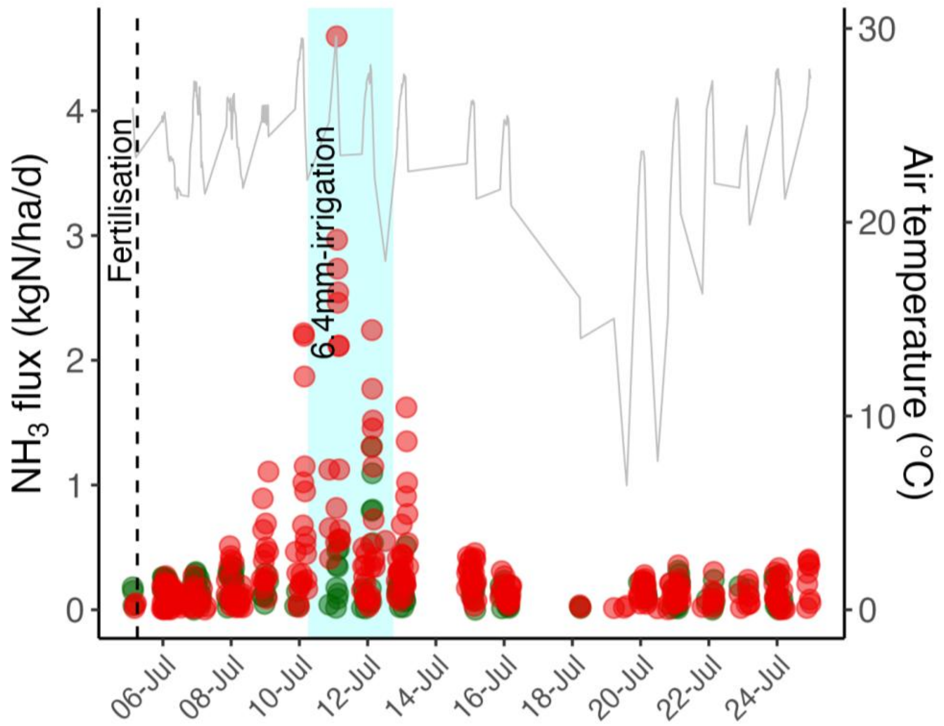
- Sugarcane, Clare, Qld (commenced in July 2024)
- Two treatments–urea (CK300) and dual inhibitor (DI)-coated urea; N rate: 200 kg N/ha
- FTIR measurement (NH_3 and N_2O)
- Sugarcane harvested in late June 2025



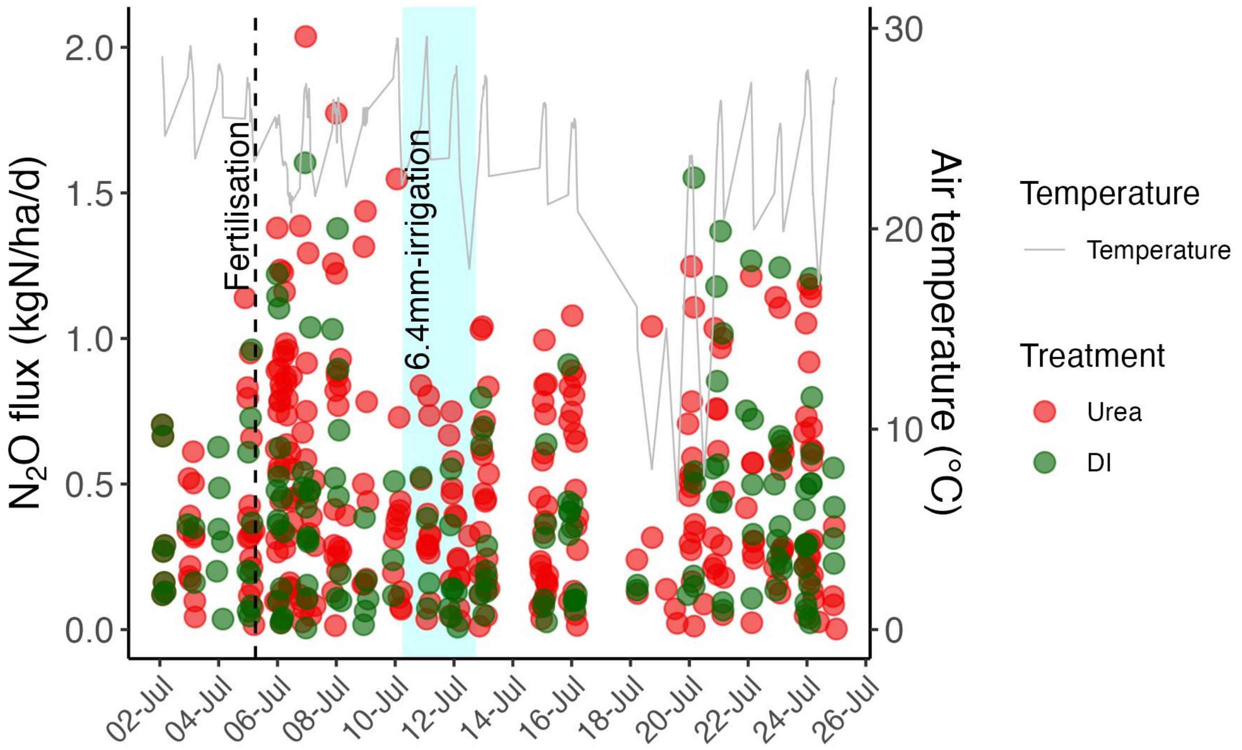
FTIR and mirror set-up position

OP-FTIR results

NH_3 volatilization

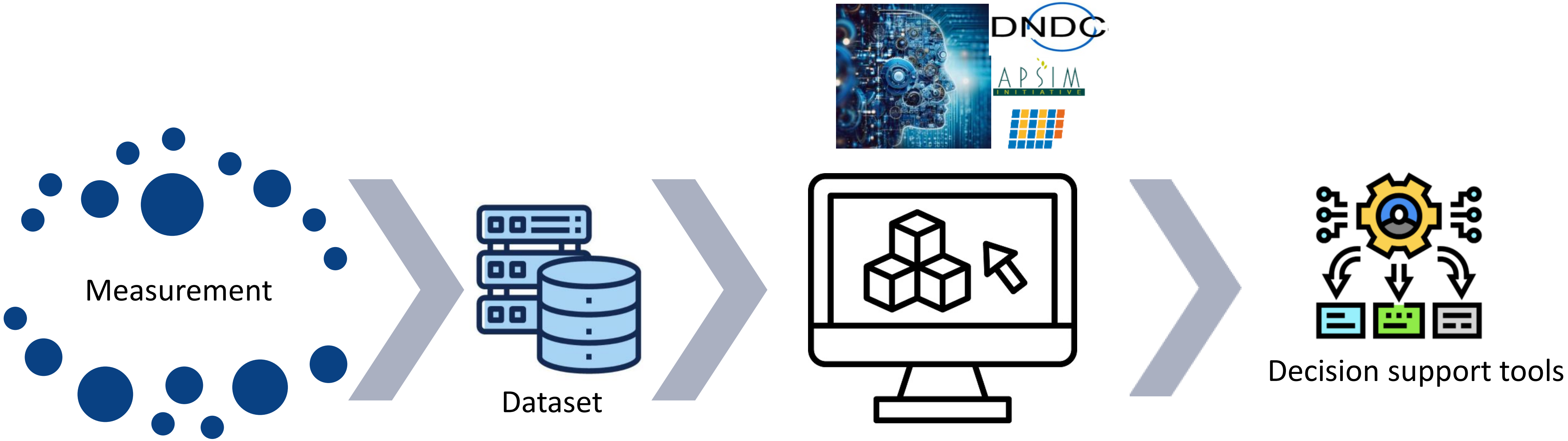


N_2O emission



Treatment	Cumulative NH_3 (kg N/ha)	Cumulative N_2O (kg N/ha)
Urea	5.4	8.0
DI	2.5	6.5
Reduction (%)	-54	-19

From data to decision



- Difficult to measure,
- costly,
- time-consuming,
- limited scales.

- Empirical model,
- Process-based models (APSIM, DNDC, WNMM, etc.),
- Scaling models (EF),
- Machine learning.

GIS-Based Agricultural Decision Support System

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Australian Government
Australian Centre for International Agricultural Research

Outcomes in The North China Plain

While maintaining/increasing crop production:

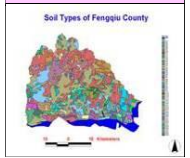
1. Up to 30% irrigation water saving
2. Up to 25% nitrogen fertiliser saving
3. Up to 70% less ammonia N losses
4. Up to 25% less N_2O (a greenhouse gas)
5. Up to 50% less nitrate leaching

Scenario Evaluation

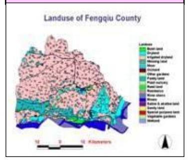
The outputs of various management scenarios are assessed against the set criteria, considering crop yield, water and fertiliser use efficiency, and environmental impacts

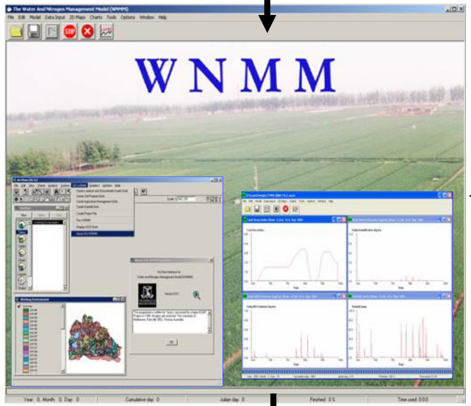
Climate

Soil



Landuse





Agricultural Survey

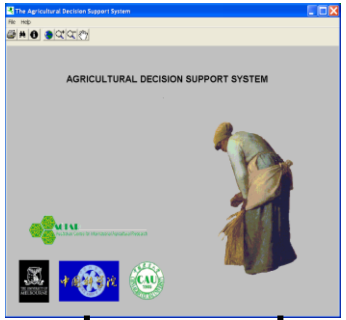
Information about agricultural management practices (soil, climate and land use)

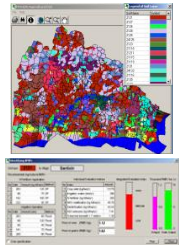
Agricultural Practices

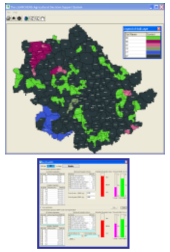
Crops
Crop harvest
N fertiliser application
Irrigation
Tillage

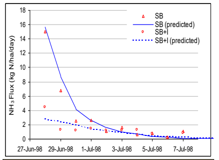
Scenario

Fertiliser (nitrogen) application and irrigation









Example: Reduced ammonia emission

Irrigating immediately after fertiliser application was predicted to reduce NH_3 loss, as confirmed through field measurements

Best Management Practices

For local agricultural extension officers and individual farmers

Crop/pasture

Crop yield
Above- and below-ground biomass

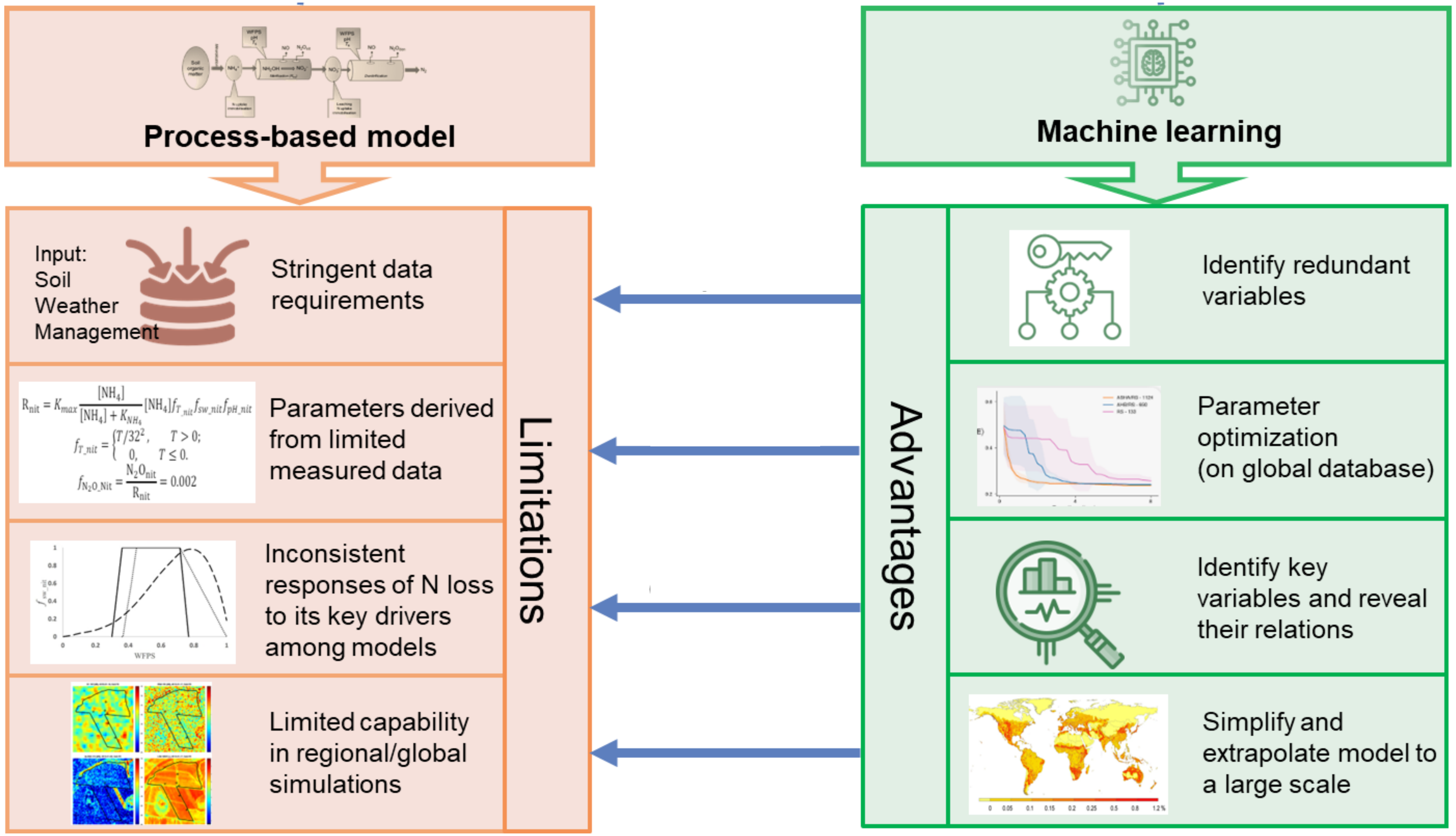
Water

Soil water content
Soil water flux
Soil drainage
Soil evaporation
Crop transpiration

Nutrients (N&P)

Soil mineral-N content
Ammonia volatilisation
Nitrous oxide emission
Nitrate leaching
Crop N uptake

Using ML to address limitations of process-based models

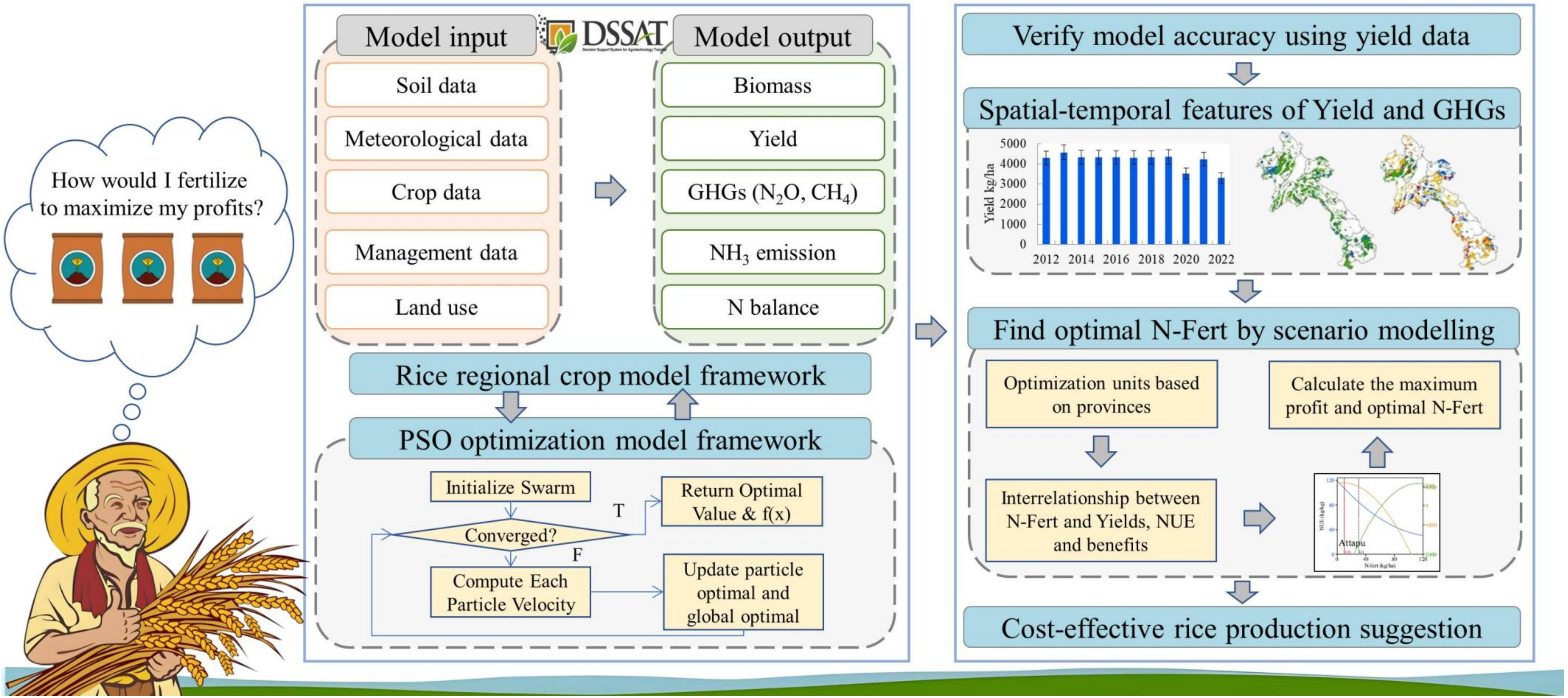


e.g. $f(T) = aT + b$

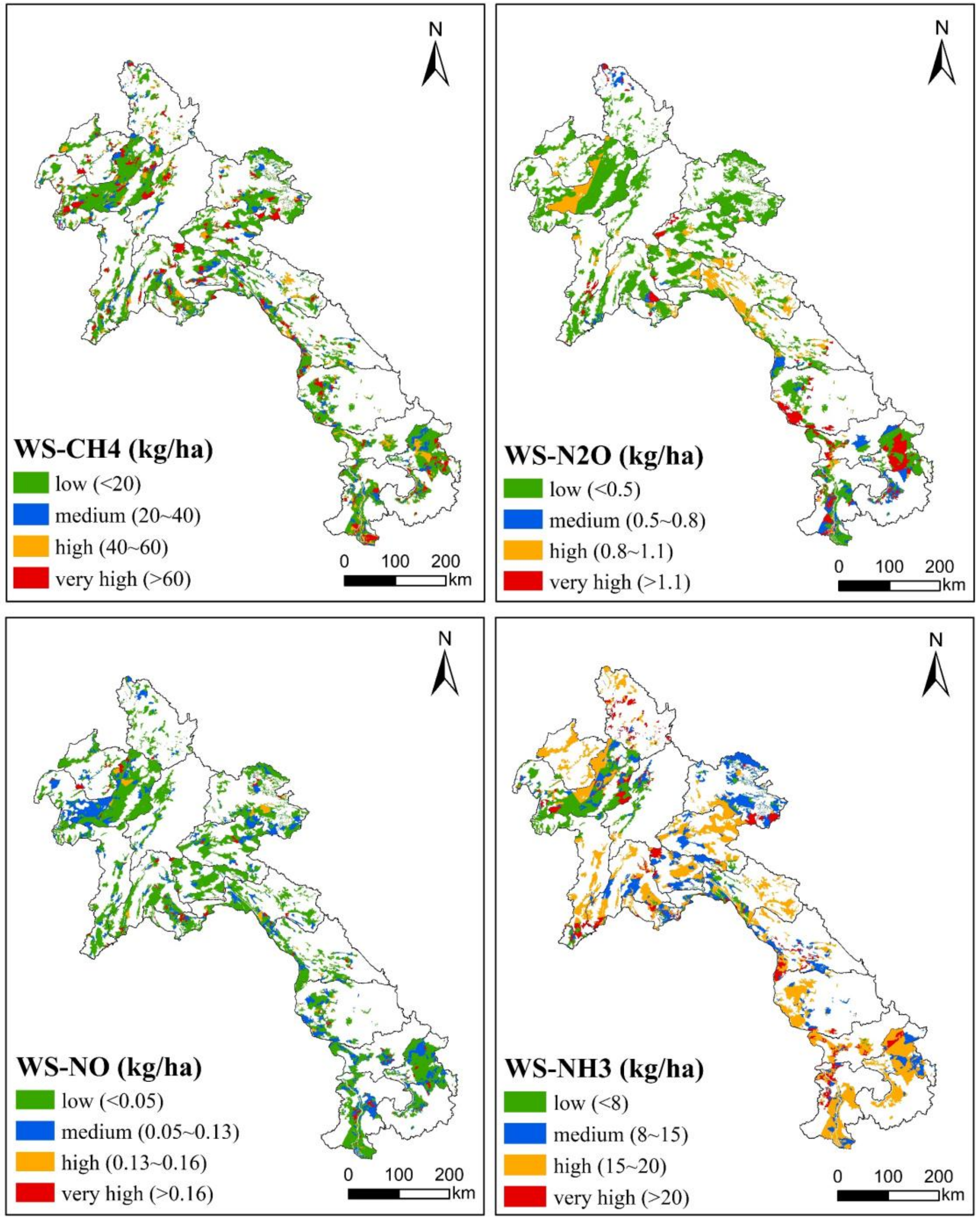
coefficient | input variable | parameter

(Lam et al., 2024 *Earth Critical Zone*)

Particle swarm optimization (PSO)-DSSAT regional rice model in Laos

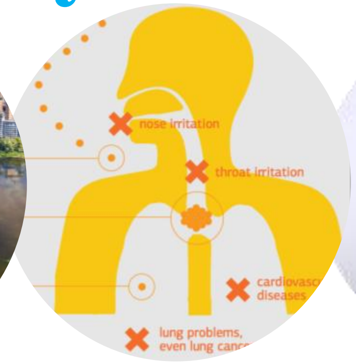


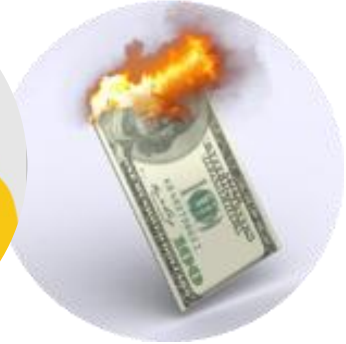
CH_4, N_2O, NO and NH_3 emissions in Laos rice system



Intensive livestock excreta N (manure) is about 50 Tg, >70% lost to environment, principally as NH_3







- livestock production is responsible for ~64% of total NH_3 emissions globally
- total NH_3-N loss from feedlots represents ~70% of N fed to cattle



➢ **Environmental pollution**
- react with other pollutants to produce particulate matters and aerosols
- promote GHG emission – N_2O
- lead to water eutrophication, soil acidification, and loss of biodiversity

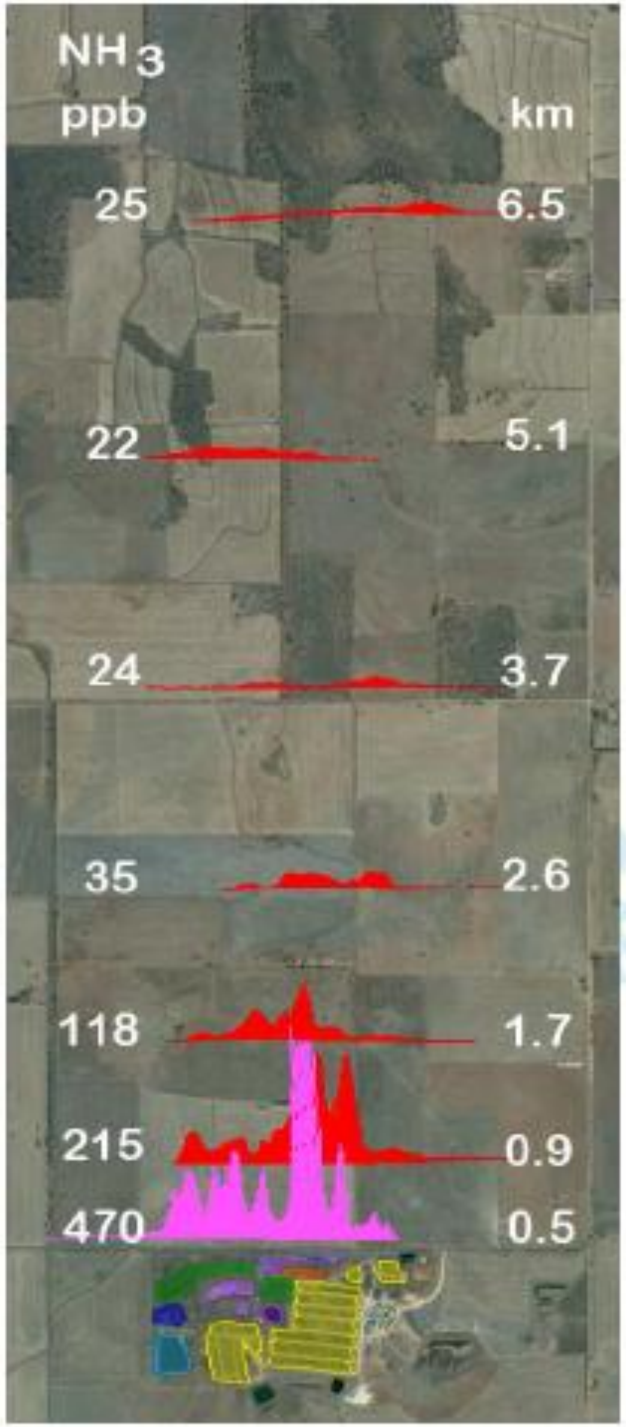
➢ **Human health**
- fine particulate matter (PM2.5) is deadly and can cause heart and lung problems

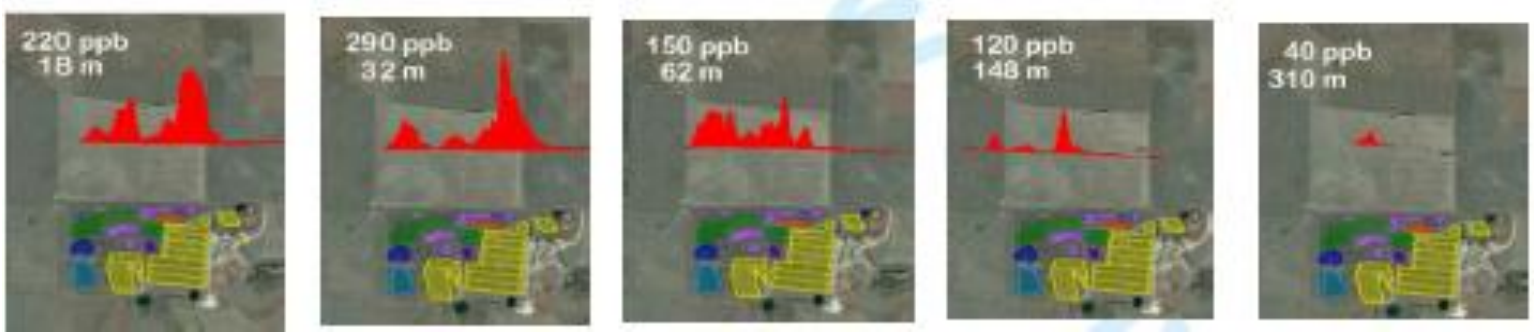
➢ **Economic loss**
- the loss of fertilizer value of manure

(Chen et al., 2015; McCrory and Hobbs, 2001; Watts et al., 2011)

Quantifying NN_3/GHG losses from large cattle feedlot

“Can’t measure, Can’t mitigate”

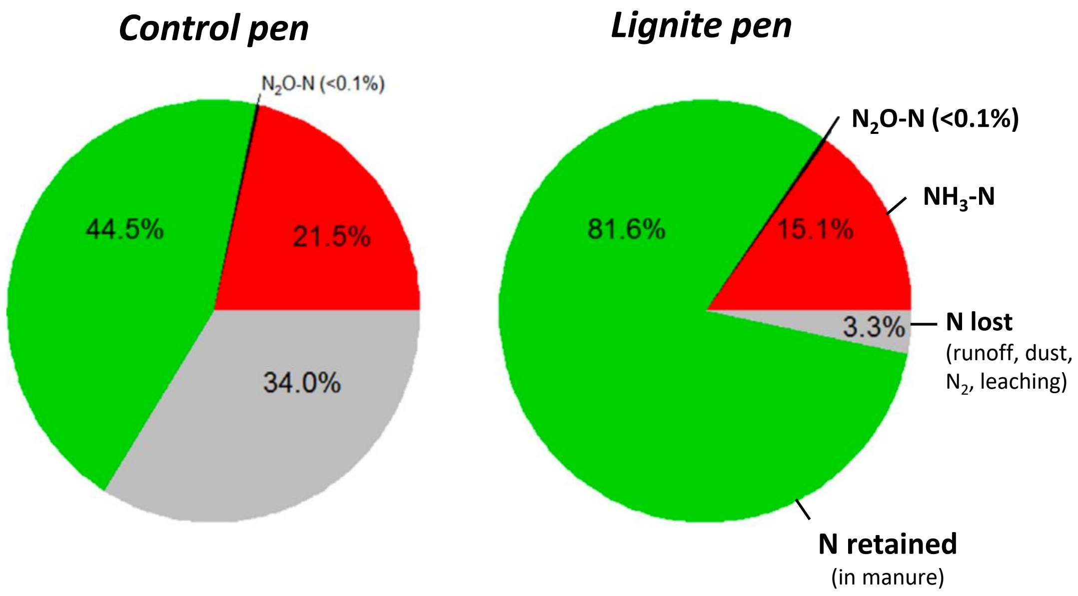




Effect of lignite (brown coal) on NH_3 losses from feedlot

- 60-70% diet N is lost as NH_3, ca 78kg N per head per year
- For feedlots with ~20,000 cattle , the average NH_3 emission, ~ 9t urea fertiliser per day (3000t urea per year, >$1m/year)

	N intake (g d^{-1})	Daily NH_3 emission (g $animal^{-1}d^{-1}$)
Control	318	155 ± 6
Lignite	318	52 ± 2

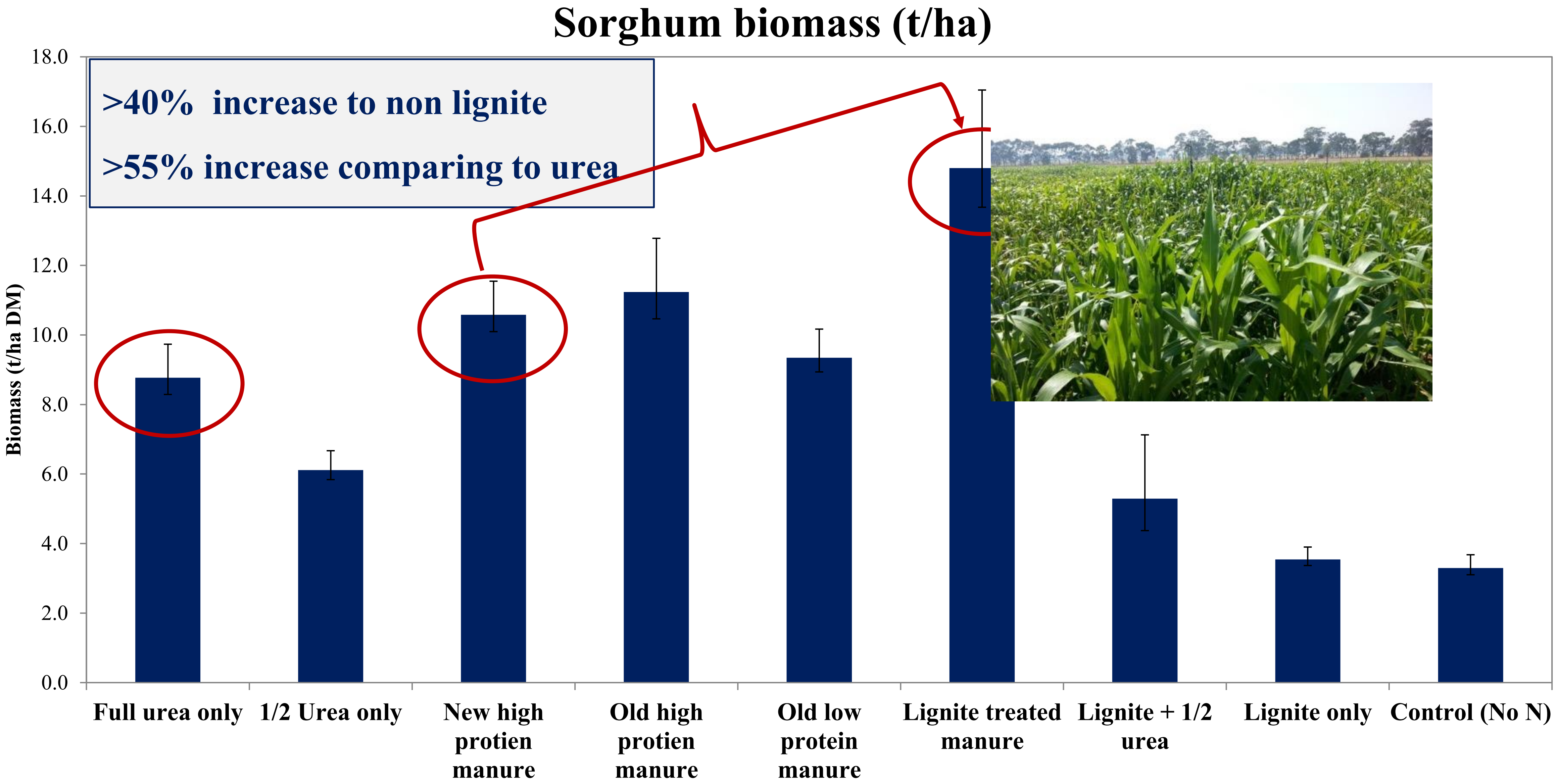


Lignite ↓ NH_3 emissions (30%) + ↑ mineral N

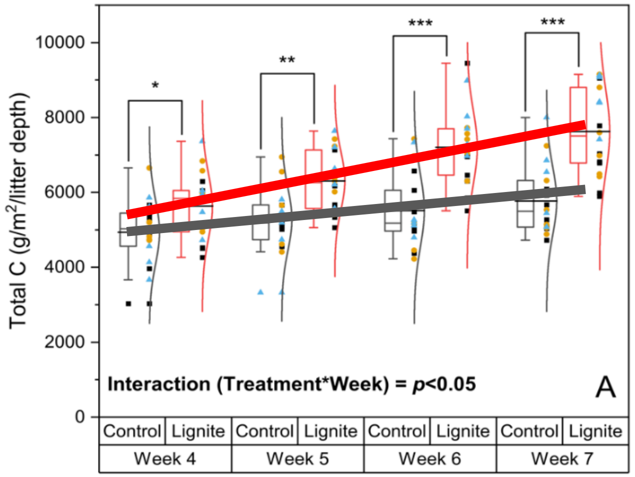
<u>NH_3 losses reduced by 67%</u>

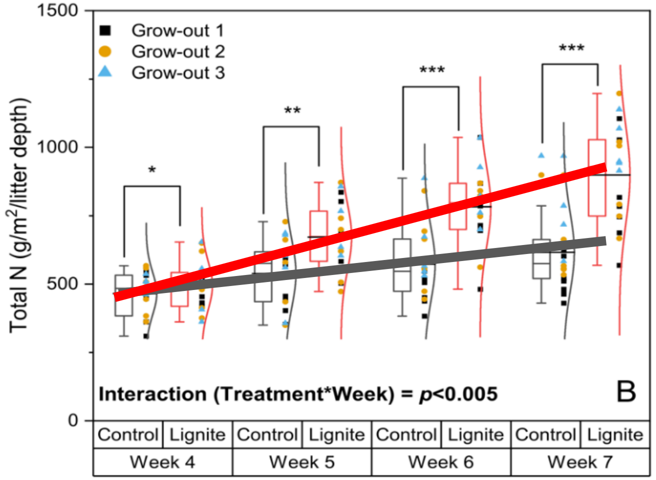
Chen et al 2015

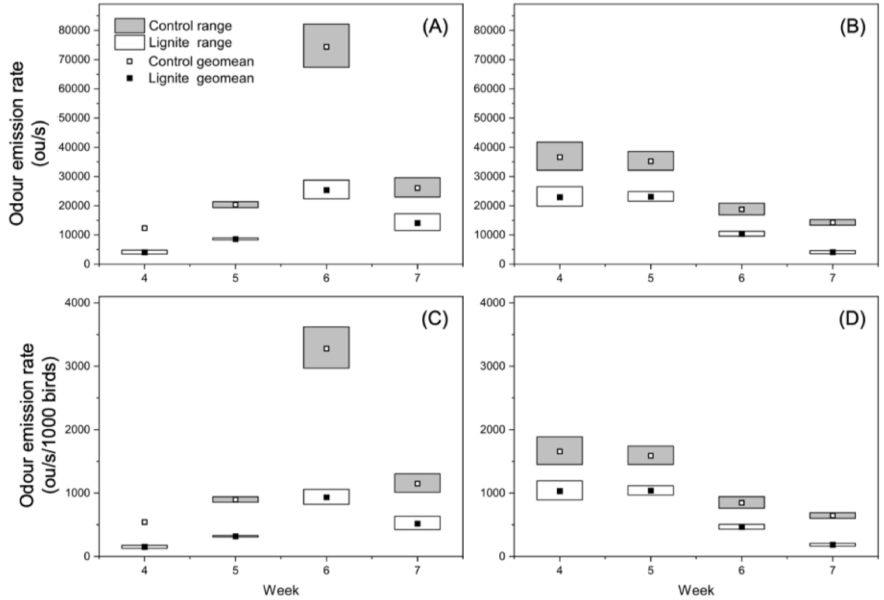
Biomass Yield



Lignite reduced NH_3-N emission, odour, C loss and increased total N poultry manure by 49-66%





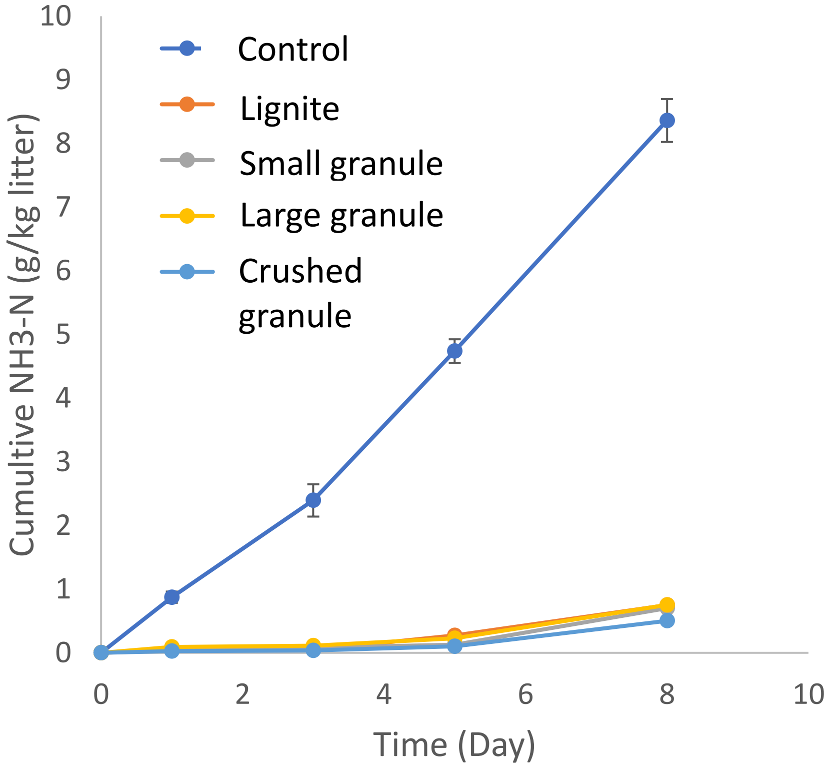


Lignite Granule

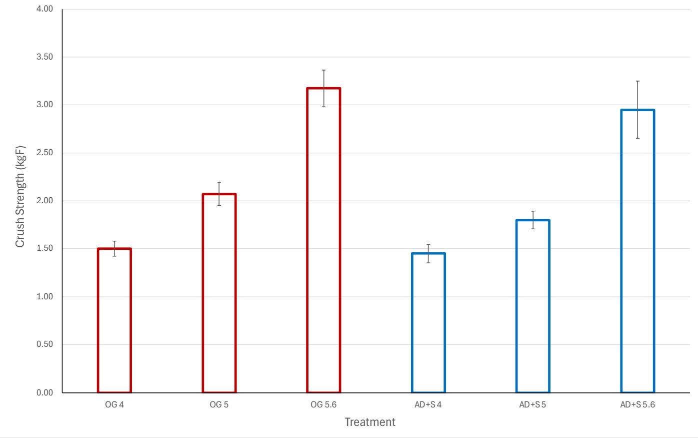
Make Lignite granule

Dewater and de-dust

Lignite granules made, at grams scale



Granules shown to be effective at reducing NH_3 emissions in acid trap incubation with poultry litter



Granules performed well in crush strength test, ensuring they can withstand transport and field application

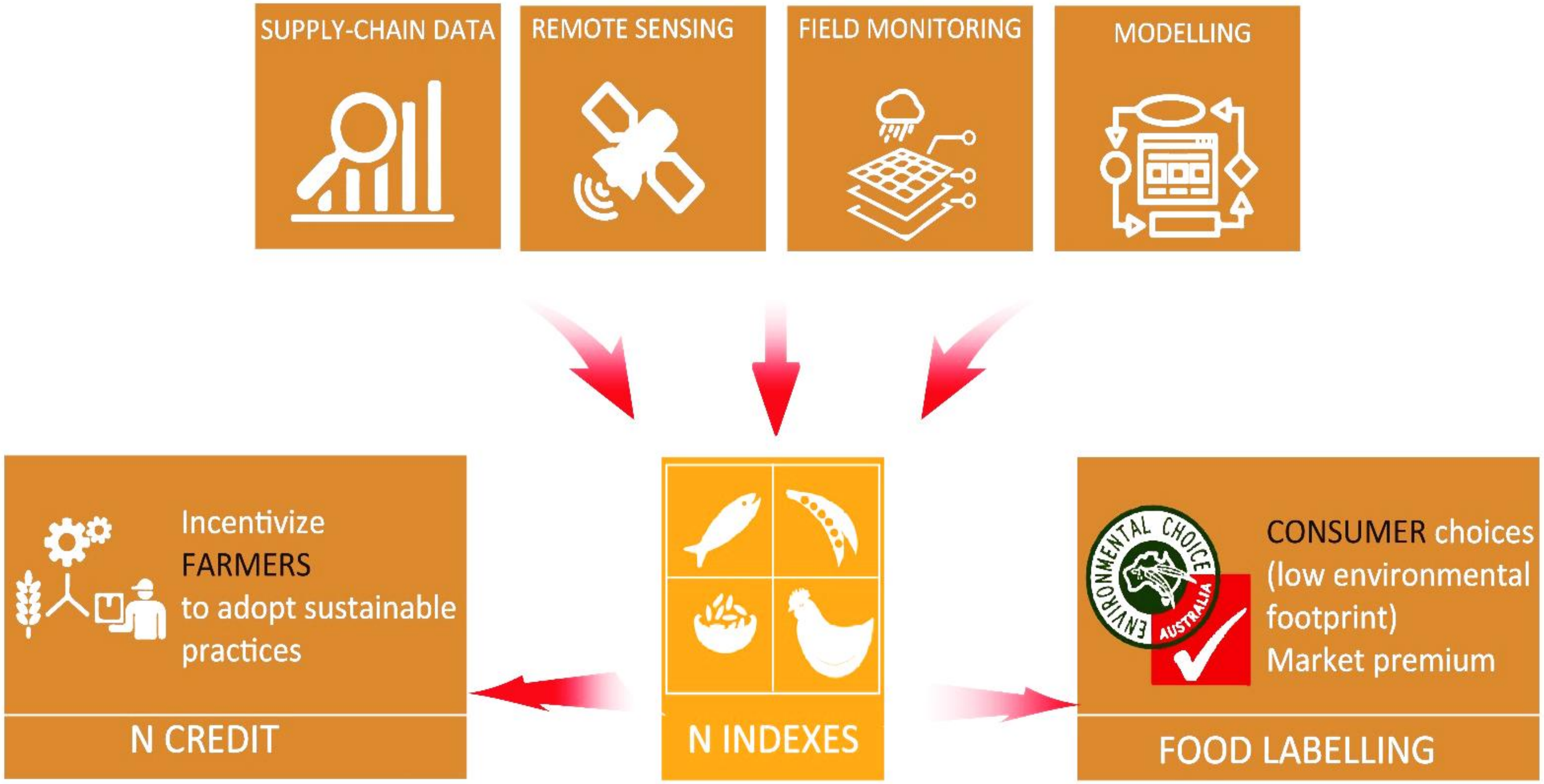
Standards: Evidence based Green index

So far, no evidenced based "**Green**"/sustainable index for agriculture products

Benchmarking

- To encourage and reward the more sustainable practices
- To give marketing, pricing advantages to more efficient producers
- To develop true environmental cost of N, trading of N cost or **N Credit**
- **Cost on prevention is lower than mitigation**
- **Ultimate goal: sustainable agricultural products**

Standards: Evidence based green index

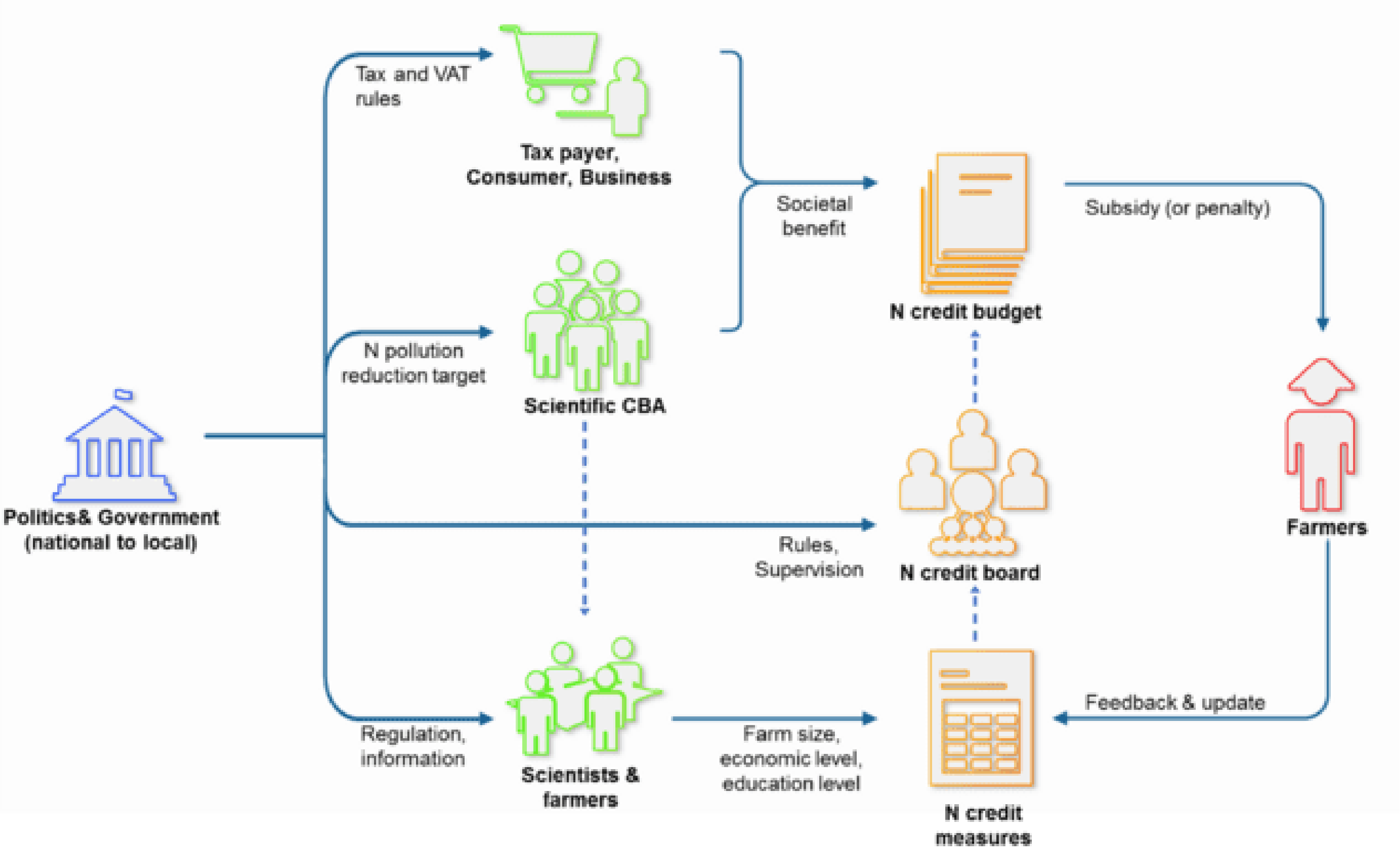


Nitrogen Credit System (NCS)

Establishment of NCS to reduce agricultural pollution and improve NUE by ***sharing responsibilities*** among farmers, suppliers, processors, retailers, consumers and governments.

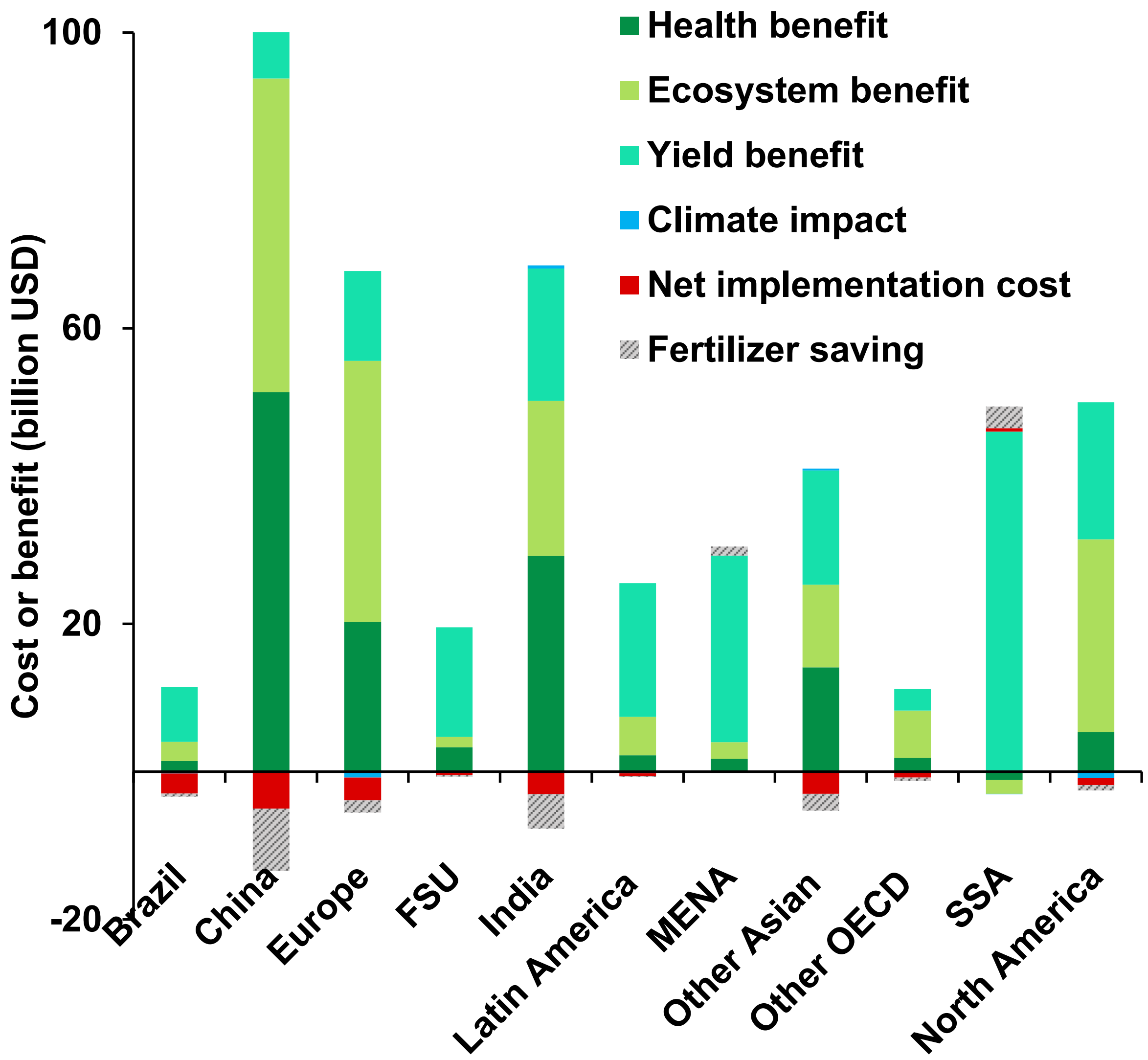
To provide financial

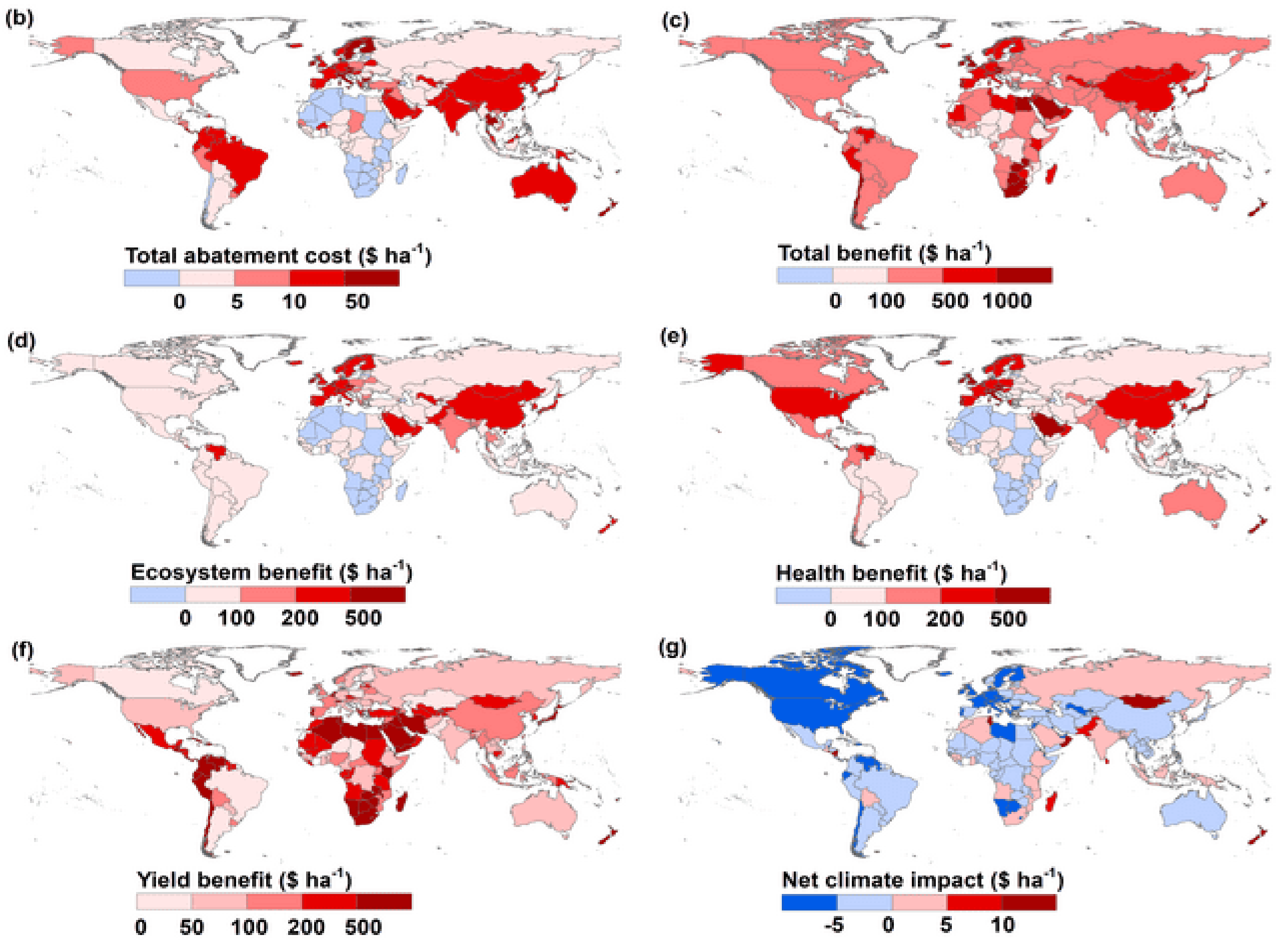
Incentives for lower environmental footprints products (including EEFs)



Gu et al. 2021, *The Innovation*

Mitigating Nr pollution from global croplands





Global overall benefits to cost ratio is 25 !

Gu etal, 2022, Nature

Why not widely adopted (in Australia)?

- Economically not profitable, participially for broadacre agriculture because the cost of processing, application and transport exceeding the increased N in manure
- Requiring more stringent ***Policy and Regulation*** (on NH_3 and odour emission standards)
- Or Financial Incentives to reward the societal

Standards: Evidence based green index

Control *VS* **MPT**

-83%

Control

1.44 g

N_2O-N loss per kg product

Damage cost

11.29-39.12

USD per ton product

MPT

0.25 g

N_2O-N loss per kg product

Damage cost

1.94-6.72

USD per ton product

Control *VS* **DMPP**

-56%

Control

0.43 g

N_2O-N loss per kg flour

&

0.06 g

NH_3-N loss per kg flour

Damage cost

3.54-12.12

USD per ton flour

DMPP

0.19 g

N_2O-N loss per kg flour

&

0.05 g

NH_3-N loss per kg flour

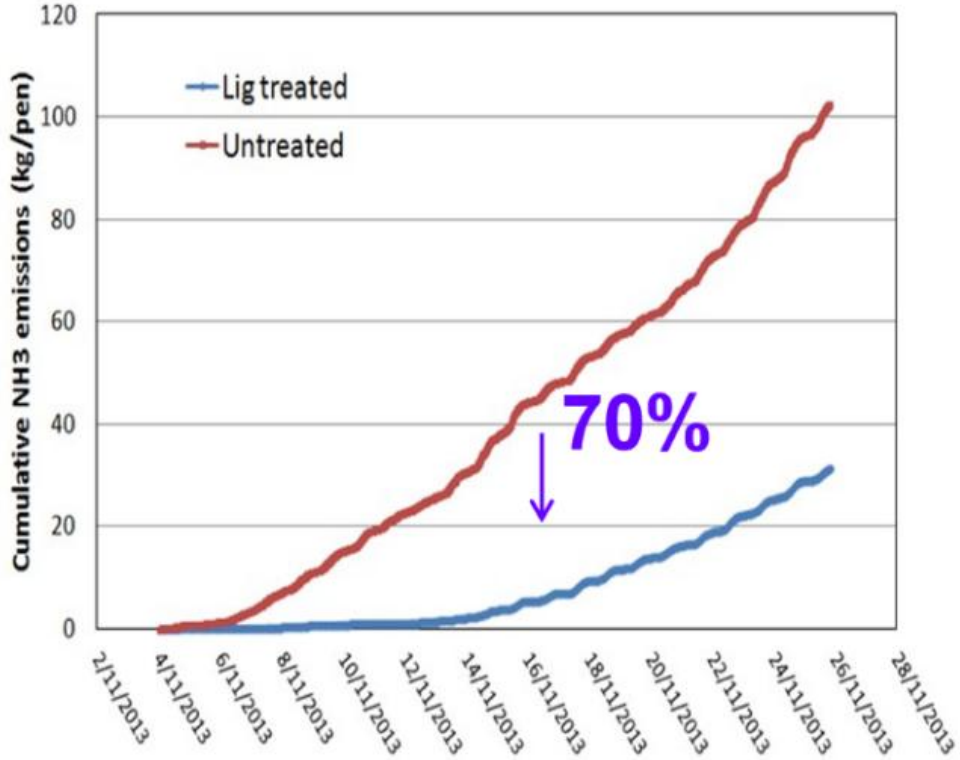
Damage cost

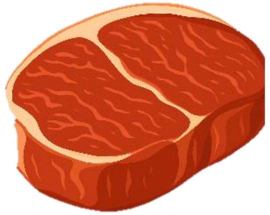
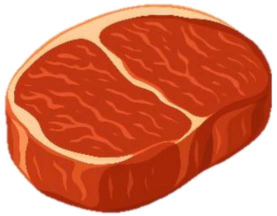
1.62-5.46

USD per ton flour

Farmers —Sustainable practice

Lignite for mitigating NH_3 volatilization

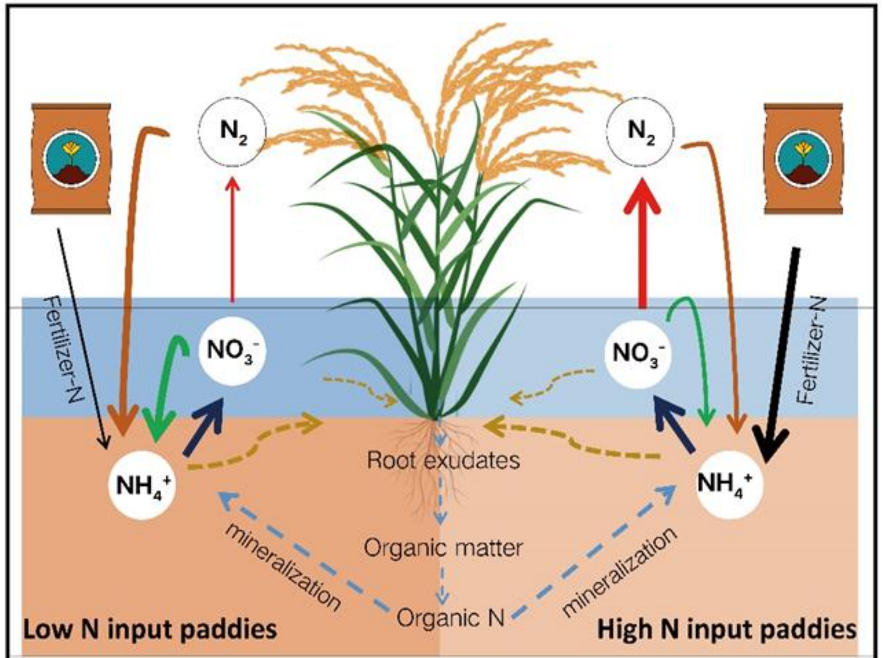


Before		After
	VS	
	-70%	
160 g NH_3-N loss per kg beef		**48 g** NH_3-N loss per kg beef
Damage Cost **0.27-5.94** USD per kg beef		Damage Cost **0.08-1.78** USD per kg beef
		

Why rice in Lao is greener— role of DNRA and BNF

THE UNIVERSITY OF MELBOURNE

Australian Government
Australian Centre for International Agricultural Research



25	N fertlization (kg urea-N ha^{-1})	100
1.82-2.98	N_2 fixation (kg N_2-N ha^{-1} day^{-1})	0.10-1.0
1.52-3.21	DNRA (kg NH_4-N ha^{-1} day^{-1})	0.40-0.66
0.13-0.64	Denitrification (kg N_2-N ha^{-1} day^{-1})	0.31-1.10

N_2fixation | DNRA | Denitrification | Nitrification

The values associated with each N cycling process represents the activity during active tillering stage of rice when the measurement was conducted

China

4.42 kg NH_3-N
&
0.27 kg N_2O-N loss
per ton rice

Damage Cost
10.07-173.17 USD per ton rice

VS

Laos

0.69 kg NH_3-N
&
0.09 kg N_2O-N loss
per ton rice

Damage Cost
1.94-28.58 USD per ton rice

Management of nutrients for improved profitability and sustainability of crop production in Lao PDR

Australian Government
Australian Centre for International Agricultural Research

Research Design Brief

ACIAR Program(s) area	SLAM
Project Title	Quantifying the impacts of nitrogen use and developing sustainable agricultural N management strategies in Laos rice-based farming systems
Project Number	SLAM/2022/102
ACIAR Research Program Manager	James Quilty

THE INTERNATIONAL PLANT NUTRITION COLLOQUIUM. Melbourne Australia 3-7 December 2028