Nitrous oxide fluxes from cropping soils in a semi-arid region in Australia: A 10 year perspective

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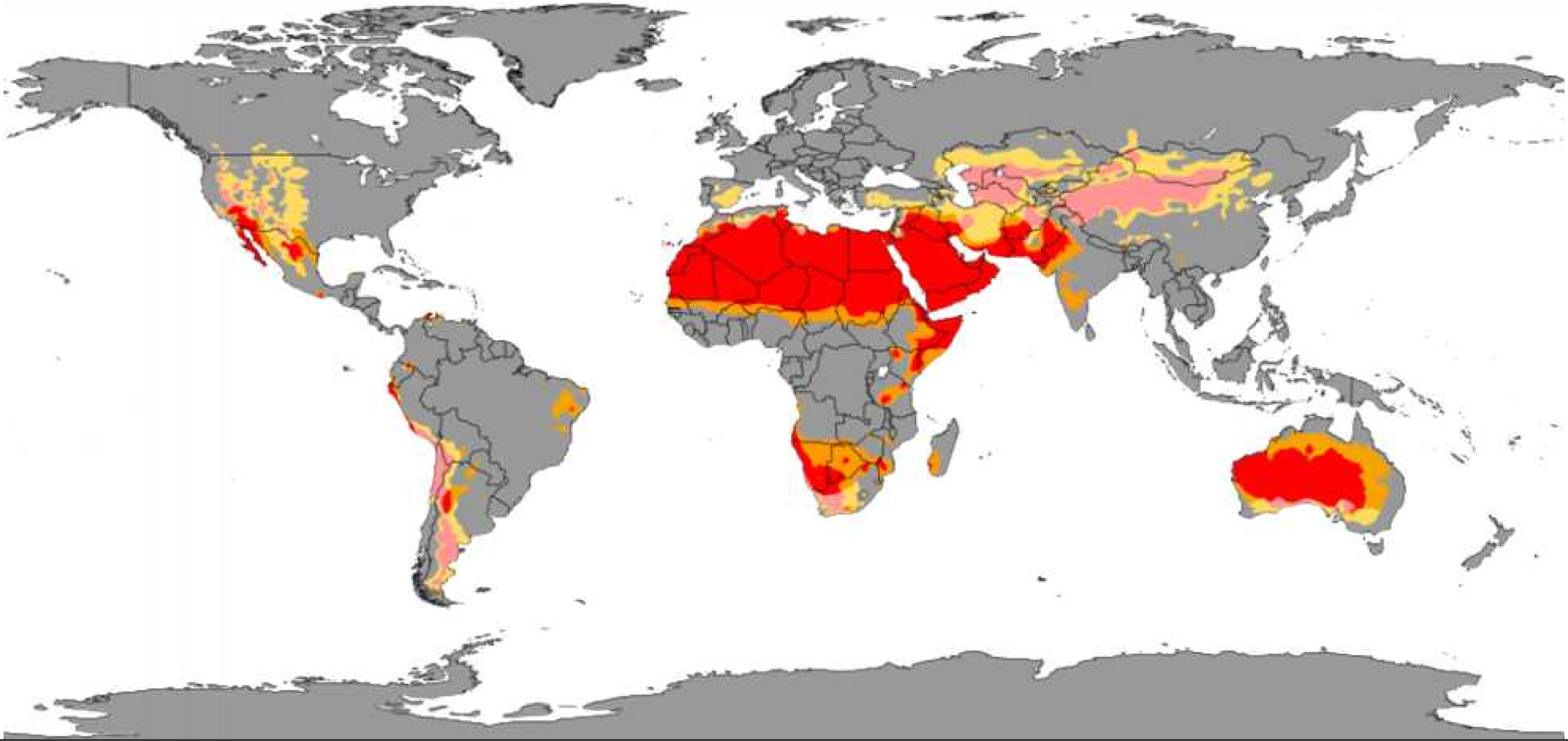
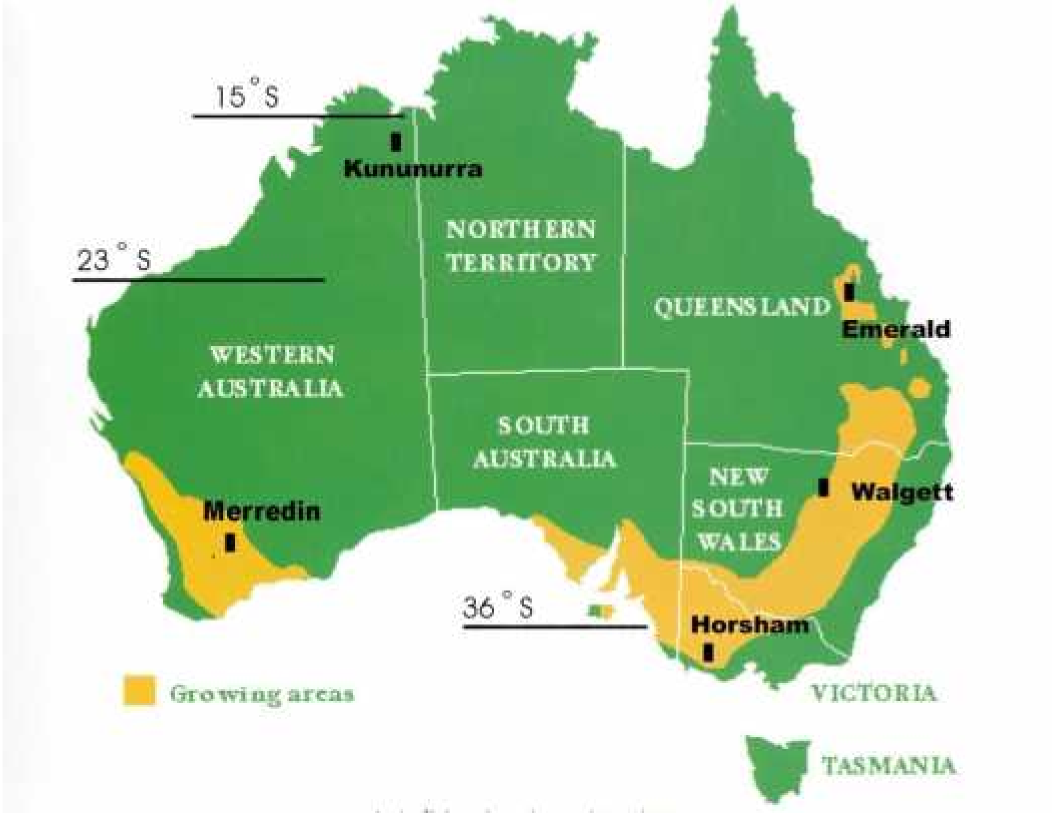
Dry (arid and semiarid) climates: 41% of earth's land surface



Western Australian Grainbelt

- 12 million hectares of arable land
- Produces up to 40% of Australia's grain exports
- A semiarid climate, with winter-dominant rainfall and hot, dry summers
- Cropping in winter; soils fallow at other times of the year
- Annual rainfall: 290–370 mm



Ancient Soils and Landscapes

- Stable i.e. limited tectonic activity
- Highly weathered lateritic landscapes
- Soils underlain by the Archaean granitic ((> 2500 Ma) and gneissic parent rock of the Yilgarn Craton
- Infertile soils deficient in P, Mo, Zn, Cu and other essential elements

Surface 120 mm	
pH ($0.01\ CaCl_2$)	6.0
C	0.98 %
N	0.08 %
Sand	93 %
Bulk density	1.4 g soil cm^{-3}
25% of WA grainbelt soils	

Yellow/brown sandy duplex
(Natric Haploxeralf; USDA Soil Taxonomy)

Source: Jenkins *et. al.* 2016. *Sci. Rep. 6:30733* | *DOI: 10.1038/srep30733*

Nitrous oxide emissions measurement and observations


50 cm x 50 cm
by variable height (15–95cm)

Nitrous oxide emissions are low from coarse-textured soils

THE UNIVERSITY OF WESTERN AUSTRALIA

Location	Soil	Crop	N Rate (kg N/ha)	Annual Rate (kg N/ha)	EF (%)
Cunderdin	sand over clay	wheat wheat	0 100	0.09 0.11	0.02
Cunderdin	sand over clay	wheat wheat	0 75	0.08 0.09	0.02
Cunderdin	sand over clay	canola canola	0 75	0.08 0.13	0.06
Cunderdin	sand over clay	lupin bare soil	0 0	0.13 0.13	na
Wongan Hills	sand	lupin wheat	0 75	0.04 0.06	na
Wongan Hills	sand	wheat wheat	20 50	0.06 0.07	na
Buntine	sand	canola canola	0 100	0.02 0.01	0.01
Buntine	sand	barley barley	0 100	0.02 0.00	0.02

Sources: Barton *et. al.* 2008. Glob. Change Biol. (GCB) 14: 177-192; Barton *et al.* 2010. Glob. Change Biol. Bioenergy 2: 1–15; Barton *et. al.* 2011. GCB 17: 1153–1166; Barton *et. al.* 2013. *Agric. Ecoyst. Environ.* (AEE) 167: 23–32; Barton *et al.* 2016. AEE 231: 320–330.

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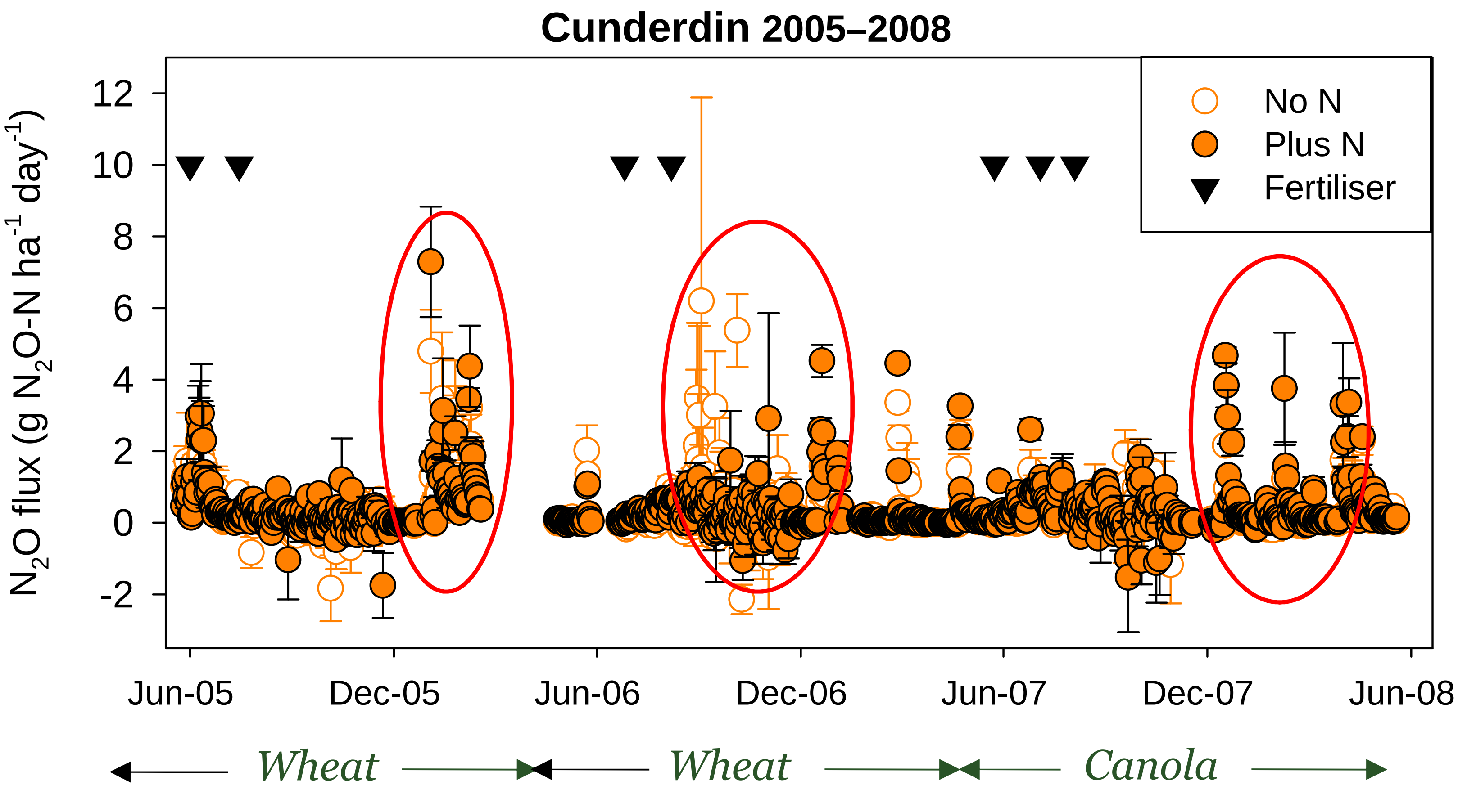
Cunderdin	sand over clay	canola canola	0 75	0.08 0.13	0.06
Cunderdin	sand over clay	lupin bare soil	0 0	0.13 0.13	na
Wongan Hills	sand	lupin wheat	0 75	0.04 0.06	na
Wongan Hills	sand	wheat wheat	20 50	0.06 0.07	na
Buntine	sand	canola canola	0 100	0.02 0.01	0.01
Buntine	sand	barley barley	0 100	0.02 0.00	0.02

International default value: 1.0%; Australian value: 0.20%

'Greatest' N_2O emissions occur following summer rainfall

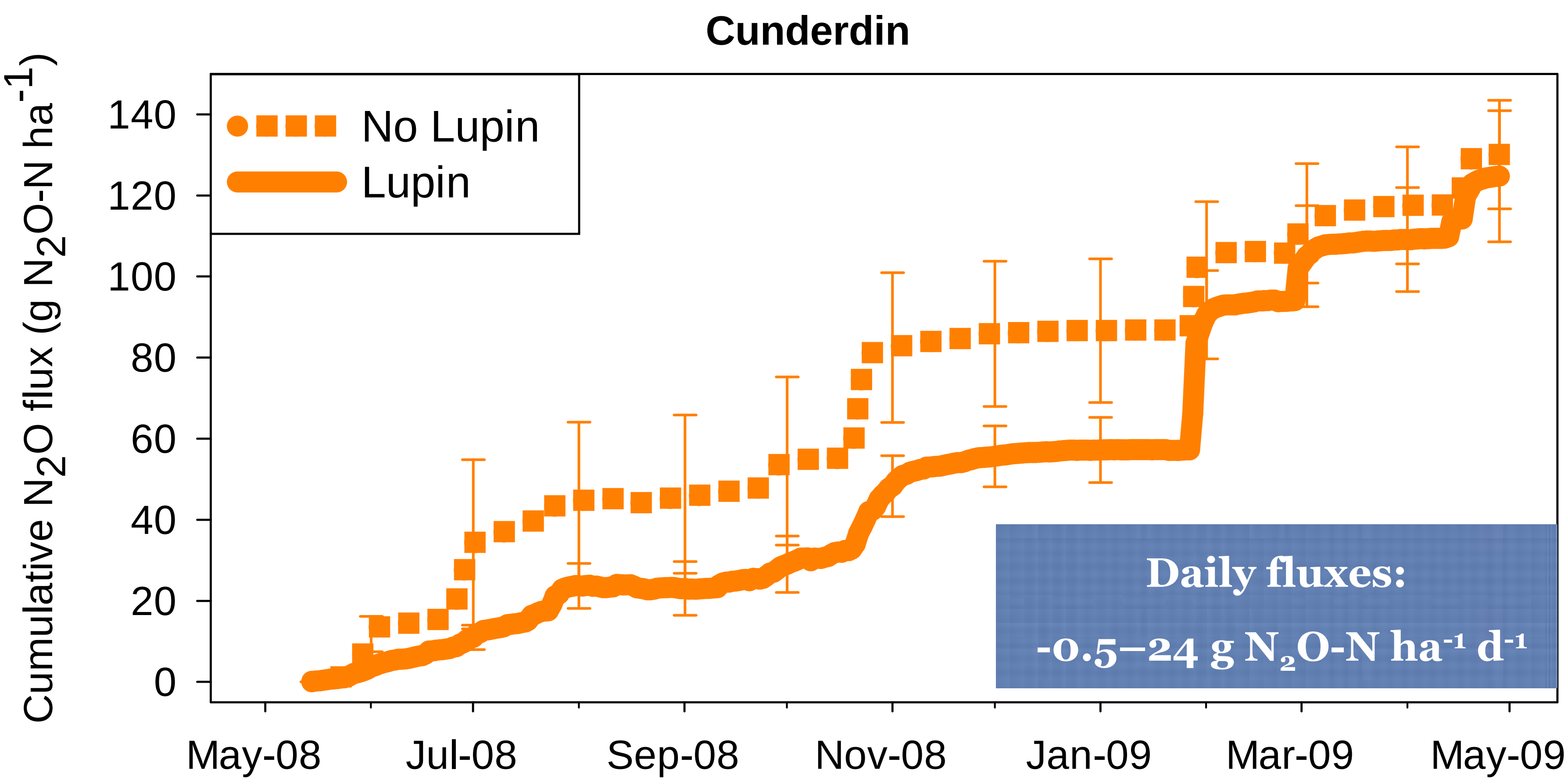


Source: Barton *et. al.* 2008. *Glob. Change Biol.* 14: 177-192; Barton *et al.* 2010. *Glob. Change Biol. Bioenergy* 2: 1–15.

Does including grain legumes in our cropping rotations increase cumulative N_2O emissions?

Photo: Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops

Grain legumes do not increase cumulative N_2O emissions



Source: Barton *et. al.* 2011. *Glob. Change Biol.* 17: 1153–1166; Barton *et. al.* 2013. *Agric. Ecoyst. Environ.* 167: 23–32 .

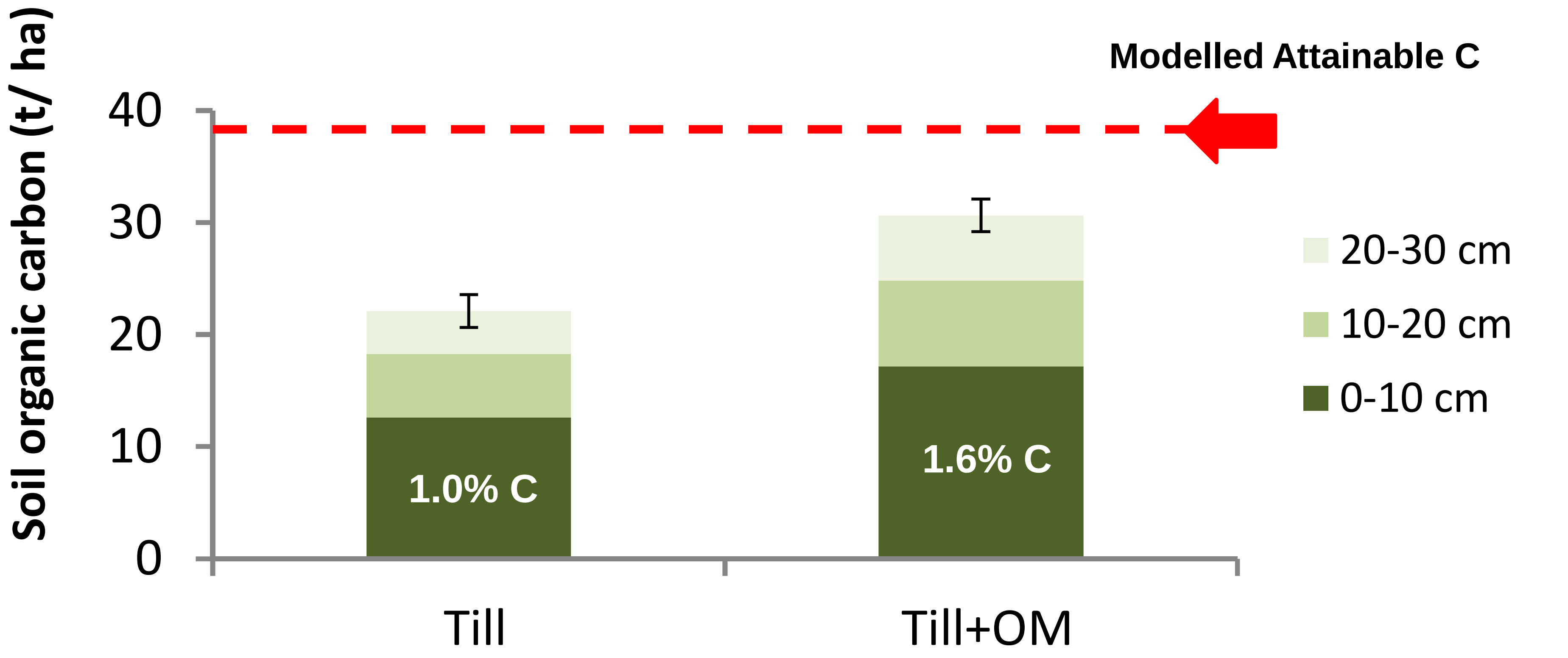
Will increasing soil organic matter contents increase cumulative N_2O emissions in coarse textured soils?

20 t organic matter (chaff)/ ha incorporated every 3 years; 80 t/ha to date when N_2O study commenced

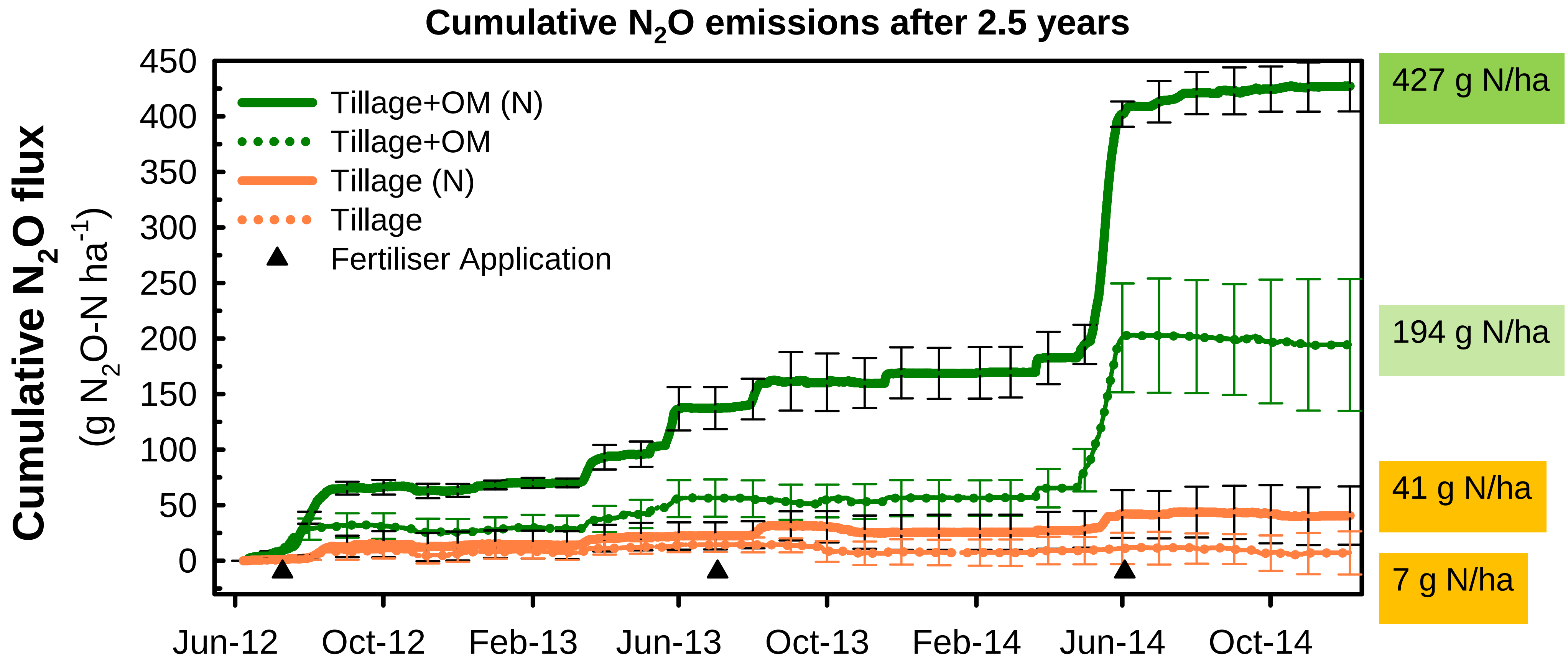
Liebe Group’s Long Term Soil Biology Trial, established 2003

Liebe long-term soil biology trial: Soil carbon stocks

RothC Model Assumptions:
60% water-use efficiency, 80% stubble retention, current rotation maintained



Increasing SOM increased N_2O emissions …



Source: Barton *et al.* 2016. *Agric. Ecoyst. Environ.* 231: 320–330.

…. But losses are still relatively small.

Location	Soil	Crop	N Rate (kg N/ha)	Annual Rate (kg N/ha)	EF (%)
Buntine (+OM)	sand	Canola	0 100	0.06 0.14	0.09
Buntine (+OM)	sand	Barley	0 100	0.15 0.27	0.12
Cunderdin	sand over clay	wheat wheat	0 100	0.09 0.11	0.02
Cunderdin	sand over clay	wheat wheat	0 75	0.08 0.09	0.02
Cunderdin	sand over clay	canola canola	0 75	0.08 0.13	0.06
Cunderdin	sand over clay	lupin bare soil	0 0	0.13 0.13	na
Wongan Hills	sand	lupin wheat	0 75	0.04 0.06	na
Wongan Hills	sand	wheat wheat	20 50	0.06 0.07	na

Nitrous oxide emissions mitigation

Mitigation Strategies

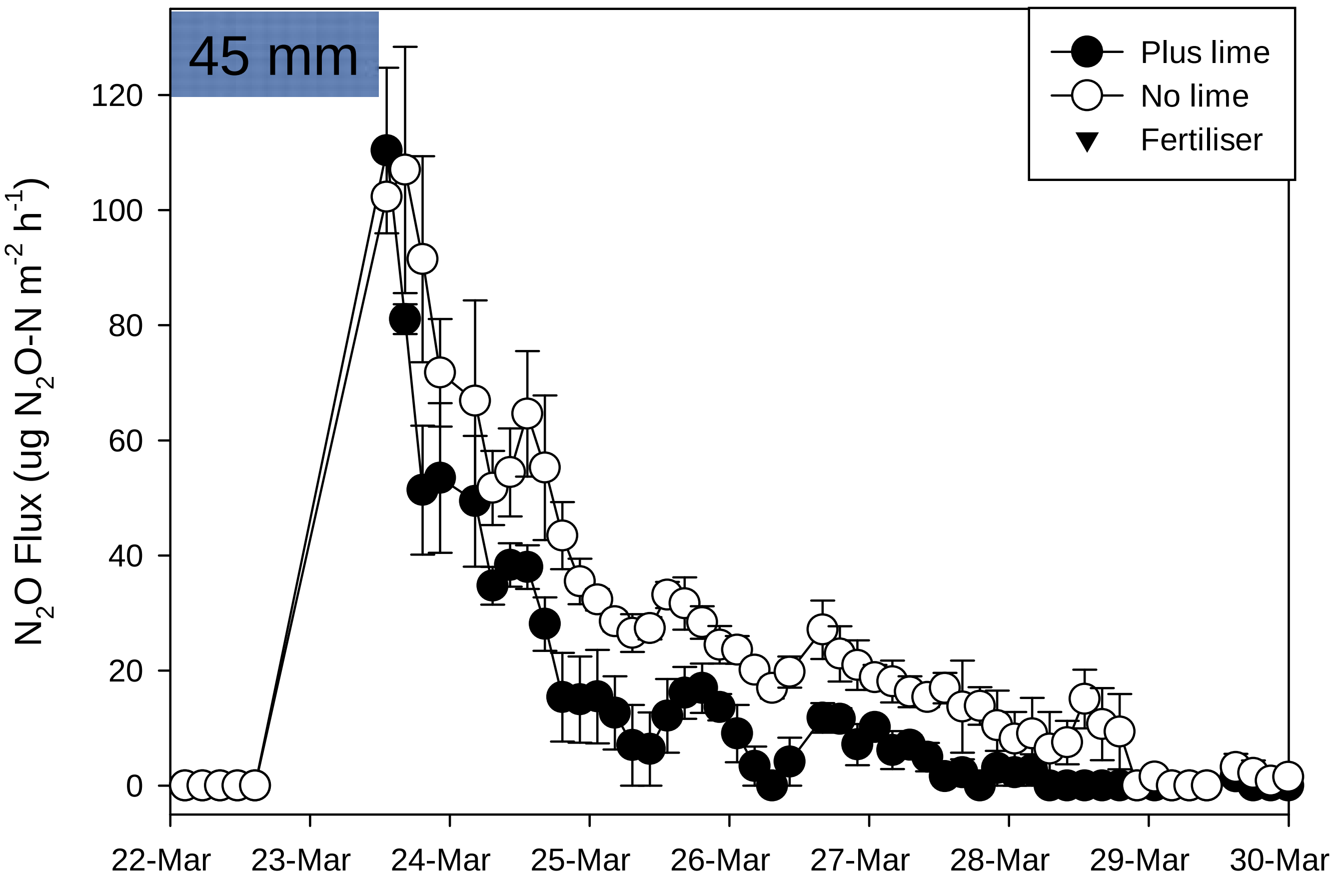
Approaches to decreasing N_2O emissions following summer rainfall events:

- ✓ **Decrease N_2O emissions from nitrification/denitrification**
- ✓ Increase soil nitrogen immobilisation of mineralised-N
- ✓ Increase plant nitrogen uptake during summer and autumn
- ✓ Include crops that produce biological nitrification inhibitors in rotations?

Mitigating Summer N_2O Emissions

Liming

Hourly N_2O emissions following summer rain



Cumulative Loss	
Lime (soil pH 6.0)	**No lime** (soil pH 4.3)
34 g N ha^{-1}	53 g N ha^{-1}

Source: Barton *et. al.* 2013. *Agric. Ecoyst. Environ.* 167: 23–32.

Increasing soil pH decreased soil N_2O emissions …

- Five summer-autumn rainfall = 79% of total N_2O emissions

Rotation	N_2O from summer rain g N_2O-N ha^{-1}	
	Plus lime	No lime
Wheat-wheat	0.09[b]	0.13[a]
Lupin-wheat	0.11[ab]	0.10[ab]

Liming decreased total N_2O emissions from wheat-wheat rotation by 30%.

Source: Barton *et. al.* 2013. *Agric. Ecoyst. Environ* . 167: 23–32.

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Is liming soil a strategy for mitigating nitrous oxide emissions from semi-arid soils?

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ABSTRACT

Nitrous oxide (N_2O) emissions in semi-arid regions are often greater following summer rainfall events when the soil is fallow, than in response to N fertiliser applications during crop growth. Nitrogen fertiliser management strategies are therefore likely to be ineffective at mitigating N_2O emissions from these cropped agricultural soils. Here we examined the influence of raising soil pH on N_2O emissions, nitrification rates, and both nitrifier and denitrifier populations following simulated summer rainfall events. The soil pH was raised by applying lime to a field site 12 months before conducting the laboratory experiment, resulting in soil of contrasting pH (4.21 or 6.34). Nitrous oxide emissions ranged from 0 when the soil was dry to 0.065 μg N_2O–N g dry soil^{-1} h^{-1} following soil wetting; which was attributed to both denitrification and nitrification. Increasing soil pH only decreased N_2O emissions when losses were associated with nitrification, and increased *amoA* gene copy numbers. We propose increasing soil pH as a strategy for decreasing soil N_2O emissions from acidic soils following summer rainfall in semi-arid regions when emissions result from nitrification.

Concluding Statements and Questions

- ✓ **Nitrous oxide emissions are (relatively) low from semiarid cropping soils in Western Australia. But how well have they been characterised in other semiarid regions? Good estimates ensure:**
  - Agriculture is accurately represented in National Greenhouse Gas Inventories
  - ‘Carbon footprints’ of agricultural products from semiarid regions are correctly estimated.
- ✓ **We cannot measure N_2O emissions everywhere and for all scenarios. But how well do we currently model N_2O emissions from semiarid regions? Particularly, highly episodic events?**
- ✓ **The regulation of N_2O emissions following summer rain is not fully understood in our region, and warrants further attention. Time to return to the laboratory?**

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- German Science Foundation

http://www.see.uwa.edu.au/research/soil-biology

N_2O Network

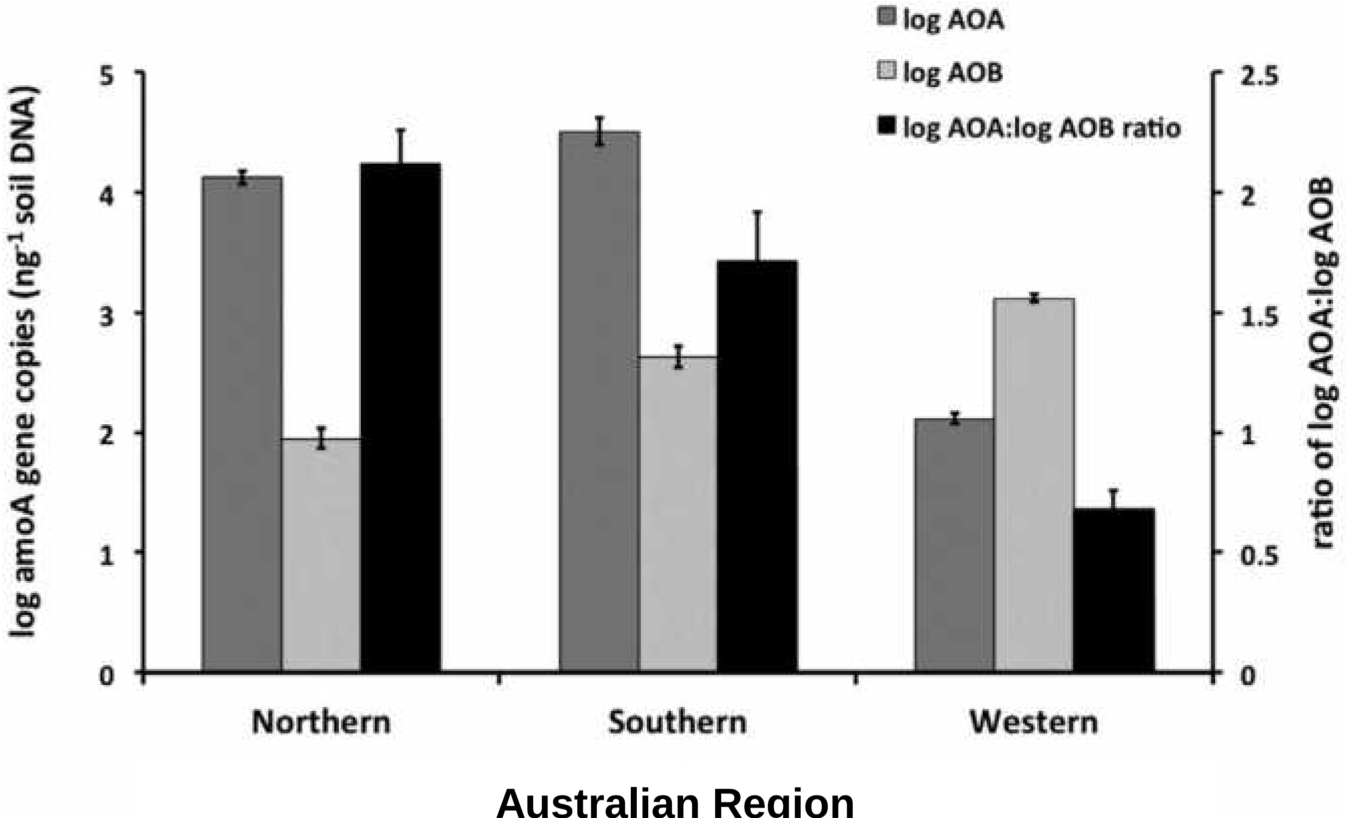
Australian Government

GRDC Grains Research & Development Corporation
Your GRDC working with you

Ammonia Oxidising Bacteria (AOB) Dominates in Our Ancient Soils

- Globally, ammonium oxidising archaea (AOA) tends to predominate over AOB in soils. **But this is not the case in Western Australia.**
- Copper deficiency could explain the unexpectedly low populations of AOA in Western Australian soils, in comparison to other regions in Australia

Ammonia oxidizer populations in agricultural soils across Australia



Source: Jenkins *et. al.* 2016. *Sci. Rep. 6:30733* | *DOI: 10.1038/srep30733*

Mitigating Summer N_2O Emissions

Nitrification Inhibitors

- "Nitrapyrin increased ammonium retention and decreased gross nitrification rates at 40 °C
- "Increasing soil organic matter from long-term additional crop residues diminished the effectiveness of the nitrapyrin"

Soil Biology & Biochemistry 88 (2015) 214–223

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Nitrapyrin decreased nitrification of nitrogen released from soil organic matter but not *amoA* gene abundance at high soil temperature

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Semi-arid

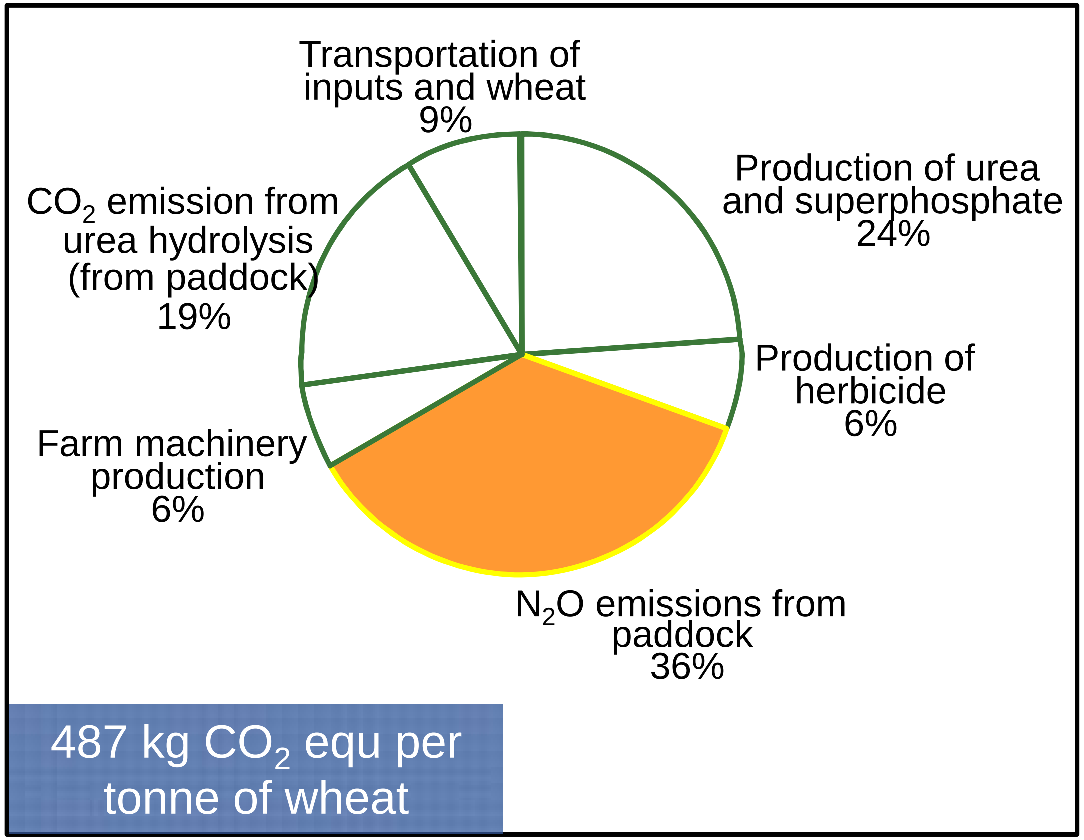
ABSTRACT

Water pulses have a significant impact on nitrogen (N) cycling, making management of N challenging in agricultural soils that are exposed to episodic rainfall. In hot, dry environments, wetting of dry soil during summer fallow causes a rapid flush of organic matter mineralisation and subsequent nitrification, which may lead to N loss via nitrous oxide emission and nitrate leaching. Here we examined the potential for the nitrification inhibitor nitrapyrin to decrease gross nitrification at elevated temperature in soils with contrasting soil organic matter contents, and the consequent effects on ammonia oxidiser populations. Soil was collected during summer fallow while dry (water content 0.01 g g^{-1} soil) from a research site with two management treatments (tilled soil and tilled soil with long-term additional crop residues) by three field replicates. The field dry soil (0–10 cm) was wet with or without nitrapyrin, and incubated (20 or 40 °C) at either constant soil water content or allowed to dry (to simulate summer drying after a rainfall event). Gross N transformation rates and inorganic N pools sizes were determined on six occasions during the 14 day incubation. Bacterial and archaeal *amoA* gene abundance was determined on days 0, 1, 7 and 14. Nitrapyrin increased ammonium retention and decreased gross nitrification rates even with soil drying at 40 °C. Nitrification was likely driven by bacterial ammonia oxidisers, as the archaeal *amoA* gene was below detection in the surface soil layer. Bacterial ammonia oxidiser gene abundances were not affected by nitrapyrin, despite the decrease in nitrifier activity. Increased soil organic matter from long-term additional crop residues diminished the effectiveness of nitrapyrin. The present study highlights the potential for nitrapyrin to decrease nitrification and the risk of N loss due to mineralisation of soil organic matter under summer fallow conditions.

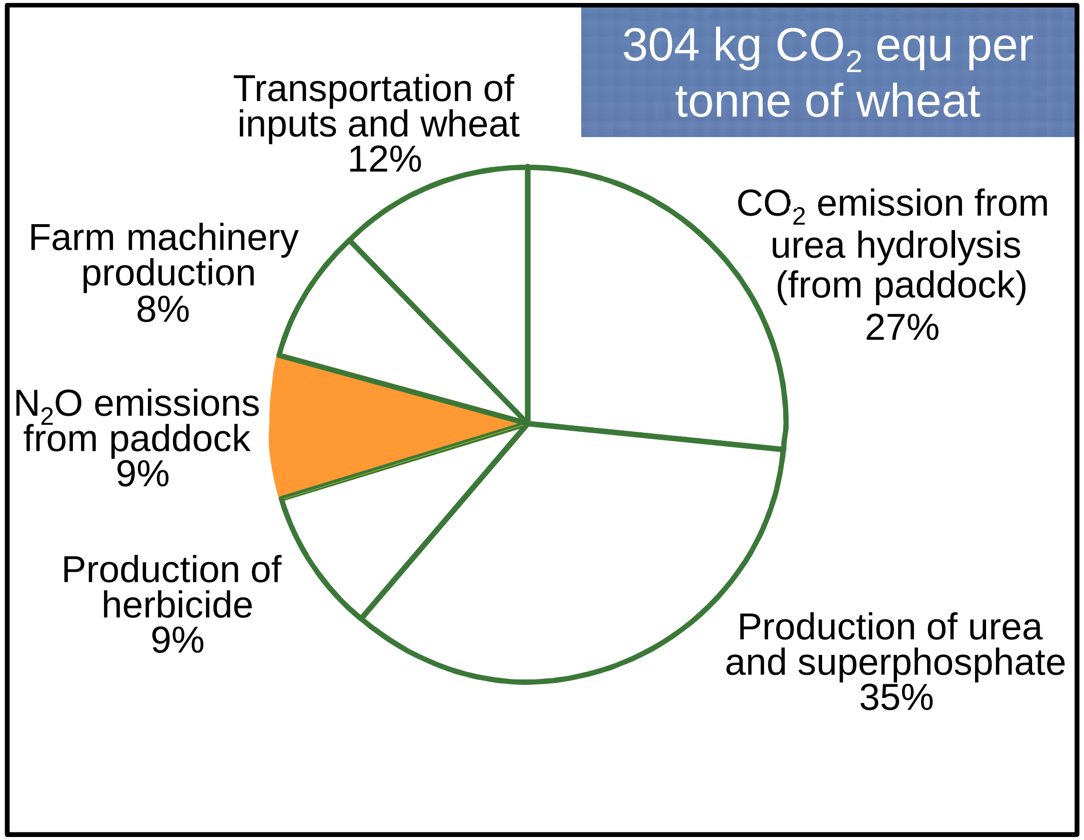
Source: Fisk et al. 2015. Soil Biology & Biochemistry 88: 214–223.

N_2O emissions need to be correctly accounted for when calculating the GHG emissions from agricultural products

Using 'international' N_2O emission value (1.0%)

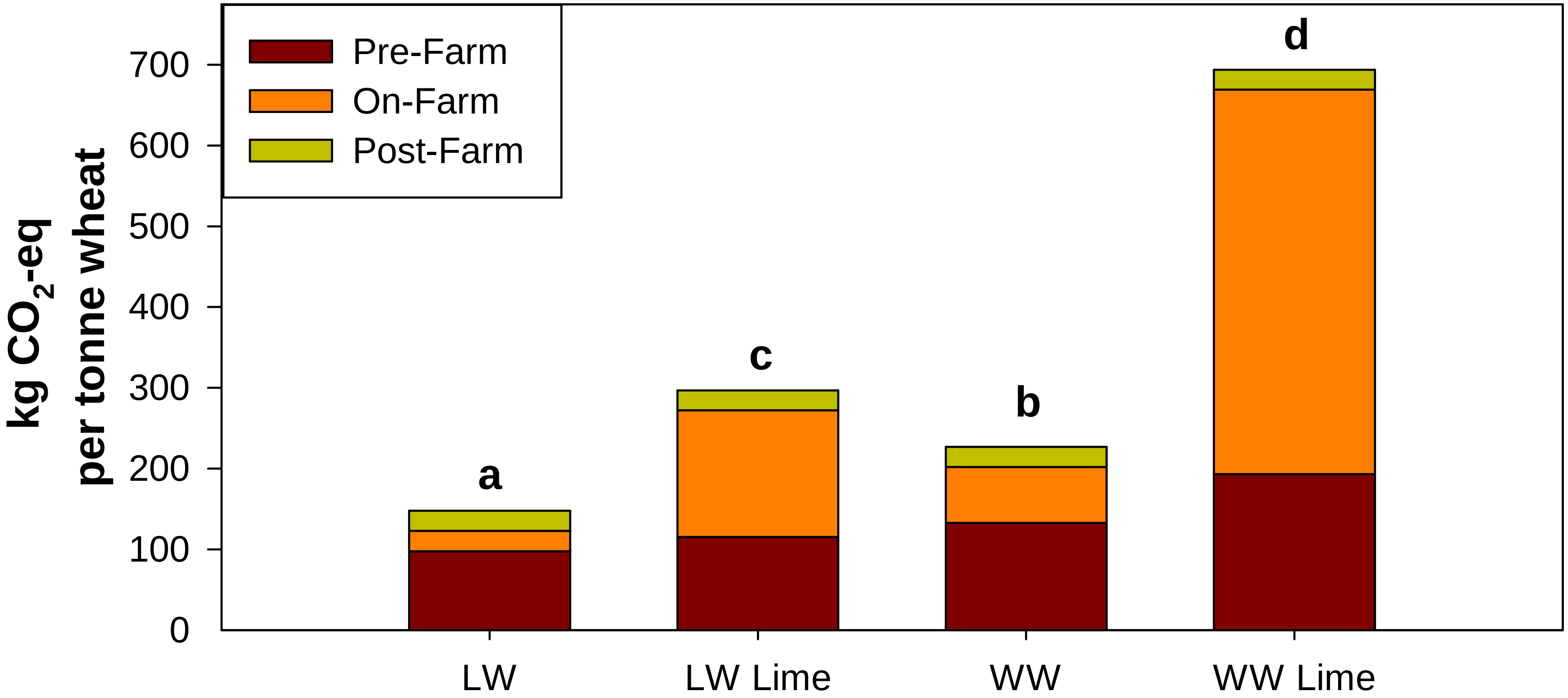


Using 'local' N_2O emission value



Source: Biswas *et. al.* 2008. *Water and Environment Journal* 22: 206-216.

…. But liming also increased the 'carbon footprint' of wheat production



LW = lupin-wheat WW= wheat-wheat

Source: Barton *et. al.* 2014. *Journal of Cleaner Production* 83: 194–203.