THE UNIVERSITY OF WESTERN AUSTRALIA

GOVERNMENT OF WESTERN AUSTRALIA
Department of Primary Industries and Regional Development

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

KIT
Karlsruhe Institute of Technology

Nitrous oxide emissions are low from sandy cropping soils in a semiarid region of Australia

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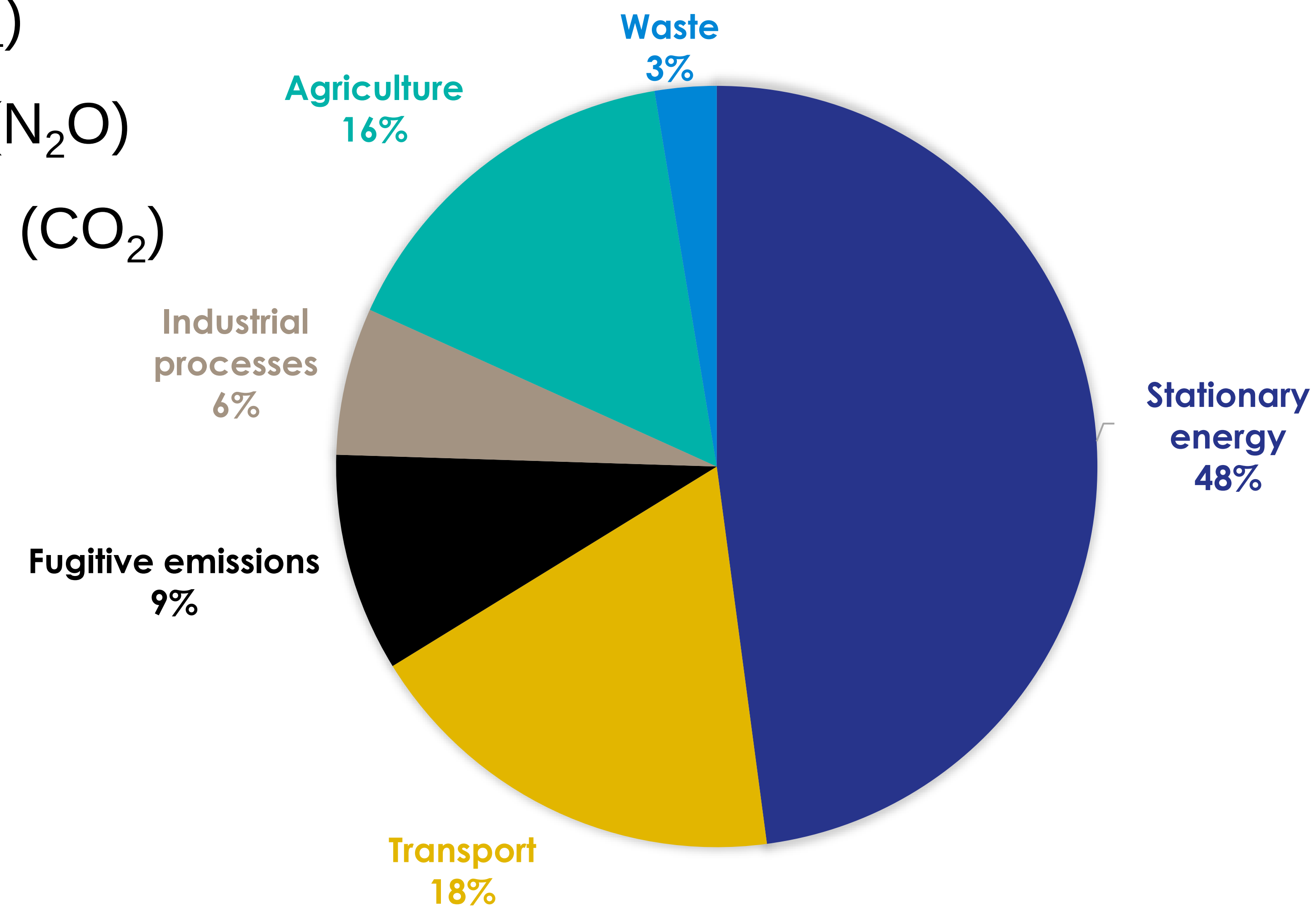
Net Zero 2050

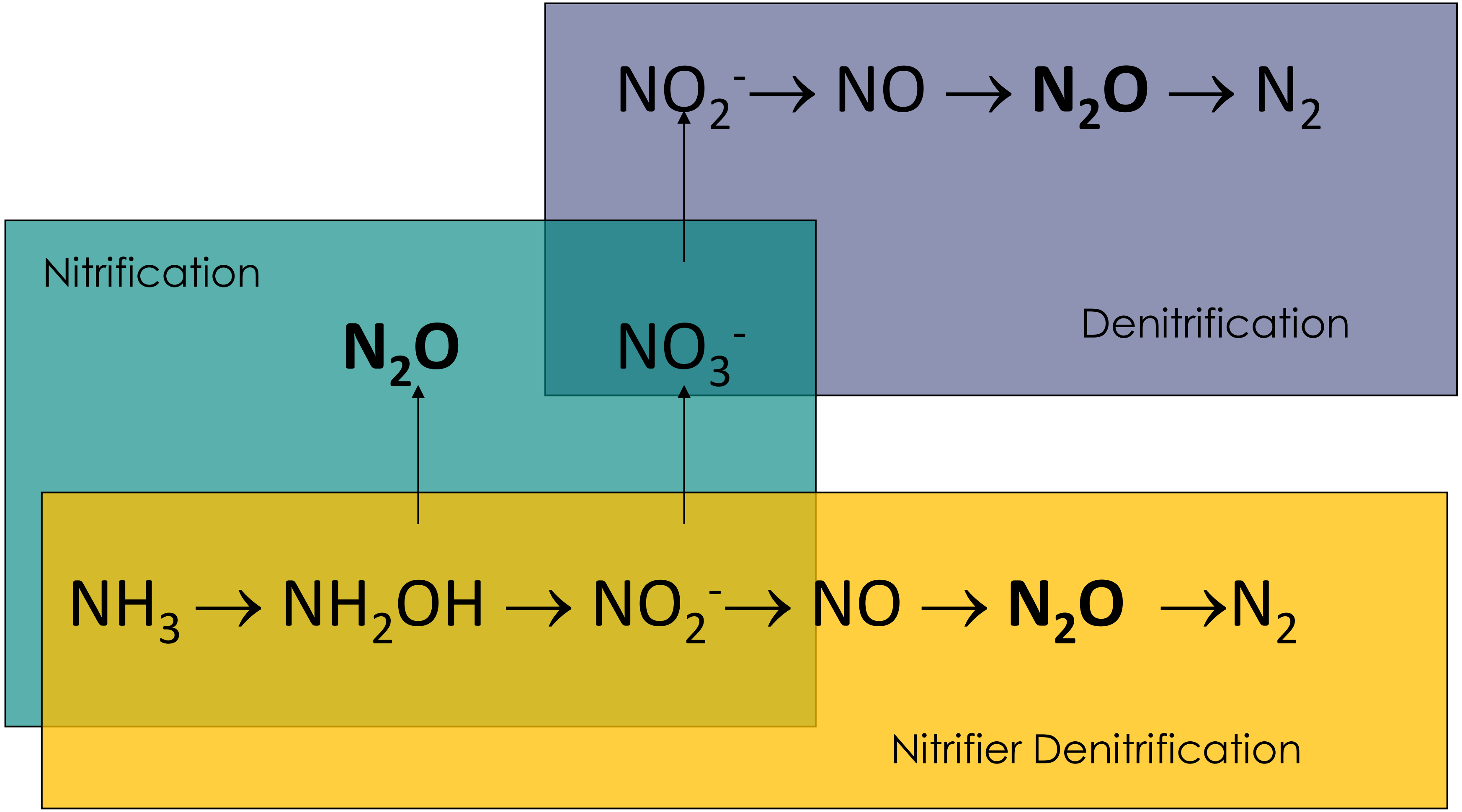
Agriculture contributes **16%** to national net emissions

- **58%** to national methane (CH_4)
- **76%** to national nitrous oxide (N_2O)
- **1%** to national **c**arbon dioxide (CO_2)



Source: Commonwealth of Australia. (2025) National Inventory Report 2022 – The Australian Government Submission to the United Nations Framework Convention on Climate Change. Australian National Greenhouse Accounts, April 2025.

Soil Biological Sources of nitrous oxide (N_2O)



Adapted from Wrage et al. (2001) Role of nitrifier denitrification in the production of nitrous oxide. Soil Biology Biochemistry 33: 1723-1732; Wrage et al. (2005) Distinguishing between sources of N_2O using new 15N- and 18O-enrichment method. Rapid Communications in Mass Spectrometry 15: 1263-1269.

Accounting for N_2O emissions from N fertilizer application to land ‘Direct source’

IPCC 2006 international default emission factor $_{\text{N fertilizer}}$ = 1.0%

i.e. 1 kg of N_2O-N will be emitted from 100 kg N fertilizer

Source: Commonwealth of Australia. (2025) National Inventory Report 2022 – The Australian Government Submission to the United Nations Framework Convention on Climate Change. Australian National Greenhouse Accounts, April 2025.

Western Australian Grainbelt

12 million hectares of arable land

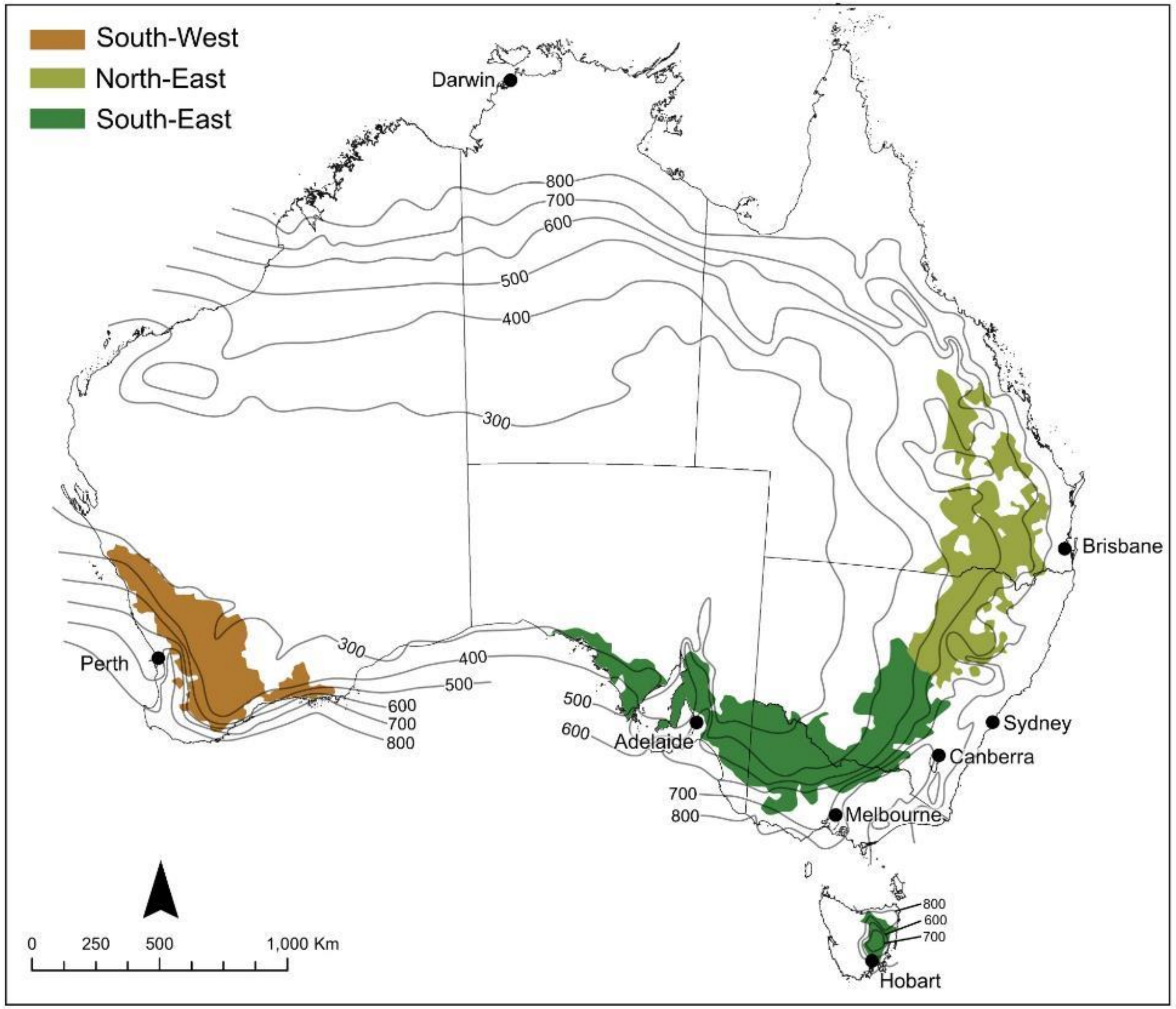
Highly weathered soils, **sandy surface horizons**

A semiarid climate, with winter-dominant rainfall and hot, dry summers

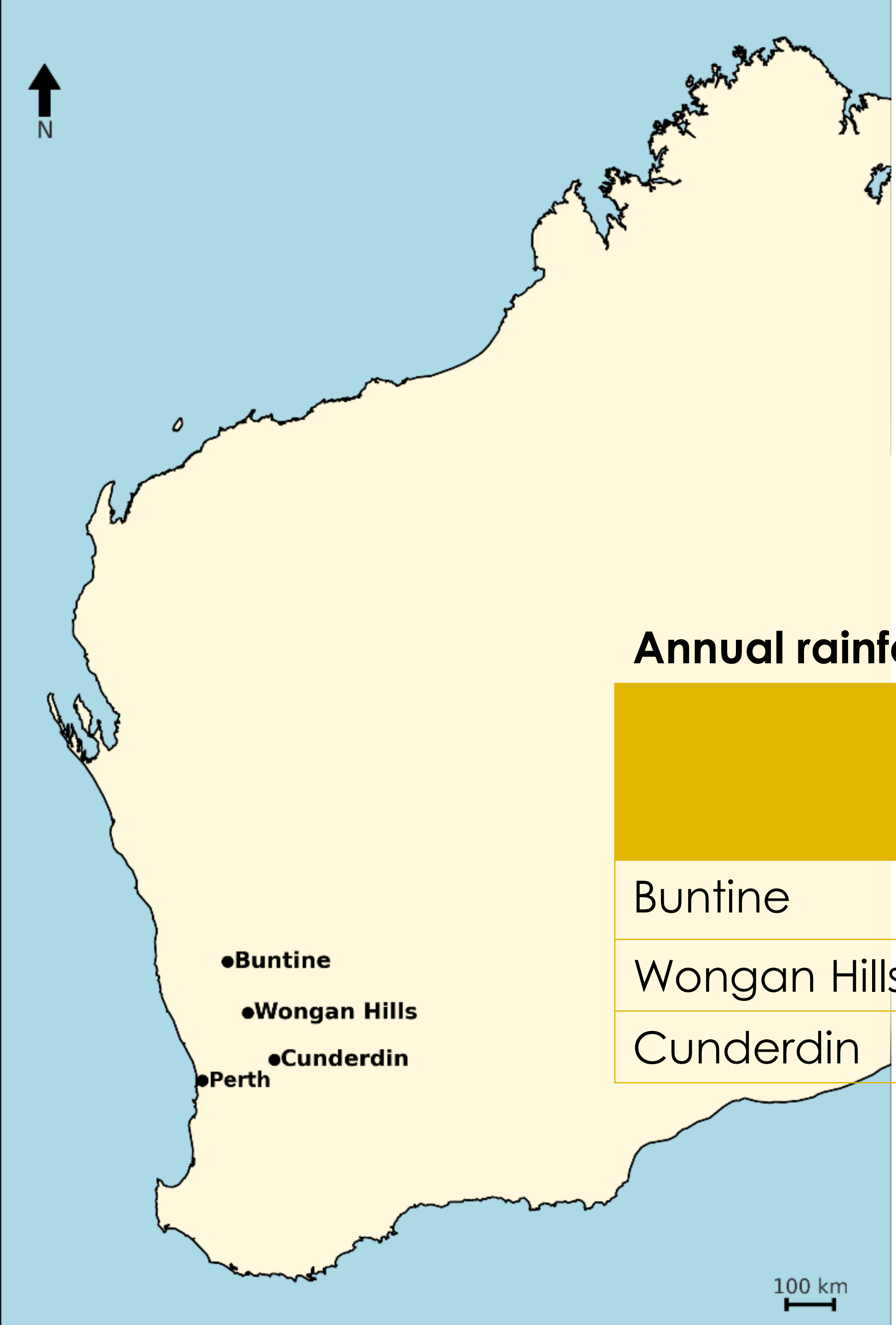
Cropping in winter; soils fallow at other times of the year

Produces up to 40% of Australia's grain exports

Extent of soil N_2O emissions?



Overall objective



Quantify effects of land management practise on annual soil N_2O emissions from cropping soils in a semi-arid environment

Land management practises: fertiliser N, inclusion of grain legumes, liming, soil C amendment

Annual rainfall and selected surface soil properties

	Australian Soil Group	Annual rainfall (mm)	%sand	%C	pH_{CaCl2}
Buntine	Tenosol	291	90	1.0	6.2
Wongan Hills	Tenosol	374	92	1.0	5.0
Cunderdin	Chromosol	368	93	1.0	6.0

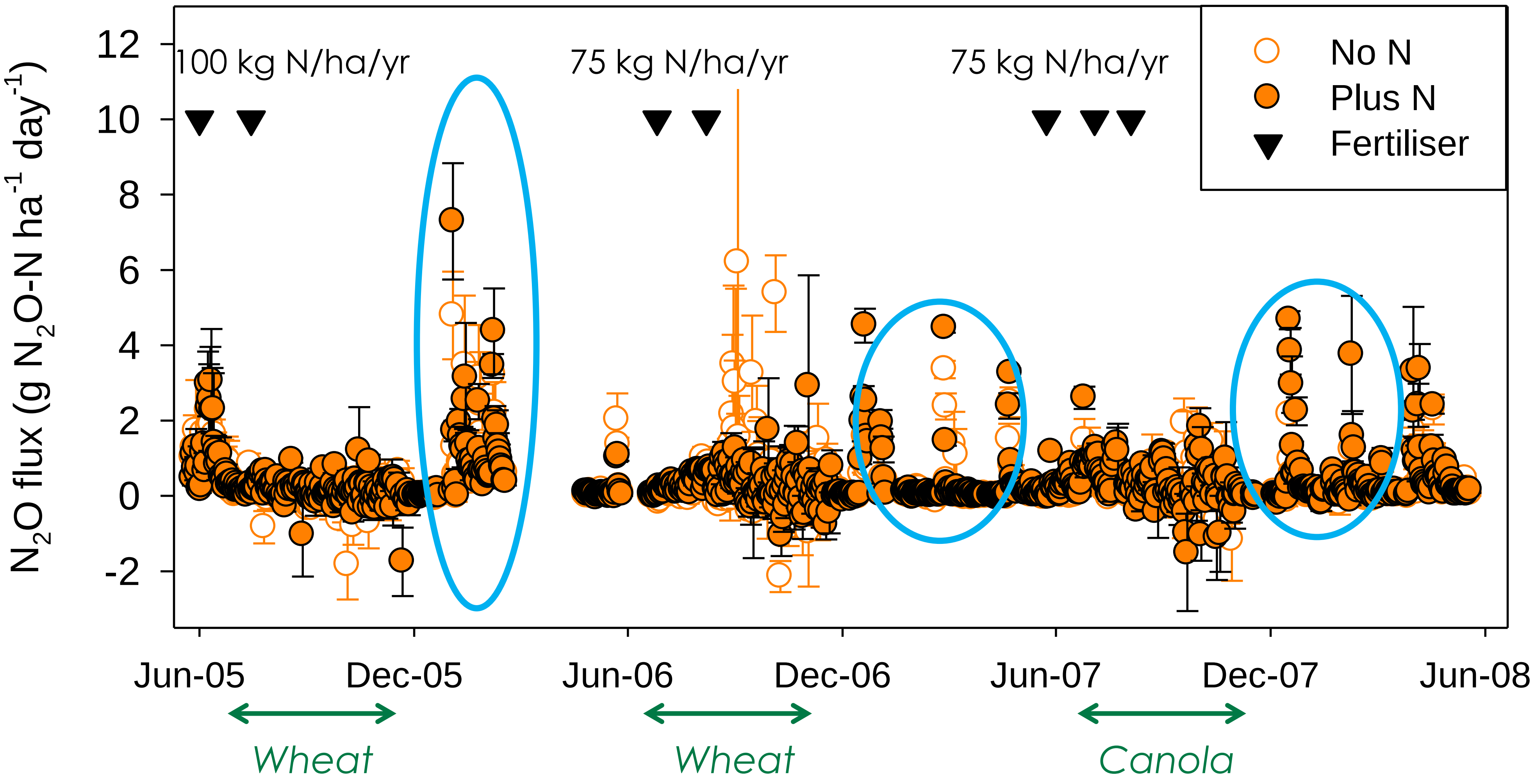
Measuring nitrous oxide emissions at Wongan Hills (above) and Cunderdin (right)

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

Rainfall triggers chambers to open

Daily N_2O emissions

Cunderdin



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

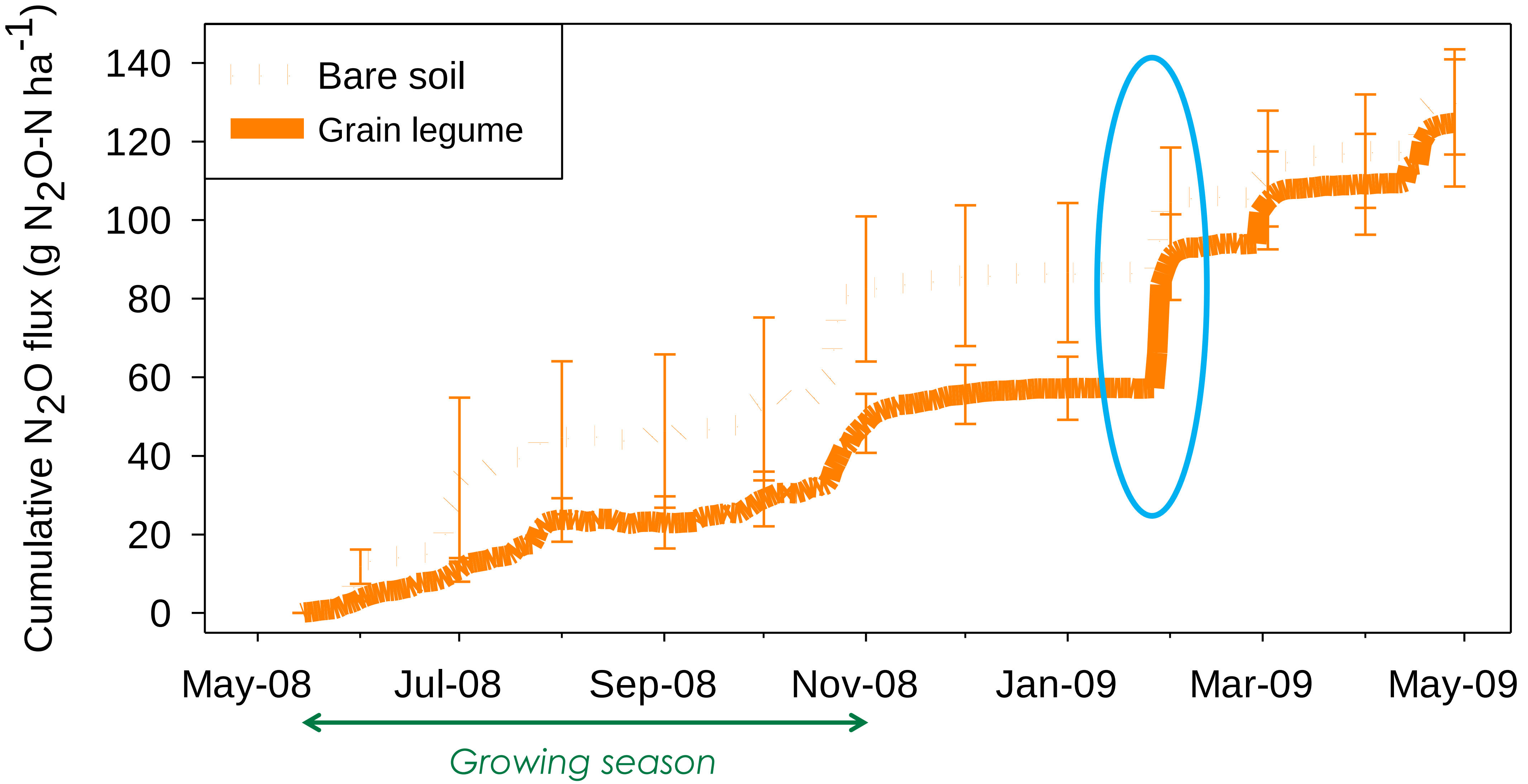
Annual soil N_2O emissions

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

Annual soil N_2O emissions from sandy, N fertilised WA cropped soils are low

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
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	0.01 0.02	0.01
Buntine	sand	barley barley	0 100	0.00 0.02	0.02

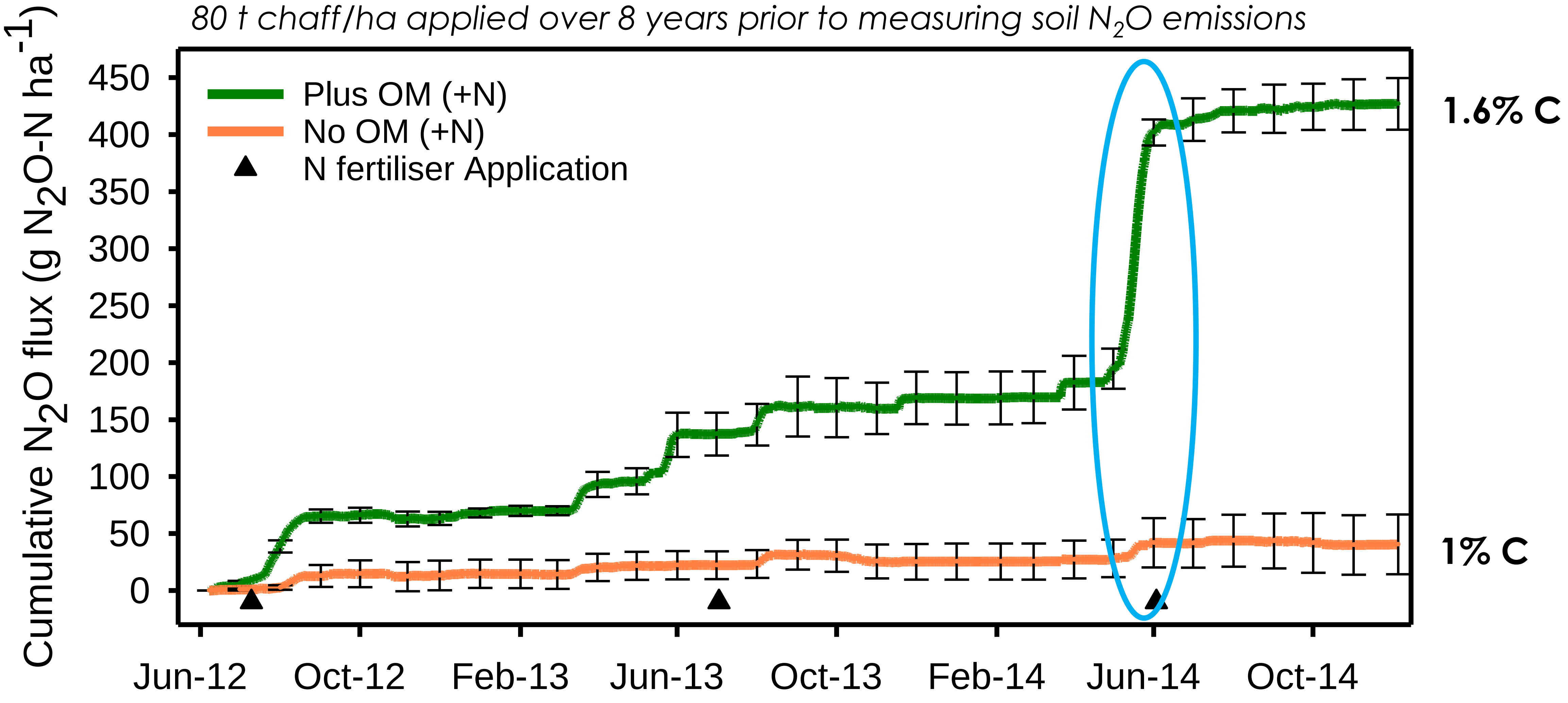
Grain legumes (lupin) do not increase cumulative N_2O emissions



Source: Barton *et. al.* 2011. *Global Change Biology* 17: 1153–1166.

‘Increasing’ soil organic carbon increased soil N_2O emissions ….

80 t chaff/ha applied over 8 years prior to measuring soil N_2O emissions



Source: Barton *et. al.* 2016. *Agriculture, Ecosystems and Environment 231*: 320–330.

…. But losses were 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 0.24	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

Accounting for N_2O emissions from N fertilizer application to land 'Direct source'

IPCC 2006 international default emission factor $_{\text{N fertilizer}}$ = 1.0%

i.e. 1 kg of N_2O-N will be emitted from 100 kg N fertilizer

Australian country specific values have been approved and vary with production system

Production system	Emission factor (% of N applied)
Irrigated pasture	0.59
Irrigated crop	0.70
Non-irrigated pasture	0.18
Non-irrigated crop (rainfed)	**0.41**
Sugar cane	1.99
Cotton	0.53
Horticulture	0.64

Source: Commonwealth of Australia. (2025) National Inventory Report 2022 – The Australian Government Submission to the United Nations Framework Convention on Climate Change. Australian National Greenhouse Accounts, April 2025.

Correctly account for soil N_2O emissions during fallow periods

55 to 85% of annual emissions

Need to expand soil N_2O measurements campaigns beyond growing season widely recognised.

Drivers of soil N_2O emissions vary between the growing season and fallow period – so important not to extrapolate.

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LETTER TO THE EDITOR

Global Change Biology WILEY

Soil N_2O emissions during dry fallow periods

Recently, Shang et al. (2024) analyzed 360 observations of soil N_2O emissions across 53 sites and showed the inclusion of these emissions during the fallow period—defined as the period between harvest and sowing of the following crop—doubled the N_2O emission factor (EF) for N fertilizer from 0.9% to 1.9%. This may be an important finding, supporting the need to improve national greenhouse gas (GHG) inventories based on the IPCC Tier 1 method.

There are, however, potential pitfalls of the proposed adjusted EFs for croplands in dry subhumid, semiarid, and arid regions with dry fallow periods. These regions cover about 47% of the Earth's terrestrial area (UNEP, 1997) and include major regions in sub-Saharan Africa (SSA), Australia, and South America, with SSA our main focus in this response.

First, it is widely recognized that expanding soil N_2O measurement campaigns to include the fallow period in croplands can increase measured cumulative emissions (Verhoeven et al., 2017). However, the drivers of the N_2O emissions in the fallow period are most likely different than those during the growing season. Fallow period N_2O emissions most likely stem from the mineralization of soil organic matter in response to soil wetting, and much less from residual N fertilizer from the growing season. Hence, emission differences between control and treatment are likely different between the growing season and the fallow period. Thus, a simple extrapolation of the EF based on an R_{fallow} (defined as the ratio of the fallow to the whole-year N_2O emissions) is most likely erroneous.

with fallow period measurements (Grace et al., 2023). As a result, we argue that the Shang et al.'s (2024) model leads to the overestimation of N_2O emissions in GHG inventories for countries having regions with dry fallow periods.

Third, Shang et al. (2024) mainly included study sites from the Global North, with a single study site for both SSA and South America. This is not a recommended practice to use such a limited dataset to extrapolate globally as farmers' practices and pedoclimatic contexts vary greatly. Furthermore, the notably high R_{fallow} observed by Dick et al. (2008) in the only SSA site (from Mali) requires scrutiny. This study involved unusually late planting of the crop, a month after the onset of the rainy season and after significant rainfall (170 mm). This is not representative of local practices where planting occurs after the first effective rains. This delayed planting artificially increased fallow period soil N_2O emissions, as the wet period before planting was included in the fallow period emission. The 4.1% EF reported by Dick et al. (2008) was also identified as a clear outlier in subsequent analyses (Zheng et al., 2019, figure S3).

Finally, we support the need for more observations of cropland N_2O emissions during the fallow period. Following a brief literature review, we found 26 articles on rainfed cropland soil N_2O emissions in SSA, and with only eight including soil N_2O emission measurements during the fallow period (Table S1). While R_{fallow} may vary from null to significant values, EFs are not necessarily impacted by fallow period N_2O emissions when considering background emissions from control treatments. Even for dry cli-

Source: Cardinael et al. 2024. *Global Change Biology* https://doi.org/10.1111/gcb.17403

Concluding statements and questions

Nitrous oxide emissions are (relatively) low from sandy, cropping soils in our region. But have not been well-characterised globally.

Good estimates ensure:

- Agriculture is accurately represented in National Greenhouse Gas Inventories
- Mitigation strategies are appropriately targeted
- ‘Carbon footprints’ of agricultural products are correctly estimated

How well do we currently model soil N_2O emissions from sandy soils in semiarid regions? Particularly, highly episodic events. We cannot measure N_2O emissions everywhere and for all scenarios, so modelling is important.

The regulation of soil N_2O emissions following summer/autumn rain is not fully understood in our region and warrants further attention if we are to model and develop mitigation strategies for these losses**.**