Nitrous oxide - an indicator of N loss?

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Take home messages

Nitrous oxide (N_2O) emissions from cropping soils are an important environmental issue, and can also be an indicator (not measurement) of agronomically significant nitrogen (N) losses from soil.

N_2O is produced in soils during,

- nitrification; the aerobic conversion of ammonium (NH_4^+) to nitrate (NO_3^-), and
- denitrification; the anaerobic conversion of NO_3^- to N_2O and di-nitrogen (N_2) gases.

During denitrification, alkaline clay soils lose about 40 times more N as di-nitrogen (N_2), than N_2O.

N_2 is not a greenhouse gas but its loss from the soil means less fertiliser N uptake by the plant.

N_2O losses from soil during several crops and crop rotations on a black cracking clay soil at Tamworth occurred predominantly during and after heavy rainfall when the soil was saturated; ideal conditions for denitrification to occur.

N_2O losses from fertiliser use form a major part of the total greenhouse gas emissions attributable to growing a crop. Utilising a nitrogen-fixing legume can reduce these emissions dramatically.

Background

Nitrous oxide (N_2O) is a greenhouse gas with 310 times the global warming potential of carbon dioxide, per molecule, and is also harmful to the ozone layer. The concentration of N_2O in the air is small but is steadily increasing. Agriculture is a major source of N_2O emissions to the atmosphere with much of the N originating from nitrogen fertiliser. N_2O emissions from the soil are a by-product of the process of nitrification, and one of the end-products of the process of denitrification.

Nitrification is the aerobic conversion of ammonium nitrogen (NH_4^+) to nitrate nitrogen (NO_3^-). Evidence from lab studies suggests that the proportion of N lost as N_2O during this conversion process is low, probably only about 0.4%, varying only a little with soil temperature and moisture.

Denitrification is the anaerobic conversion of nitrate nitrogen to the gases N_2O and di-nitrogen (N_2). This process occurs in waterlogged soils and requires an energy source (carbon) and warm soil temperatures. How much N is actually lost in the form of N_2O during denitrification depends on the soil's pH. In low pH (acidic) soils the N lost in the N_2O form can be half or more of the total N lost. However, in high pH (alkaline) soils the amount of N_2O lost in proportion to N_2 is very low. At pH >8, there is about 40 times more N_2 coming from denitrification as there is N_2O.

The typical concentration of N_2O in air is only 0.32 parts per million, but with sensitive equipment we can measure an increase in this concentration inside a sealed chamber over the soil. In a GRDC-funded research project, we have been measuring N_2O emissions from soil in 4 different cropping rotations on a black cracking clay soil near Tamworth during the last two and a half years.

Results

Table 1. Losses of nitrogen as N_2O from black cracking clay soil near Tamworth

Crop / Year	N added*	N_2O-N loss in season	N_2O-N loss in fallow
	(kg N/ha)	(g N/ha) [% of N added]	(g N/ha) [% of N added]
Canola (Ca) 2009	80	293 [0.33]	342 [0.62]
Chickpea (Cp) 2009	(41)**	28 [0.07]	113 [0.35]
Wheat 2010 (after Ca)	80	531 [0.54]	154 [0.64]
Wheat 2010 (after Cp)	80	389 [0.36]	168 [0.45]
Wheat 2010 (after Cp)	0	98 [na]	93 [na]
Sorghum 2010 (after Cp)	40	400 [0.78]	-

* N applied as urea at sowing, except for chickpea ** N added to the soil via biological N_2 fixation

Agronomically, these losses are insignificant. However, while we cannot say definitively how much of the N_2O has come from nitrification or denitrification, it is likely that denitrification dominated during and after periods of heavy rainfall when we measured highest rates of N_2O emissions. The majority of the losses occurred when soil moisture was saturated for a number of days; ideal conditions for denitrification. In the cases of wheat and sorghum sowing in 2010, rainfall immediately after sowing led to significant rates of N_2O loss from the applied fertiliser N. For example, in the 5 days after sowing wheat (with fertiliser applied), 139 g of N_2O-N/ha was emitted from the soil. If all of this had come from denitrification, that would mean another 5.5 kg N/ha was also lost as N_2. The N_2 emitted is not a greenhouse gas but does mean reduced plant N uptake.

Environmentally, these losses of N_2O from cropping soils are significant, with the N_2O emitted directly from the soil accounting for about 45% of the total greenhouse gas emissions coming from the entire operation of growing, fertilising, spraying and harvesting a wheat crop. Another 27% of the total came from urea production and urea hydrolysis in the soil. A complete Life Cycle Assessment of the CO_2-equivalents produced by our canola-wheat and the chickpea-wheat rotation treatments showed 1926 kg CO_2–e/ha coming from the canola-wheat compared to only 730 kg CO_2–e/ha from the chickpea-wheat (nil N applied), and 1290 kg CO_2–e/ha from the chickpea-wheat+N.

Losses of N_2O continue from the soil even after harvest (Table 1) as the crop residues constitute an organic N source that feeds mineralised N back into the soil. During the fallow period, the mineralised (nitrate) N is susceptible to denitrification loss should waterlogging conditions occur.

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