Strategies to reduce nitrous oxide emissions from nitrogen fertiliser applied to dryland sorghum. Part 4. Using ^{15}N to discover the fate of N fertiliser

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Key findings

For three seasons, we applied isotope-labelled urea (^{15}N) to sorghum in small (0.75–1.0 m^2) plots, then calculated nitrogen (N) recovery by comparing the amount applied with the total ^{15}N found in grain, crop residues and soil.

Between 55–85% of the N fertiliser applied was recovered at harvest, meaning a 15–45% loss, presumably during wet soil conditions when nitrate denitrification led to N_2 and N_2O gaseous losses.

In very wet conditions, little of the applied N remained in the soil at harvest, while in a dry season there was more of the applied N found in the soil at harvest than in the plant.

Introduction

During the past three years we have used isotope-labelled (^{15}N) urea fertiliser to trace the fate of applied nitrogen (N) in six season-long mini-plot field experiments with sorghum near Tamworth and Quirindi/Breeza in NSW. Normal N fertiliser contains ^{14}N, so using ^{15}N allows us to trace the urea-N applied into the harvested grain, the plant residues, large roots, and the soil profile after harvest. Due to its high cost, we used a 10% blend of ^{15}N with 90% ^{14}N fertiliser, which is a high enough ratio for us to easily identify and trace the fate of the applied N fertiliser. The difference between what we applied and the total of what we were able to find, either in the plant at harvest or in the soil post-harvest, was generally assumed to be N lost by denitrification when urea was mixed/banded into the soil at sowing. In treatments where we split the N application between banding at sowing and topdressing at the 7-leaf stage, some of the N loss could have occurred as ammonia volatilisation from the topdressing application.

At harvest, adjacent crop rows were sampled to quantify any applied N had been scavenged. We also excavated all the soil in the whole row-width around the application band to account for possible lateral movement of the ^{15}N. The mini-plots used for these experiments were either 0.75 m^2 or 1.0 m^2 and had raised steel borders to minimise surface runoff as a possible loss pathway. Possible leaching of applied N as nitrate in soil water was accounted for by deep coring to 150 cm depth.

Trials conducted in 2012–13 using ^{15}N applied at three N rates (40, 120 and 200 kg N/ha) were reported previously, but those results are repeated here for comparison with more recent trial results.

Trials in 2013–14 compared urea applied at 100 kg N/ha as either:

1. urea side-banded at sowing
2. urea topdressed at 7-leaf stage
3. Entec® urea side-banded at sowing.

Entec® urea is urea coated with the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP) [Incitec Pivot Fertilisers Ltd]. Trials were run at Tamworth and Quirindi.

In 2014–15, our treatments compared urea added at sowing, and urea split between sowing (33%) and 7-leaf stage topdressing (67%). At the Tamworth site, there were also two different N rates applied, depending on whether the previous crop was sorghum (120 kg N/ha) or soybean (40 kg N/ha). At Breeza, there was just one N rate (90 kg N/ha).

Site details

2012–13

Location:	**Tamworth**
Co-operator:	**NSW Department of Primary Industries (Tamworth Agricultural Institute)**
Agronomy:	**MR Bazley sown on 75 cm rows on 23 October 2012, harvested on 21 March 2013**
In-crop rainfall:	**322 mm**
Location:	**Quirindi**
Co-operator:	**Ian Carter (Romney Vale)**
Agronomy:	**MR Bazley sown on 75 cm rows on 8 December 2012, harvested on 3 March 2013**

In-crop rainfall: **407 mm**

2013–14

Location: **Tamworth**

Co-operator: **NSW Department of Primary Industries (Tamworth Agricultural Institute)**

Agronomy: **MR Bazley sown on 75 cm rows on 5 November 2013, harvested on 10 March 2014**

In-crop rainfall: **226 mm**

Location: **Quirindi**

Co-operator: **Ian Carter (Romney Vale)**

Agronomy: **MR Bazley sown on 75 cm rows on 22 October 2013, harvested on 19 March 2014**

In-crop rainfall: **183 mm**

2014–15

Location: **Tamworth**

Co-operator: **NSW Department of Primary Industries (Tamworth Agricultural Institute)**

Agronomy: **MR Bazley sown on 75 cm rows on 28 October 2014, harvested on 6 March 2015**

In-crop rainfall: **422 mm.**

Location: **Breeza**

Co-operator: **NSW Department of Primary Industries (Liverpool Plains Field Station)**

Agronomy: **MR Bazley sown on 100 cm rows on 11 November 2014, harvested on 20 March 2015**

In-crop rainfall: **264 mm**

Treatments

Tamworth 2012–13
40 kg N/ha urea side-banded at sowing
120 kg N/ha urea side-banded at sowing
200 kg N/ha urea side-banded at sowing

Quirindi 2012–13
40 kg N/ha urea side-banded at sowing
120 kg N/ha urea side-banded at sowing
200 kg N/ha urea side-banded at sowing

Tamworth 2013–14
100 kg N/ha urea side-banded at sowing
100 kg N/ha Entec® urea side-banded at sowing
100 kg N/ha urea topdressed at 7-leaf stage

Quirindi 2013–14
100 kg N/ha urea side-banded at sowing
100 kg N/ha Entec® urea side-banded at sowing
100 kg N/ha urea topdressed at 7-leaf stage

Tamworth 2014–15	
Name	Pre-crop, fertiliser
sorg_+N	After sorghum, 120 kg N/ha urea side-banded at sowing
soy_+N	After soybean, 40 kg N/ha urea side-banded at sowing
sorg_split	After sorghum, 40 kg N/ha urea side banded at sowing + 80 kg N/ha topdressed as urea at booting.
soy_split	After soybean, 10 kg N/ha urea side banded at sowing + 30 kg N/ha topdressed as urea at booting.

Breeza 2014–15	
N side-banded at sowing	N topdressed at booting
90 kg N/ha urea	0
30 kg N/ha urea	60 kg N/ha urea

Results

2012–13

- Total N loss (as $N_2 + N_2O$) was 28–45% of applied N (Figure 1). All loss was assumed to be through denitrification since the fertiliser was incorporated to prevent volatilisation, and no ^{15}N was detected below 60 cm depth, so no leaching occurred. The metal sides of the mini-plots prevented surface runoff losses. The 2–10% of applied ^{15}N detected in the adjoining plant rows was included with the plot grain and crop residue values.
- At the Tamworth (drier) site, there was no effect from N fertiliser rate on the proportion lost (21%; Figure 1–left).
- At the Quirindi (wetter) site, N losses were 43%, 44% and 27% from the 40, 120 and 200 kg N/ha treatments, respectively (Figure 1–right). It is likely that the proportion lost from the 200 kg N/ha rate was lower either because the denitrification process became carbon limited, or because some of the excess nitrate N moved lower down the soil profile during the heavy rainfall period rather than being denitrified. As a result, some of the excess N was available late in the season for uptake leading to increased grain protein in this treatment at Quirindi.

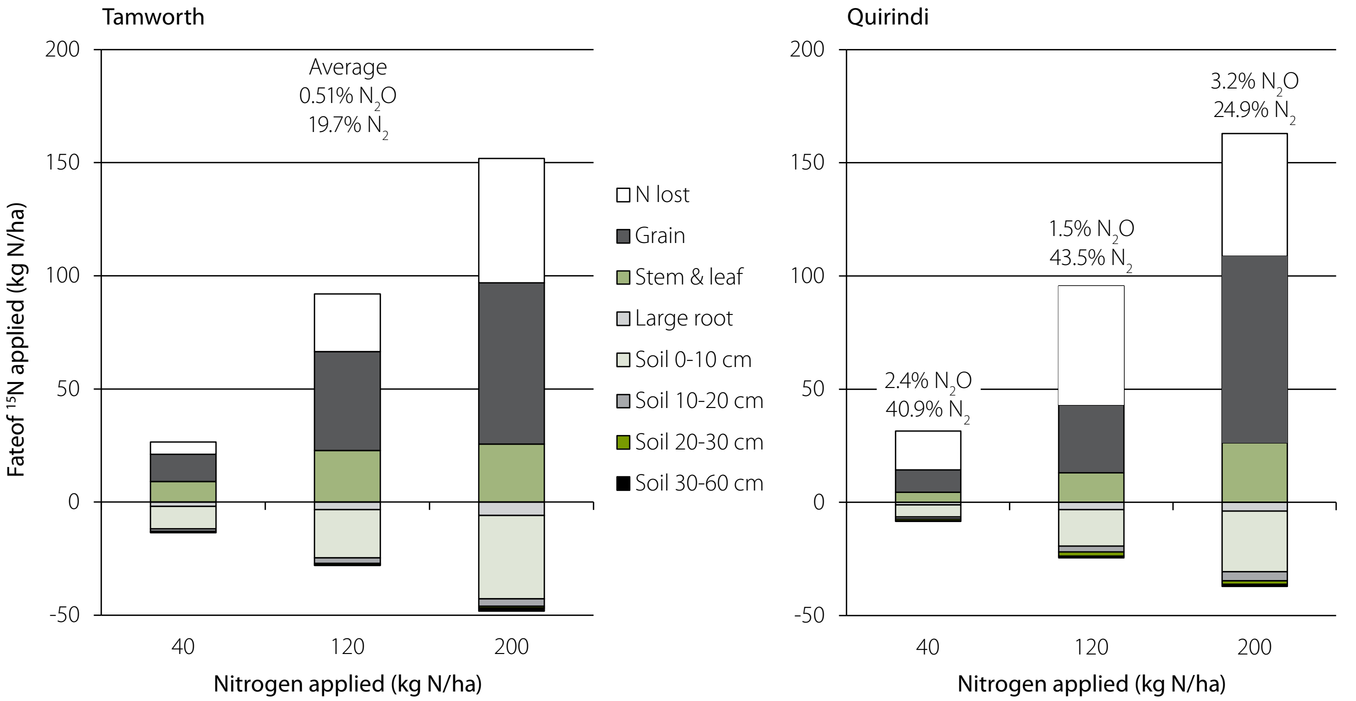

Figure 1. *Fate of applied ^{15}N in trials at Tamworth (left) and Quirindi (right) in the 2012–13 sorghum season. At both trials, rates of N applied were 40, 120 and 200 kg N/ha side-banded at sowing. Loss percentages written on graphs are estimates of N lost through nitrous oxide (N_2O) and di-nitrogen (N_2) during denitrification*

2013–14

- At the Tamworth site, there was an average N loss of 26%, with no difference in total N loss between the three treatments. However, there were distinct treatment differences in the fate of the recovered N (Figure 2–left).
- Only 10% of the N applied was found in plant tissue at harvest when urea was applied at the 7-leaf stage, compared with an average of 36% of the fertiliser N in the plant when N was applied at sowing. This is because there was only one rainfall event after the late-applied N fertiliser, and therefore limited opportunity for plant uptake of the top-dressed N.

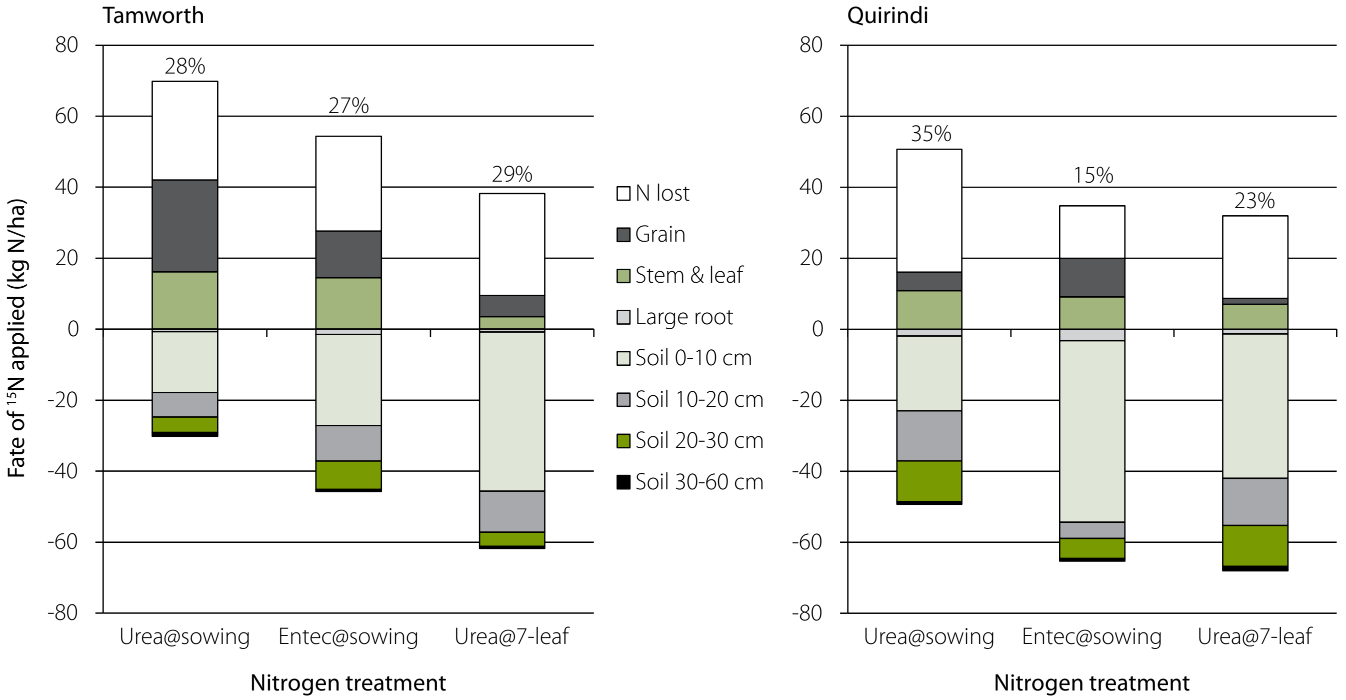

Figure 2. *Fate of applied ^{15}N in trials at Tamworth (left) and Quirindi (right) in the 2013–14 sorghum season. Rate of N applied was 100 kg N/ha for all treatments*

- More of the applied N from Entec® was recovered in the soil at harvest compared with urea (at both sites). Poor recovery of fertiliser N by the crop during this very dry season could have contributed to this difference.
- More of the N applied at the 7-leaf stage was retained in soil to benefit the following crop, along with N mineralised from the crop residues. Compared with the previous year, more of the applied ^{15}N was found in lower depths of the soil profile, indicating nitrate leaching occurred with the end of season rainfall after crop uptake had ceased.
- At the Quirindi trial, there was only 15% total N lost from the Entec® inhibitor treatment, compared with an average N loss of 29% from urea either applied at sowing or at the 7-leaf stage (Figure 2. right).
- The main difference between the urea and the inhibitor treatment was in the extra 15% of applied N found in the soil at harvest in the treatment where the inhibitor had been used, compared with ordinary urea.
- Crop N uptake of applied fertiliser N was low across all treatments but, especially in the late-applied urea treatment, which contributed very little N to the harvested grain. Only 13% of the late-applied N was found in the plant tissue (including grain) at harvest, compared with an average of 28% in the other treatments applied at sowing.

2014–15

- At Tamworth, overall N losses averaged 29% and were not proportionately affected by whether the previous crop was sorghum or soybean (Figure 3, left).
- Total N losses at Tamworth were 4% greater when the N was applied all at sowing. This difference in N loss was due to an extra 4% found in the top 0–10 cm of the soil of the split N treatments. There was no difference in N recovery in the crop uptake between all at sowing and the split application treatments. This is despite significantly greater biomass and grain yields (data not shown) in the split treatments compared with the all at sowing treatments.
- Very little of the applied fertiliser N was recovered in the soil below 10 cm depth, despite the very high in-crop rainfall experienced, especially at the Tamworth site. This is similar to soil ^{15}N recovery patterns in the 2012–13 trials. In 2014–15, the intense rainfall events occurred in December–January once the crop had established so downward movement of nitrate-N with percolating water was minimal compared with results from 2013–14 (see above) where late season rainfall moved unused nitrate-N into the 10–20 cm and 20–30 cm soil layers (Figure 2).

- At Quirindi there was a 4% greater loss from the split application treatment, which was primarily due to less of the applied ^{15}N being recovered from the 0–10 cm soil depth (Figure 3–right). There was less rainfall in total at Quirindi and none for six days after the topdressing application, so ammonia volatilisation could have contributed to the N loss in this trial.

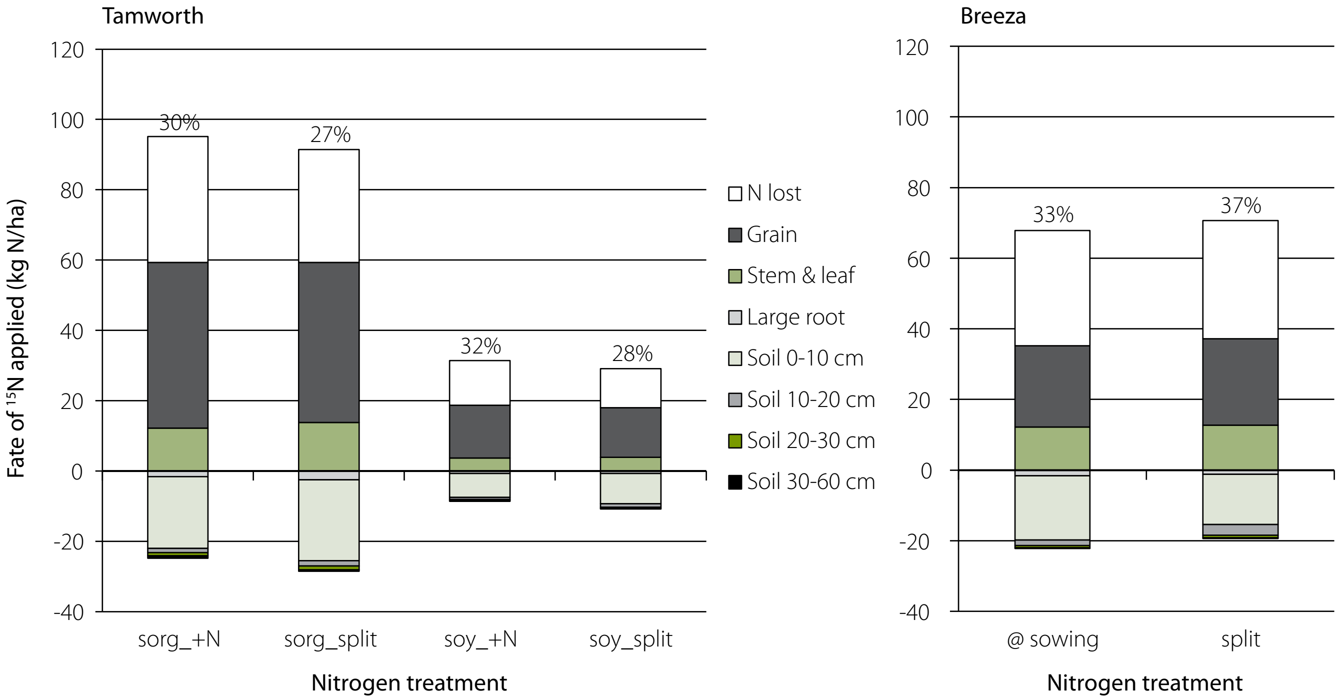

Figure 3. *Fate of applied ^{15}N in trials at Tamworth (left) and Breeza (right) in the 2014–15 sorghum season. Rate of N applied was 120 kg N/ha (post-sorghum) and 40 kg N/ha (post-soybean) at Tamworth; and 90 kg N/ha at Breeza*

Summary

In three very different sorghum seasons in terms of rainfall conditions, our ^{15}N trials have shown total N losses were 15–45% depending on the N application strategy. Total N loss results were often surprising, with those from the very dry 2013–14 season higher than expected, probably because of late rainfall events on unused soil nitrate, while those from the very wet 2014–15 season were perhaps lower than expected, probably because the intensive rainfall conditions occurred after the crop had established and already taken up much of the ^{15}N applied.

In 2012–13, increasing the rate of applied N led to more N loss, especially in the very wet Quirindi trial, but losses from the 200 kg N/ha rate treatment could have been limited by available carbon at the soil surface.

In 2013–14, strategies employed to delay the availability of soil nitrate during the initial two months before rapid crop N uptake, were found to either reduce total N loss compared with the standard urea applied all at sowing (Breeza), or were no different in terms of N loss (Tamworth). Both trials found the Entec® treatment retained more of the applied N in the soil at harvest. The delayed urea application strategy led to poor crop N uptake due to prolonged dry conditions post-application, but much of the applied N was recovered in, or returned to, soil in crop residues after harvest.

The split N strategy examined in 2014–15 slightly reduced total N loss at Tamworth, compared with the all at sowing standard practice, with the difference being related to more N retained in the soil at harvest. The opposite effect was found in the Breeza trial where dry conditions after applying N as topdressing most likely led to losses through ammonia volatilisation.

It should be remembered that the ^{15}N recovered in the grain, crop residue and soil represent only the N applied as fertiliser and does not include the uptake of N sourced from mineralisation of soil organic matter and previous crop residues.

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