Increased N efficiency in pastoral systems: the urine-N cascade

Tim Clough
Soil factors
Plant factors
Climate
Management

SOIL PHYSICS

BIOLOGY

CHEMISTRY

TIME
UREA – dominant urinary-N compound

Concentration a function of animal N intake - plant N concentration & intake
UREA

Duration a function of urease activity

Concentration a function of animal N intake - plant N concentration

Soil concentration

Time
UREA

Duration a function of urease enzyme activity

Urease inhibition e.g. nBPT

Soil concentration

Concentration a function of animal N intake
- plant N concentration

Reduce plant N concentration
N partitioning through diet?
UREA transformed to **AMMONIUM (NH₄⁺)**

Ammonia (NH₃) loss

Removed via NH₃ loss, plant uptake, nitrification

UREA transformed to AMMONIUM (NH$_4^+$)

Ammonia (NH$_3$) loss: average of 10% of N deposited typically over 2-5 days

\[
\text{Urea} + \text{H}_2\text{O} \xrightarrow{\text{urease}} \text{NH}_4^+ + \text{CO}_3^{2-} \\
\text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{OH}^- \quad \text{Soil pH 8-9} \\
\text{NH}_4^+ + \text{OH}^- \leftrightarrow \text{NH}_3 + \text{H}_2\text{O}
\]

Soil pH 8-9
Ammonia volatilisation

\[
\text{NH}_3(\text{g}) \text{ atmosphere} \\
\text{NH}_3(\text{g}) \leftrightarrow \text{NH}_3(\text{aq}) \\
\text{soil} \\
\text{NH}_4^+(\text{aq}) \\
\text{Urea fertiliser} \\
(\text{NH}_2)_2\text{CO} \\
\text{NH}_4^+ (\text{exchange sites}) \\
\text{Organic N}
\]
Main factors affecting NH$_3$ volatilisation from soil - summary

1. soil pH and temperature
2. position of ammoniacal-N in soil
3. windspeed
4. urine-N rate
5. soil moisture
AMMONIUM nitrified to NITRITE ($\text{NO}_2^-$)

- $\text{NO}_2^-$ peak at ~ 7 days
- Gateway for most gaseous N losses.
Fig. 4 Transformations of mineral nitrogen in soil (for explanations see text).

N Wrage, G.L Velthof, M.L van Beusichem, O Oenema

Role of nitrifier denitrification in the production of nitrous oxide

Soil Biology and Biochemistry, Volume 33, Issues 12–13, 2001, 1723 - 1732
Figure 1. Nitrogen transformation processes affecting nitrous oxide and di-nitrogen production in soil (1 = nitrification; 2 = denitrification; 3 = dissimilatory reduction of nitrate to ammonium; 4 = chemo-denitrification; 5 = nitrogen fixation)
Figure 6. Regression results. Single-factor regression models of (a) cumulative nitrite (c-\(\text{NO}_2^-\)) versus cumulative solution-phase ammonia (c-\(\text{slNH}_3\)) and (b) cumulative actual \(\text{N}_2\text{O}\) production (c-\(\text{aN}_2\text{O}\)) versus c-\(\text{NO}_2^-\) with regression lines, and multiple regression models describing (c) c-\(\text{NO}_2^-\) and (d) c-\(\text{aN}_2\text{O}\) as functions of cumulative solution-phase ammonium (c-\(\text{slNH}_4^+\)) and cumulative acidity (c-H\(^+\)) with 1:1 lines, for all microcosm data (Series 1-3).

Venterea et al. 2015 Nature Science Reports – in revision
Figure. 5. Gene copy abundances in Series 3 microcosm experiment. (a) amoA-b, (a) amoA-a, and (c) nxrA following addition of Ur at 1000 mg N kg⁻¹ soil with soils at 85% of FC. Asterisks indicate significant differences between soils at $P < 0.05$. Normalized gene abundances are expressed relative to the number of copies of prokaryotic (bacteria+archaea) 16S rRNA genes in each sample (45).

Venterea et al. 2015 *Nature Science Reports – in revision*
Ammonium ($\text{NH}_4^+$) nitrified to nitrite ($\text{NO}_2^-$) cont’d.

So we need to retain the $\text{NH}_4^+$ and prevent $\text{NO}_2^-$ formation.

**Nitrification inhibition**
- add chemicals manually or biologically e.g. BNI
- (targeting ‘who’?)

Or enhance plant N uptake – Root architecture? Plant activity? Gibberellic acid?
Nitrite nitrified to nitrate ($\text{NO}_3^-$)

- Removed via plant uptake, leaching, denitrification, immobilisation.
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Balaine et al. showed that the WFPS (%) affects the N2O-N (mg m\(^{-2}\) h\(^{-1}\)) emissions. The graph illustrates the relationship between WFPS and N2O-N with different bulk densities (1.1 to 1.5). The emissions increase with increasing WFPS and then decrease as WFPS approaches 95%. The error bars indicate the variability in the data.
Experimental set up for measuring relative soil gas diffusivity.

Relate microbial process to Dp/Do? – use isotopomers?

How much does ‘critical’ Dp/Do vary with soil O₂ demand?
Fig. 1 Development of mean maximum N2O concentration and observed diffusion flux (a), time- and depth-specific contour plot of the N2O concentration over time for treatment TC (b), time- and depth-specific contour plot of the redox potential over time

Hansen et al. 2014 Flooding-induced N2O emission bursts controlled by pH and nitrate in agricultural soils Soil Biology and Biochemistry, Volume 69, 2014, 17 - 24
What don’t we know with respect to increasing N use efficiency?

Dissolved organic-N leaching – Horotiu soil, autumn urine event leads to DON concentrations ~ 30% of NO$_3^-$

Immobilisation of urinary-N ? Priming?

Urine patch and fertiliser N interaction: Effects of fertiliser rate and season of urine application on nitrate leaching and pasture N uptake.
Summary - Interventions:

Chemical: Inhibitors and growth promoters (nBPT, nitrification inhibitors, GA).

Biological: Plant: N content, rooting structure, activity.

Physical: Soil oxygen status, pH

Do we know which microbes to target with interventions?