MM12: Nitrification Inhibitors and Combined Inhibitors

Category

Cropland and grassland management: nutrient management

Overview

When applied to soils, part of the nitrogen in ammonia-based fertilisers and in organic nitrogen sources is converted to nitrate by nitrifying bacteria. In this process other nitrogen compounds, including N_2O, are also released. Nitrification inhibitors alter these biochemical processes by depressing the activity of the nitrifiers, leaving the fertiliser in the soil in ammonium form longer, improving its plant availability (Akiyama *et al.* 2010, Macadam *et al.* 2003, Rodgers 1986). Consequently, nitrification inhibitors can reduce N_2O emissions and also nitrate leaching in high rainfall circumstances. As these compounds are degraded by soil bacteria, the temporary inhibition effect disappears (de Klein *et al.* 2011). Various compounds have been identified as nitrification inhibitor, probably the most widely studied ones are dicyandiamide (DCD), 3,4-dimethyl pyrazole phosphate (DMPP) and nitrapyrin.

Furthermore, urea based fertilisers have a high rate of ammonia volatilisation when applied to soils, due to the urease enzyme in soil bacteria. This leads not only to ammonia (and indirect N_2O) emissions, but reduces the N plants can utilise. Urease inhibitors delay the urea hydrolysis to ammonia, reducing ammonia emissions (Harty *et al.* 2016). Using urea in combination with urease inhibitors and nitrification inhibitors can further reduce N_2O emissions.

Mitigation summary

Table 1 Effects on emissions

GHG categories	Effect*	Notes
Enteric CH_4		
Manure CH_4		
Manure N_2O		
Soil N_2O: applied N	-	
Soil N_2O: grazing	-	
Energy CO_2: fieldwork	(+)	
Energy CO_2: other		
CO_2 liming and urea		
CO_2 sequestration below ground		
CO_2 sequestration above ground		
Pre-farm emissions		Production of inhibitor
Post-farm emissions		
Substitution of higher C products		
Production increases by more than the emissions		

GHG categories	Effect* Rating	Notes
Confidence in mitigation effect	High	
Cost-effectiveness**	High	
Confidence in cost-effectiveness	Moderate	

* ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential synergies

Table 2 Likely effects on the abatement potential of other measures

Measure	Impact
	-
	-

Inclusion in other marginal abatement cost curves

Table 3 Past assessment of the measure

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
Yes	Yes	Yes	No	Yes	?

What does the measure entail?

Nitrification and urease inhibitors can be injected into the soil together with liquid fertilisers, can be applied as a coating on granular fertilisers and can be mixed into slurry before application. Additionally, they can be spread after grazing to reduce emissions from the urine.

We considered the application of DCD and *N*-(*n*-butyl) thiophosphoric triamide (NBPT, e.g. in the commercial product Agrotain®), as these are the compounds where most experimental results are available in the UK. Application rate is generally 10-15 kg DCD ha^{-1} once or twice a year (Cardenas *et al.* 2019, de Klein *et al.* 2011, Misselbrook *et al.* 2014) and 0.5-1 g for each kg of urea applied (Harty *et al.* 2016).

Abatement rate

The effectiveness of nitrification inhibitors in reducing N_2O emissions and nitrogen leaching depend on a variety of factors. In a meta-analysis of 113 datasets of field experiments Akiyama *et al.* (2010) found that the N_2O reduction effect depended on the type of nitrification inhibitor and land use type. The effect also depends on the type of fertiliser used (Misselbrook *et al.* 2014) and on environmental conditions at the site (Cardenas *et al.* 2019).

UK experiments showed variable results. In fertiliser experiments by Misselbrook *et al.* (2014) across six sites (including arable and grassland fields), N_2O emissions from ammonium nitrate were significantly reduced at two sites (average effect -43%), while N_2O

emissions from urea treatment were significantly reduced at four sites (average effect -54%). The mean N_2O emission reduction across the six experiments was 38% and 64% for DCD applied with ammonium nitrate and urea, respectively. There was no significant effect of DCD on ammonia emissions, apart for one site, and yield was not significantly affected either in all but one case (where it was reduced by 20%).

Cattle urine experiments by the same authors showed significant reduction in 3 out of 4 cases, with a mean effect of -70%. Ammonia emissions and grass yields were not significantly affected. Slurry experiments did not reveal any significant effect, as variability amongst the replicates were very high.

Grassland experiments in the UK with ammonium nitrate and urea fertiliser showed mixed results too. Cardenas *et al.* (2019) found that DCD increased the N_2O emission factor at one site significantly (by 20%), decreased it at another site significantly (by 52%), and had no significant effect at another three sites. When DCD was applied with urea the N_2O emission factor changed significantly at only one site (-94%). However, applying urea instead of ammonium fertiliser reduced the N_2O emission factor by 49%, and using urea combined with DCD resulted in 85% reduction in the N_2O emission factor compared to using ammonium nitrate only. Yield changes were not significant in any case.

Experiments at two permanent grassland sites in Ireland showed that urea applied with a combination of urease and nitrification inhibitor reduced N_2O emissions by 56% (Harty *et al.* 2016).

Urease inhibitors – as their primary aim – also reduce the NH_3 volatilisation from urea on average by 50% (Silva *et al.* 2017), thus reducing indirect N_2O emissions. This effect is not considered in the study, resulting a small (less than 10%) underestimation of the GHG abatement rate.

Table 4 Data from literature on abatement

Abatement	Value	Country	Reference
N_2O emissions	Average: -38% (95% confidence interval: -44% to -31%) DCD: -30% (CI -36% to -26%) nitrapyrin: -50% (CI -55% to -30%) DMPP: -50% (CI -55% to -42%)	Across the world	(Akiyama *et al.* 2010) meta-analysis
N_2O emission factor	DCD with ammonium nitrate: -38% DCD with urea: -64% DCD with cattle urine: -70%	UK, grass and arable	(Misselbrook *et al.* 2014) - experiments
N_2O emission factor	DCD with ammonium nitrate: -19% DCD with urea: -66%	UK, grass	(Cardenas *et al.* 2019) - experiments
N_2O emission factor	DCD and NBPT with urea: -56%	Ireland, gass	(Harty *et al.* 2016) - experiments

Cost

The cost of the measure consists of the additional cost of the inhibitor(s) and, in case of application for grazed land, additional spreading costs.

Table 5 Financial costs and benefits of the measure

Costs/savings	Value ('-' sign for savings)	Notes
DCD cost, for rate 15 kg DCD ha^{-1} once a year	£0.5 (kg N)$^{-1}$	£5 kg^{-1} in Eory *et al.* (2015); 15 kg DCD ha^{-1} once a year, assuming 150 kg N ha^{-1} average fertilisation of croplands with synthetic N, therefore DCD application is 0.1 kg (kg N)$^{-1}$
DCD cost, for rate 10 kg DCD ha^{-1} twice a year	£100 ha^{-1}	£5 kg^{-1} in Eory *et al.* (2015)
NBPT (Agrotain®) cost	£0.087 (kg N)$^{-1}$	30% active ingredient content in Agrotain®; average of $9-10 acre^{-1} and $3-4 acre^{-1}£: £13 ha^{-1} (https://talk.newagtalk.com/forums/thread-view.asp?tid=368542&DisplayType=flat, https://www.farmprogress.com/agrotain-boosting-urea-efficiency, respectively) assuming 150 kg N ha^{-1} average fertilisation of croplands with synthetic N
AGROTAIN® PLUS SC (urea + urease inhibitor NBPT and nitrification inhibitor DCD)	no information	https://kochagronomicservices.com/solutions/agricultural-nutrient-efficiency/agrotain-plus-sc/ can be combined with liquid manure and urea ammonium nitrate
ALZON® neo-N (urea + urease inhibitor 2-NPT and nitrification inhibitor MPA)	£0.02 (kg N)$^{-1}$	"a £15-20 premium over straight urea" https://www.thescottishfarmer.co.uk/business_sales/15636959.all-weather-fertiliser-arrives/
Spreading cost	£11 ha^{-1}	For grazed land only, assuming two spreading Contractor spreading €40 t^{-1} for bagged fertiliser, i.e. ~€6 ha^{-1} https://www.teagasc.ie/media/website/publications/2015/DairyNews_June2015.pdf

Applicability

Nitrification inhibitors can be applied in combination of both synthetic and organic fertilisers, both on cropland and grassland. In our analysis, due to the potential complications when using these compounds with organic fertilisers, we only considered the application with synthetic fertilisers.

The proportion of different N fertilisers used are likely to change over the coming years both as a result of relative prices and of potential regulatory changes. However, as the direction of these changes are not clear, the modelling assumed that the proportion stays constant.

Current uptake and maximum additional future uptake

Current uptake is likely to be negligible in the UK for nitrification inhibitors (Gooday *et al.* 2014); Glenk et al. (2014) found 4.3% of dairy farmers reporting on use. Available information from the US shows that the cumulative uptake of urease inhibitors, nitrification inhibitors and controlled release urea was 10% amongst corn farmers (Weber and McCann 2015).The maximum additional future uptake in this study, based on the information above, is assumed to be 95%.

Assumptions used in the MACC

Parameter	Change in value	Notes
EF_1 for AN	-25%	
EF_1 for urea	-50%	
Leaching, ammonia volatilisation	No effect	
Current uptake	0	
Cost of urease inhibitor and nitrification inhibitor	£0.1 (kg N)$^{-1}$	

Wider effects

Table 6 Wider effects of the measure

Aspect	Effect	Reference
Positive effects		
Off-farm GHG		
Production		
Adaptation		
Environment	Reduced nitrate leaching and ammonia emissions	
Negative effects		
Off-farm GHG	GHG emissions from the production of the inhibitors	
Production		
Adaptation		
Environment	No scientific publication was found on the potential effects of the inhibitors on human health or biodiversity	

1.1.1 Identified implementation challenges and barriers

Table 7 Potential barriers of the measure

Barrier to uptake	Reference
Confusing information about the various inhibitor and controlled/slow release fertiliser products	
Cost	
Other key risks/uncertainties	**Reference**

References

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