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December 2025

Scientific review of Nitrogen fertiliser rates for silage production in Northern Ireland

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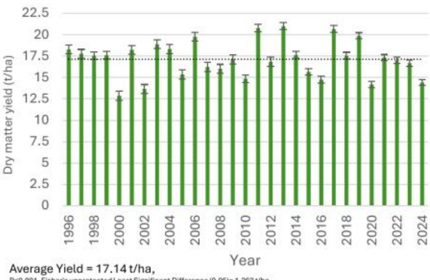
11th December 2025

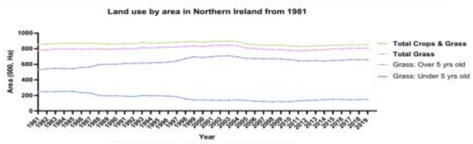
afbini.gov.uk

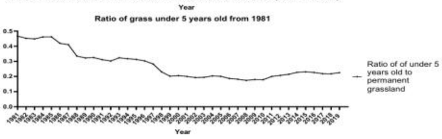
Overview of the region

Dry matter yield (t/ha) of grass silage under 4-5 cuts annually in the 1st year of cutting

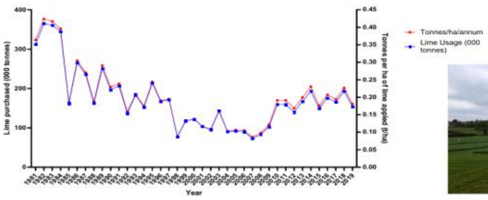


Average Yield = 17.14 t/ha,
P<0.001, Fisher's unprotected Least Significant Difference (0.05)= 1.263 t/ha





Lime purchased (000 tonnes) and corresponding annual rate (t/ha/annum) if divided by area of Total Crops and Grass



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Evolution of the RB209

7th Edition (Defra 2000)

Maximum N rates (kg N/ha/yr) for intensively cut grass systems or grazed systems at high stock densities, as influenced by Soil Nitrogen Supply (SNS) and Grass Growth Class (adapted from RB209 7th edition)

Grassland system	Grass Growth Class	SNS status		
		Low	Moderate	High
Cutting ($N_{7.5}$)	All	420	380	340
Grazing – dairy cattle ($N_{7.5}$)	Average, Poor, Very Poor	380	340	300
	Good	420	380	340
	Very Good	460	420	380

Based on N opt of 7.5 kg Dm/kg N applied

8th Edition (2010)

Milk Yield (l/cow/year)	Concentrate use (t/cow/year)	Stocking rate (LU/ha)	Total N requirement		
			Cut		Grazed
			kg/ha	Indicative yield (t DM/ha)	kg/ha
8,000 to 10,000	4.4	4.0	360	11.2	280
		3.5	310	10.6	210
		3.0	260	9.7	150
8,000 to 10,000	3.7	3.0	370	11.3	300
		2.6	310	10.5	210
		2.2	240	9.4	150
6,000 to 8,000	2.2	2.6	360	11.2	320
		2.2	280	10.1	210
		1.8	200	8.5	140
6,000 to 8,000	1.5	2.2	360	11.2	340
		1.8	260	9.8	210
		1.6	210	8.8	170
6,000 to 8,000	0.9	1.9	330	10.9	320
		1.7	280	10.1	240
		1.5	230	9.1	190
4,000 to 6,000	0.9	2.4	350	11	330
		2.1	280	10.1	240
		1.8	210	8.8	180
4,000 to 6,000	0.5	2.1	320	10.7	290
		1.9	270	9.9	230
		1.7	220	8.9	190
< 5,000 extended grazing	0.5	2.5	350	11.1	340
		2.2	310	10.6	240
		2.0	270	9.9	200

Based on N_{opt} of 10.0 kg Dm/kg N applied

Current recommendations

June 2016

AHDB
AGRICULTURE & HORTICULTURE DEVELOPMENT BOARD

Research Review No. 3110149017

Review of evidence on the principles of crop nutrient management and nutrition for grass and forage crops

Paul Newell Price[1], Kate Smith[2] and John Williams[2]

[1]ADAS Gleadthorpe, Meden Vale, Mansfield, Nottinghamshire, UK, NG20 9PD
[2]ADAS Boxworth, Battlegate Road, Boxworth, Cambridgeshire, UK, CB23 4NN

Published 2017.

Latest update published in June 2023 (current online version). N rates in Table 3.8 remain unchanged.

Table 3.8 Nitrogen recommendations for grass silage

Target annual DM yield[a] (t/ha)	N application rate (kg N/ha)				Total N applied[b]
	1st cut	2nd cut	3rd cut	4th cut	
5–7	70	-	-	-	70
7–9	80	50	-	-	130
9–12	100	75	75[c]	-	250
12–15+	120	90	70[c]	30[c]	310[d]

a. DM yield as harvested in the field for all cuts combined. Does not include spoilage in the clamp. Fresh yield is four times these values if the silage is 25% DM.

b. As manufactured fertiliser and crop available nitrogen from organic materials.

c. If previous growth has been severely restricted by drought, reduce or omit this application.

d. This total N could be applied to a three-cut system (yielding around 15 t DM/ha), with the fourth cut recommendation of 30 kg N/ha being split between the second and third cuts.

Nutrients Action Programme (NAP) Proposed Changes

2019-2022 NAP

Table 4

Regulation 10 – Nitrogen application standards for grassland crops

	Dairy Cattle[2]	*Other livestock*[2]
Balance of crop nitrogen requirement (kg N/ha/yr) (e.g. from chemical fertiliser or organic nitrogen supply other than livestock manure)[1]	272	222

[1] This table does not imply any departure from regulation 9(1) which prohibits the application to the agricultural area on a holding of livestock manure in amounts which exceeds 170 kg N/ha/yr, including that deposited by the animals themselves.

[2] The dairy cattle figures (dairy cows and heifer replacements) apply where it can be demonstrated that more than 50% of the livestock manure applied to the agricultural area, both by land application and by the animals themselves, arises from dairy cattle. In all other cases the figures for other livestock will apply.

2026-2029 NAP

Table 7: N Fertiliser Limits for Grass Silage

Farm Enterprise Type	*Typical number of silage cuts per year*	*Target annual DM yield (t/ha)*	*Total crop N requirement (kg N/ha/yr) RB209 (2019)*	*Derogated farm operating up to 250 kg N/ha/yr limit. Additional fertiliser N required**	*Non-derogated farm operating up to 170 kg N/ha/yr limit. Additional fertiliser N required***	*Extensive farm operating up to 120 kg N/ha/yr. Additional fertiliser N required****	
Extensive, low input	1-2	5-7	70	N/A	N/A	22	
Extensive	2	7-9	130	N/A	N/A	82	
Dairy & Intensive beef	3	9-12	250	150	182	N/A	**40 kg**
Intensive, high yielding, high input	3-4	12-15+	310	210	242	N/A	**30 kg**

*A derogated farm with input of up to 250 kg N/ha/yr from livestock manure. This slurry would supply 100 kg N/ha/yr plant available N. The remainder of crop requirement should come from inorganic fertiliser.
** A non-derogated farm with input of up to 170 kg N/ha/yr from livestock manure. This slurry would supply 68 kg N/ha/yr plant available N. The remainder of crop requirement should come from inorganic fertiliser.
*** All of the above are whole-farm limits. Silage fields will require proportionally more nitrogen and grazed fields lower

During drought conditions, there should be no application of nitrogen fertiliser.

Overview of datasets

Overview details of studies with sward characteristics and N fertiliser rates used at AFBI Hillsborough and at the eight-study sites

Study	Year	Location	RB209 Grass Growth Class*	Number of cuts	Growing Conditions	Nitrogen (N) fertiliser rates used (kg/ha)															
						0	75	80	100	130	150	160	200	225	250	240	300	310	320	400	500
(Higgins et al., 2012)	2007	AFBI Hillsborough	V. Good	4	Good	x	x				x			x			x				
(Higgins et al., 2012)	2008	AFBI Hillsborough	V. Good	4	Good	x	x				x			x			x				
(Higgins et al., 2012)	2009	AFBI Hillsborough	V. Good	4	Good	x	x				x			x			x				
(Cardenas et al., 2019)	2011	AFBI Hillsborough	V. Good	3	Good	x		x				x				x			x	x	
DARD E&I 11/04/02	2012	AFBI Hillsborough	V. Good	3	Poor	x		x				x				x			x	x	
(Forrestal et al., 2017)	2013	AFBI Hillsborough	V. Good	4	Poor	x			x				x				x			x	x
(Forrestal et al., 2017)	2014	AFBI Hillsborough	V. Good	5	Good	x			x				x				x			x	x
Eight-study sites	2022-24	Ballybogey	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	Coleraine	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	Dark Hedges	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	Glenwherry	Average	3	Good	x				x					x			x			
Eight-study sites	2022-24	Greenmount	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	Moneyglass	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	Slemish	V.Good	3	Good	x				x					x			x			
Eight-study sites	2022-24	The Loup	V,Good	3	Good	x				x					x			x			

*Grass Growth Class has been informed though yield potential of the site compared to indicative RB209 response class

Assessment of data

Hillsborough data

- 1 Site x 7 years = 7 site x year data sets
- N rates up to 500 kg/ha
- 2 years – atypical weather (2012 & 2013)

Eight sites data

- Two different grass growth classes (GGC)
- 8 sites x 3 years = 24 site x year data sets

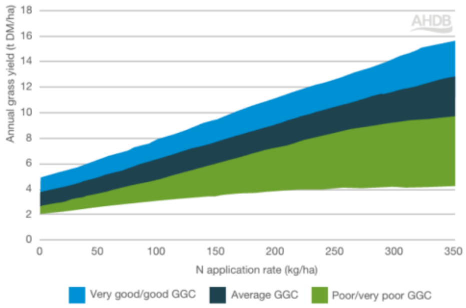


Figure 3.1 Indicative grass dry matter yield by grass growth class (GGC)
Grass swards greater than three years old with minimal clover and low to moderate soil nitrogen supply (SNS).

Overview of soil fertility – Hillsborough Site

Experimental Site	Year	Location	Soil pH	P Index	K Index	Mg Index	S Index
Higgins et al 2012*	2007	AFBI Hillsborough	5.70	3	3	3	3
Higgins et al 2012*	2008	AFBI Hillsborough	5.80	3	3		
Higgins et al 2012*	2008	AFBI Hillsborough	5.78	3	3		
Cardenas et al 2019	2011	AFBI Hillsborough	6.45	3	3		
DARD E&I 11/04/02	2012	AFBI Hillsborough	5.91	3	2+	4	3
Forrestal et al 2017	2013	AFBI Hillsborough	5.77	4	2+	5	3
Forrestal et al 2017	2014	AFBI Hillsborough	5.61	3	2-	4	3

*This was a liming trial. Lime was added in small amounts annually. Data on yield and soil pH are available at plot level. The quoted figure is a mean across the experimental site (117 plots)

In all trials it was not possible to add lime to bring the sites to the optimum pH. This would have required extension of the trials by 1 year each. P & K were applied as per soil results to ensure non-limiting.

Overview of soil fertility at each of the eight sites

Experimental Site	Soil pH	P Index	K Index	Mg Index	S Index
1	6.15	3	2+	6	4
2	6.07	3	2+	4	4
3	5.85	2+	2+	6	4
4	5.54	3	2-	7	3
5	5.85	3	2-	6	3
6	5.83	3	2-	4	4
7	5.96	3	3	6	4
8	6.55	3	2-	6	3

In all trials it was not possible to add lime to bring the sites to the optimum pH. This would have required extension of the trials by 1 year each. P & K were applied as per soil results to ensure non-limiting.

Comparison with RB209 – Very Good Grass Growth Class (GGC)

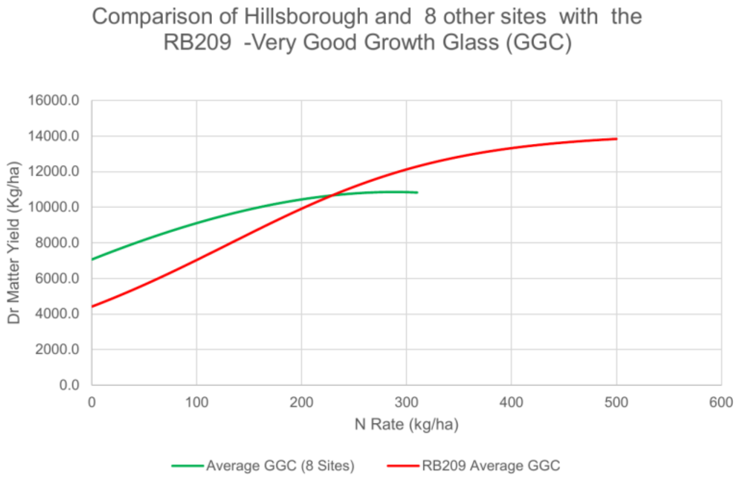
Curve and estimated parameters

Fitted Curve: A + B*(R**X) + C*X

Parameter	estimate	s.e.
R	0.9972	0.00383
B	-15951	
C	-7.303	
A – Poor	21146	
A – Typical Year	23328	

Percentage variance accounted for 87.3

Comparison with RB209 – Average Grass Growth Class (GGC)



Curve and estimated parameters

Fitted Curve: A + B*(R**X) + C*X

Parameter	estimate	s.e.
R	1.00257	0.0075
B	-13957	
C	75.98	
A - Good GGC	19183	
A - Very Good GGC	21164	

Percentage of variance accounted for 71.6

Breakeven values (kg DM/ kg N)

Breakeven Kg Dm silage/ kg N required at various prices of silage and fertiliser

Can Price (£/tonne)			£200	£225	£250	£275	£300	£325	£350	£375	£400	£425	£450	£475	£500	£525	£550	£575	£600
(£/ Kg N)	Fresh)*	DM	£0.74	£0.83	£0.93	£1.02	£1.11	£1.20	£1.30	£1.39	£1.48	£1.57	£1.67	£1.76	£1.85	£1.94	£2.04	£2.13	£2.22
Silage Price (£/tonne)*	£25.0	£92.6	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0
	£27.5	£101.9	7.3	8.2	9.1	10.0	10.9	11.8	12.7	13.6	14.5	15.5	16.4	17.3	18.2	19.1	20.0	20.9	21.8
	£30.0	£111.1	6.7	7.5	8.3	9.2	10.0	10.8	11.7	12.5	13.3	14.2	15.0	15.8	16.7	17.5	18.3	19.2	20.0
	£32.5	£120.4	6.2	6.9	7.7	8.5	9.2	10.0	10.8	11.5	12.3	13.1	13.8	14.6	15.4	16.2	16.9	17.7	18.5
	£35.0	£129.6	5.7	6.4	7.1	7.9	8.6	9.3	10.0	10.7	11.4	12.1	12.9	13.6	14.3	15.0	15.7	16.4	17.1
	£37.5	£138.9	5.3	6.0	6.7	7.3	8.0	8.7	9.3	10.0	10.7	11.3	12.0	12.7	13.3	14.0	14.7	15.3	16.0
	£40.0	£148.1	5.0	5.6	6.3	6.9	7.5	8.1	8.8	9.4	10.0	10.6	11.3	11.9	12.5	13.1	13.8	14.4	15.0
	£42.5	£157.4	4.7	5.3	5.9	6.5	7.1	7.6	8.2	8.8	9.4	10.0	10.6	11.2	11.8	12.4	12.9	13.5	14.1

*Assuming silage is 27 % dry matter with no feed out or fermentation losses

Future N prices

Carbon Border Tax Adjustment Mechanism (CBAM) effective in the EU in 2026 and in the UK in 2027 will add 10-15 % (£44-66/tonne at current prices) to urea fertiliser (Milenkova and English, 2025).

Economic N optimum rate

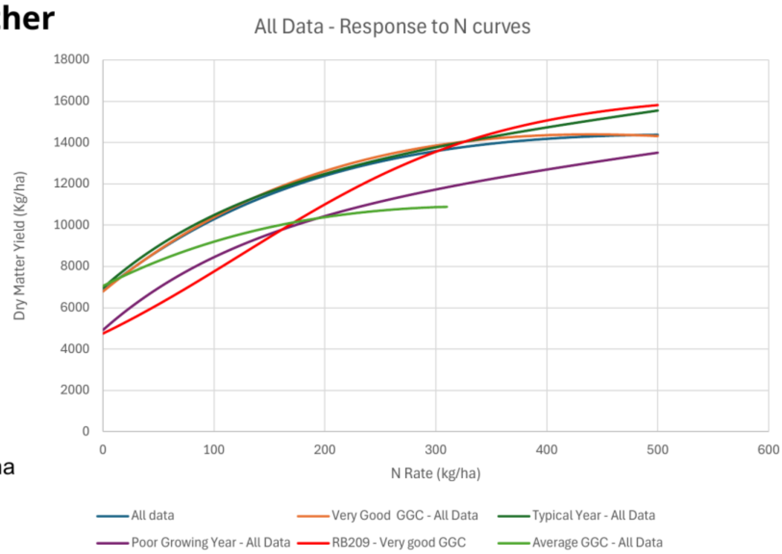
N_{opt} = The rate of N whereby the dry matter yield increase is insufficient to cover the additional cost of N applied

- Calculated using a nonlinear regression

Yields and dry matter per Kg of applied N per ha for different growing conditions (Typical v Poor) and grass growth class (GGC)

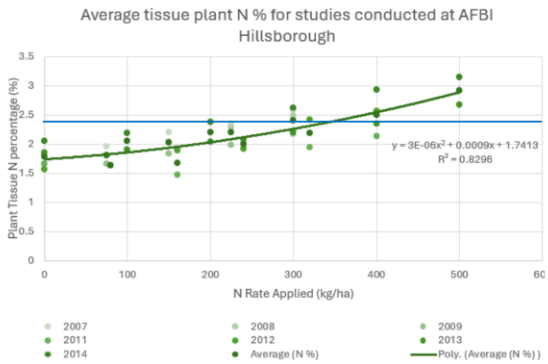
	Hillsborough Data				Eight Sites Data			
N Rate (Kg/ha)	Typical Year (DM Yield (kg/ha)	Typical Year (Kg Dm/ Kg N)	Poor Year (DM Yield (kg/ha)	Poor Year (Kg Dm/ Kg N)	Very Good GGC	Very Good GGC (Kg Dm/ Kg N)	Average GGC	Average GGC (Kg Dm/ Kg N)
0	7377	-	5195	-	6945.0	-	7065.0	-
10	7745	36.8	5563	36.8	7365.1	42.0	7296.6	23.2
20	8100.8	35.6	5918.8	35.6	7775.3	41.0	7522.6	22.6
30	8444.8	34.4	6262.8	34.4	8175.3	40.0	7742.8	22.0
40	8777.2	33.2	6595.2	33.2	8564.7	38.9	7957.1	21.4
50	9098.4	32.1	6916.4	32.1	8943.4	37.9	8165.3	20.8
60	9408.8	31	7226.8	31	9311.0	36.8	8367.3	20.2
70	9708.5	30	7526.5	30	9667.4	35.6	8562.9	19.6
80	9997.9	28.9	7815.9	28.9	10012.0	34.5	8752.0	18.9
90	10277.3	27.9	8095.3	27.9	10344.8	33.3	8934.3	18.2
100	10546.9	27	8364.9	27	10665.2	32.0	9109.7	17.5
110	10807.1	26	8625.1	26	10973.1	30.8	9278.0	16.8
120	11058.1	25.1	8876.1	25.1	11268.2	29.5	9439.0	16.1
130	11300.1	24.2	9118.1	24.2	11549.9	28.2	9592.6	15.4
140	11533.3	23.3	9351.3	23.3	11818.1	26.8	9738.5	14.6
150	11758.2	22.5	9576.2	22.5	12072.3	25.4	9876.5	13.8
160	11974.8	21.7	9792.8	21.7	12312.2	24.0	10006.5	13.0
170	12183.3	20.9	10001.3	20.9	12537.5	22.5	10128.2	12.2
180	12384.1	20.1	10202.1	20.1	12747.7	21.0	10241.4	11.3
190	12577.3	19.3	10395.3	19.3	12942.4	19.5	10345.8	10.4
200	12763.2	18.6	10581.2	18.6	13121.2	17.9	10441.3	9.6
210	12941.9	17.9	10759.9	17.9	13283.8	16.3	10527.7	8.6
220	13113.6	17.2	10931.6	17.2	13429.6	14.6	10604.6	7.7
230	13278.6	16.5	11096.6	16.5	13558.3	12.9	10671.8	6.7
240	13437	15.8	11255	15.8	13669.4	11.1	10729.1	5.7
250	13589	15.2	11407	15.2	13762.4	9.3	10776.3	4.7
260	13734.8	14.6	11552.8	14.6	13836.9	7.5	10812.9	3.7
270	13874.5	14	11692.5	14	13892.4	5.5	10838.9	2.6
280	14008.3	13.4	11826.3	13.4	13928.4	3.6	10853.8	1.5
290	14136.4	12.8	11954.4	12.8	13944.3	1.6	10857.5	0.4
300	14259	12.3	12077	12.3	13939.7	-0.5	10849.5	-0.8
310	14376.1	11.7	12194.1	11.7	13914.0	-2.6	10829.7	-2.0
320	14488	11.2	12306	11.2				
330	14594.8	10.7	12412.8	10.7				
340	14696.6	10.2	12514.6	10.2				
350	14793.6	9.7	12611.6	9.7				
360	14885.9	9.2	12703.9	9.2				
370	14973.6	8.8	12791.6	8.8				

All Data – Together

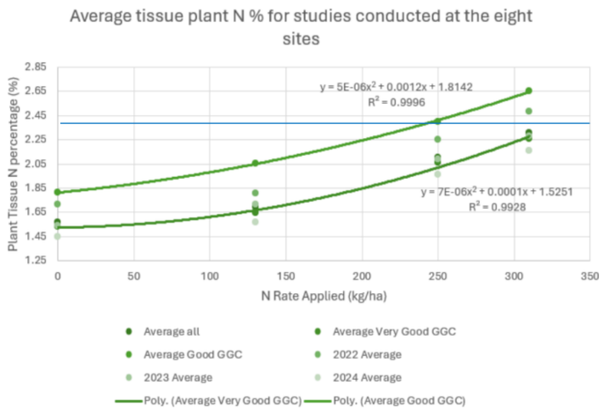


N Opt – Values
All Data = 280 kg/ha
Very Good GGC = 280 kg/ha
Typical Year = 330 kg/ha
Poor Year = 330 kg/kg N
Average GGC = 170 kg/ha

Grass Tissue Analysis (N %)

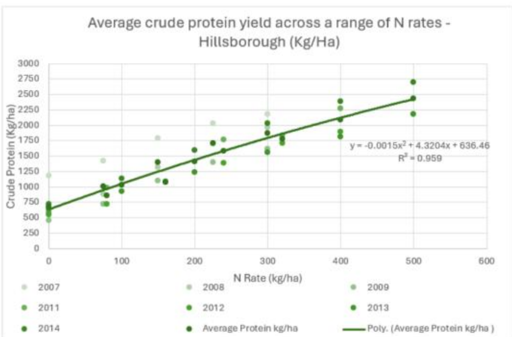


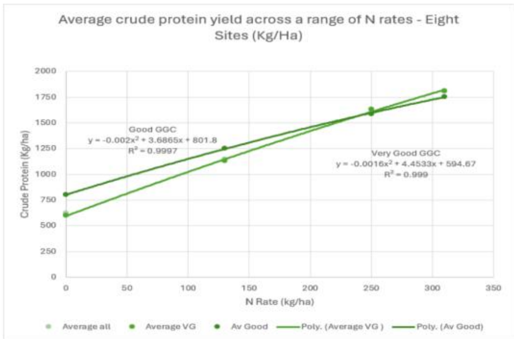
Hillsborough site
2.25 % = 288 Kg N/ha
2.4 % = 342 Kg N/ha



Average GGC **2.4 %** = 242 Kg N/ha **2.25 %** = 199 Kg N/ha
Very Good GGC **2.25 %** = 315 Kg N/ha

Crude protein production across a range of N rates (kg/ha)

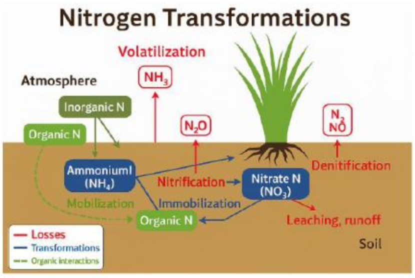




Crude protein production 4.2 - 4.35 Kg/ha per Kg of N applied

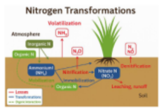
Assessment of N losses

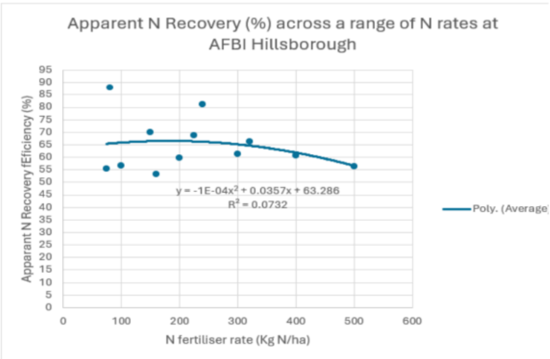
- Apparent N Recovery Percentage $\text{ANR \%} = \left(\frac{N\,offtake_{treatment} - N\,offtake_{control}}{NRate}\right) x\ 100$
- Nitrogen Use Efficiency (NUE) $NUE = \frac{Sum\ N\ inputs\ (Fertiliser\ N\ applied\ +\ N\ deposition)}{(N\ offtake\ +\ losses)}$
- Gaseous emission – N_20 + Ammonia NH_3

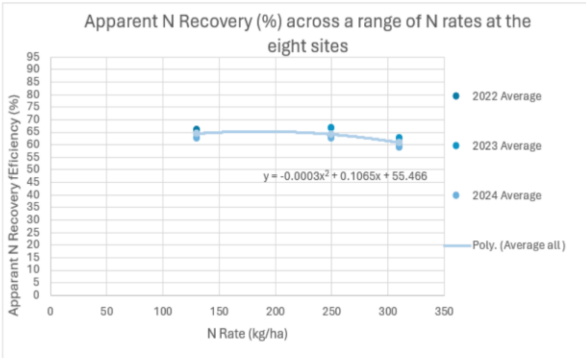


ANR %

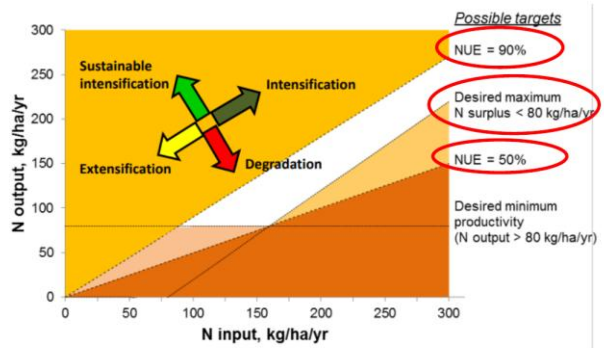
$$\text{ANR \%} = \left(\frac{N\,offtake_{treatment} - N\,offtake_{control}}{NRate}\right) x\ 100$$







EU Nitrogen Expert Panel NUE recommendations



N deposition (kg/ha/annum)

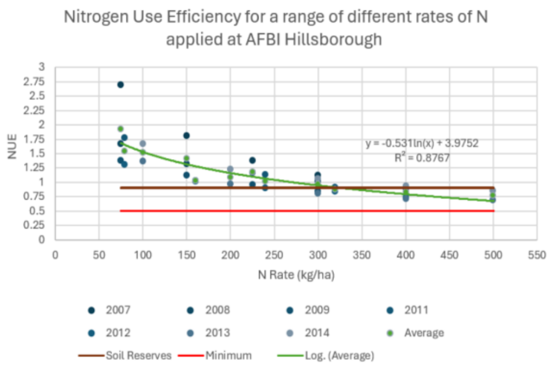
Location	Kg N/Annum Deposited
Ballybogey	6.71
Coleraine	5.81
Dark Hedges	6.71
Glenwherry	14.43
Greenmount	5.7
MoneyGlass	6.28
Slemish	11.82
The Loup	6.61
Hillsborough	8.92

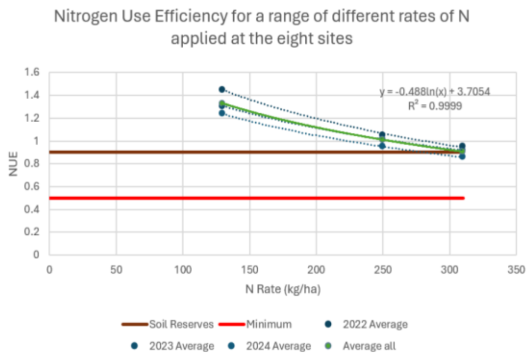
Source: Site Relevant Critical Loads & Search by Location | APIS

Onema, O., Brentrup, F., J, L., P, B., Billen, G., A, D., Erisman, J.W., T, G., M, H., Haniotis, T., J, H., Hoxha, A., Jensen, L., Oleszek, W., C, P., D, P., Quemada, M., M, S., Ma, S., Winiwarter, W., 2015. Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems Prepared by the EU Nitrogen Expert Panel.

Nitrogen Use Efficiency

$$NUE = \frac{Sum\ N\ inputs\ (Fertiliser\ N\ applied\ +\ N\ deposition)}{(N\ offtake\ +\ losses)}$$



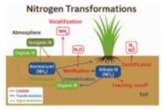


327 kg/ha N

NUE is typically higher in field trials than on-farm (Cassman et al., 2002, Ladha et al., 2005)

313 kg/ha N

N Surpluses – NUE



N surpluses calculated from N inputs - N offtake (kg/ha)

Dataset	N applied (kg/ha)															
	0	75	80	100	130	150	160	200	225	240	250	300	310	320	400	500
Hillsborough	-101.7	-77.1	-69.5	-56.2	-	-65.6	-4.7	-19.2	-39.8	-33.7	-	10.3	-	28.8	63.9	118.8
8 Sites	-81.6				-40.5						-1.9		26.2			

Gaseous losses: nitrous oxide N_20 + ammonia NH_3

Nitrous oxide is a long-lived GHG, with a warming potency of at least x300 that of carbon dioxide (CO2), (IPCC, 2014)

Studies using AFBI Hillsborough site:

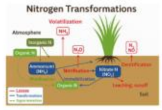
N_20

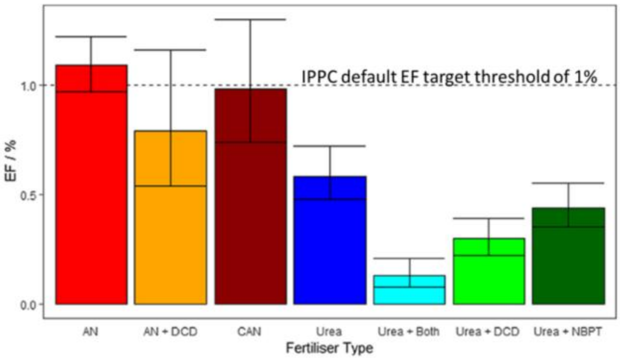
- Cardenas, L.M., Bhogal, A., Chadwick, D.R., McGeough, K., Misselbrook, T., Rees, R.M., Thorman, R.E., Watson, C.J., Williams, J.R., Smith, K.A., Calvet, S., 2019. Nitrogen use efficiency and nitrous oxide emissions from five UK fertilised grasslands. Science of The Total Environment 661, 696-710.
- Rahman, N., Richards, K.G., Harty, M.A., Watson, C.J., Carolan, R., Krol, D., Lanigan, G.J. and Forrestal, P.J., 2021. Differing effects of increasing calcium ammonium nitrate, urea and urea+ NBPT fertiliser rates on nitrous oxide emission factors at six temperate grassland sites in Ireland. Agriculture, Ecosystems & Environment, 313, p.107382.

NH_3

- Forrestal P. J., Harty M., Carolan R., Lanigan G. J., Watson C. J., Laughlin R. J., McNeill G., Chambers B. J. & Richards K. G. 2015. Ammonia emissions from urea, stabilized urea and calcium ammonium nitrate: insights into loss abatement in temperate grassland. Soil Use and Management, 284141690. doi: 10.1111/sum.12232

N_2O emission factors by N type –UK wide study





Comparison of the EFs for different fertiliser types, AN, CAN and urea, with and without DCD and NBPT inhibitors.

Source (Cowan et al., 2020)

Cowan, N., Levy, P., Moring, A., Simmons, I., Bache, C., Stephens, A., Marinheiro, J., Brichet, J., Song, L., Pickard, A., McNeill, C., McDonald, R., Maire, J., Loubet, B., Voylokov, P., Sutton, M. and Skiba, U. 2019. Nitrogen use efficiency and N_2O and NH_3 losses attributed to three fertiliser types applied to an intensively managed silage crop. Biogeosciences, 16(23), 4731—4745.

N_20 emissions

2011 experimental year

$$EF_1 = \frac{(N_2O_{total(fertiliser)} - N_2O_{total(control)})}{Fertiliser N_{applied}} \times 100$$

Ammonium Nitrate

Emission factor (% of N applied lost as N_2O)

	C	AN80	AN160	AN240	AN320	AN400	s.e.d.
Crichton	–	1.06abc	1.14abc	1.23abc	1.34abc	1.74c	0.23
Drayton	–	1.18c	1.04c	0.74bc	0.87c	0.86c	0.15
North Wyke	–	2.04bcd	1.29abc	1.36abc	2.86d	2.87d	0.40
Hillsborough	–	0.67b	0.59ab	0.64b	0.44ab	0.65b	0.17
Pwllpeiran	–	0.71bc	0.62bc	0.58bc	0.77bc	0.69bc	0.12
Mean	–	1.132	0.936	0.91	1.256	1.362	
Hills % of Mean		59%	63%	70%	35%	48%	

Letters a to f indicate significant differences between treatments ($P < 0.05$).

Protected Urea

Emission factor (% of N applied lost as N_2O)

	AN320	AN320+DCD	U320	U320+DCD	s.e.d.
Crichton	1.34abc	1.00abc	0.91ab	0.60a	0.23
Drayton	0.87c	0.86c	0.24ab	0.08a	0.15
North Wyke	2.86d	1.89bcd	0.63ab	0.30a	0.4
Hillsborough	0.44ab	0.53ab	0.30ab	0.03a	0.17
Pwllpeiran	0.77bc	0.37ab	0.52bc	0.03a	0.12
Mean	1.256	0.93	0.52	0.208	
Hills % of Mean	35%	57%	58%	14%	

Letters a to f indicate significant differences between treatments ($P < 0.05$).

Source (Cardenas et al., 2019)

Source (Rahman et al., 2021)

N_20 emissions

2013 & 2014 experimental year

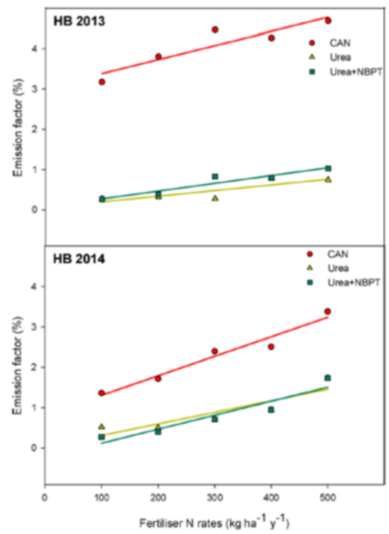
Cumulative N_2O-N emission (kg ha^{-1}) and emission factors (%) from five N application rates at six site-years in Ireland.

		Control (0)	CAN 100	Urea 100	Urea + NBPT 100	CAN 200	Urea 200	Urea + NBPT 200	CAN 300	Urea 300	Urea + NBPT 300	CAN 400	Urea 400	Urea + NBPT 400	CAN 500	Urea 500	Urea + NBPT 500
12a) Cumulative emission (kg ha−1)																	
MP	2013	0.89e	1.43de	0.96e	1.15e	2.05cde	1.09e	1.32e	4.28a	1.98cde	2.39bcde	3.77ab	2.40bcde	3.92ab	3.52abc	3.06abcd	3.77ab
	2014	0.73e	1.12cd	0.91de	1.02cde	3.60ab	1.30cde	1.54cd	4.03a	1.93bcd	3.82ab	3.50ab	4.67a	5.75a	4.63a	5.00a	5.08a
JC	2013	0.98g	1.64efg	1.02efg	1.16efg	2.59def	1.45fg	2.36def	4.09bc	1.93efg	2.84de	5.39a	2.67de	3.46cd	4.85ab	4.80ab	4.41ab
	2014	0.93f	1.37def	0.99f	1.12def	2.23cd	1.12def	1.68ef	4.58bc	1.93de	1.93de	5.42b	2.03cd	1.76de	7.44a	4.81bc	4.81bc
HB	2013	0.48h	3.66e	0.74g	0.73g	8.09d	1.08g	1.21g	13.87c	1.26g	2.88fg	17.57b	3.52f	3.55f	23.90a	4.09e	5.48e
	2014	0.37e	1.70e	0.87e	0.63e	3.72cd	1.35e	1.13e	7.42bc	2.44de	2.50cd	10.19b	4.05cd	4.10cd	16.96a	8.88bc	8.87bc
Mean		0.73e	1.82de	0.91e	0.97e	3.71c	1.23de	1.54de	6.38b	1.91de	2.73cd	7.64b	3.22c	3.76c	10.22a	5.11bc	5.40bc
12b) Emission factor (%)																	
MP	2013	–	0.54	0.06	0.26	0.58	0.1	0.22	1.13	0.36	0.5	0.72	0.38	0.76	0.53	0.43	0.58
	2014	–	0.39	0.18	0.29	1.44	0.28	0.41	1.1	0.4	1.03	0.69	0.98	1.25	0.78	0.85	0.87
JC	2013	–	0.66	0.04	0.18	0.81	0.24	0.69	1.04	0.32	0.62	1.1	0.42	0.62	0.77	0.76	0.69
	2014	–	0.44	0.06	0.19	0.65	0.1	0.38	1.22	0.33	0.33	1.12	0.28	0.21	1.3	0.78	0.78
HB	2013	–	3.18	0.26	0.25	3.81	0.3	0.37	4.46	0.26	0.8	4.27	0.76	0.77	4.68	0.72	1
	2014	–	1.33	0.5	0.26	1.68	0.49	0.38	2.35	0.69	0.71	2.46	0.92	0.93	3.32	1.7	1.7
Mean			1.09	0.18	0.24	1.49	0.25	0.41	1.88	0.39	0.66	1.73	0.62	0.75	1.9	0.88	0.93

CAN= Calcium Ammonium Nitrate; NBPT= N-(n-butyl) thiophosphoric triamide. MP= Moorepark; JC= Johnstown Castle; HB= Hillsborough sites. Values with different letters (a to g) within a row indicate significant differences ($P < 0.05$) between treatments (CAN, Urea and Urea+NBPT) and fertiliser rates.

Source (Rahman et al., 2021)

N_20 emission factors 2013 & 2014



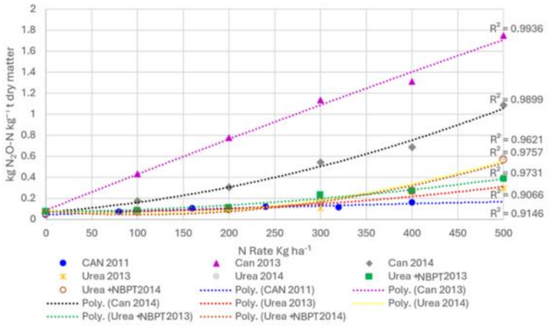
Relationship between N_2O-N emission factors with five N application rates at Hillsborough

Relationship between N treatments & N_2O EF

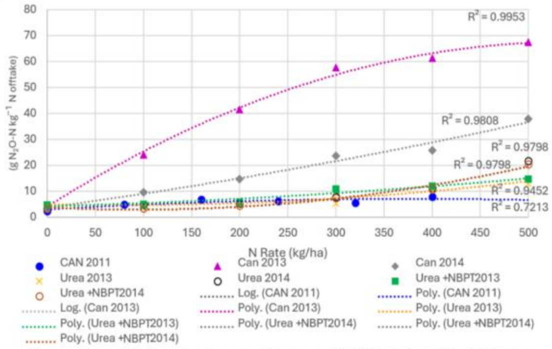
Treatments	R2	Equations	P value
MP 2013			
CAN	0.01	y=0.0001x+0.67	0.90
Urea	0.88	y = 0.0010x-0.04	0.02
Urea + NBPT	0.68	y = 0.0012x+0.11	0.08
MP 2014			
CAN	0.01	y = 0.0003x+0.87	0.98
Urea	0.82	y = 0.0020x-0.07	0.03
Urea + NBPT	0.60	y = 0.0020x+0.17	0.12
JC 2013			
CAN	0.19	y = 0.0005x+0.72	0.47
Urea	0.93	y = 0.0016x-0.13	0.01
Urea + NBPT	0.49	y = 0.0010x+0.28	0.19
JC 2014			
CAN	0.84	y = 0.0022x+0.28	0.03
Urea	0.80	y = 0.0016x-0.18	0.04
Urea + NBPT	0.45	y = 0.0010x+0.08	0.22
HB 2013			
CAN	0.84	y = 0.0035x+3.03	0.03
Urea	0.72	y = 0.0014x+0.05	0.07
Urea + NBPT	0.90	y = 0.0019x+0.07	0.01
HB 2014			
CAN	0.96	y = 0.0048x+0.80	0.01
Urea	0.80	y = 0.0028x+0.01	0.04
Urea + NBPT	0.90	y = 0.0034x-0.24	0.01

HB Hillsborough, JC – Johnston Cartle, MP – Moorepark

Gaseous losses N_2O – Yield scaled emissions



Comparison of N_2O generated per unit of dry matter grown for differing N rates.



Comparison of N_2O emissions per kilogram of N Offtake for differing N rates

NH_3 emissions

Source (Forrestal., 2015)

Ammonia (NH_3) losses for different fertilizer N treatments

Site		Johnstown Castle - NH_3-N loss (% of applied N)					Hillsborough - NH_3-N loss (% of applied N)				
Season		**Spring**		**Summer**			**Spring**		**Summer**		
Fertiliser date		March 10	April 28	June 3	July 7	August 18	March 24	May 6	June 9	July 28	September 8
Volumetric moisture		45.4%	37.4%	34.4%	28.8%	27.5%	46.0%	41.7%	24.9%	16.8%	25.5%
	Kg N Ha^{-1}										
CAN	40	5 e	7 c	2 b	4 c	2 c	4 bc	2 b	3 d	4 b	8 b
Urea	80	68 ab	38 ab	24 a	24 a	43 a	14 ab	19 a	49 a	34 a	43 a
Urea	40	53 c	25 b	20 a	26 a	30 b	21 a	8 b	33 b	31 a	33 a
Urea + NBPT	40	15 de	6 c	5 b	9 bc	6 c	2 c	2 b	4 d	4 b	9 b
Urea + DCD	40	77 a	42 a	22 a	22 a	45 a	9 bc	7 b	20 c	13 b	19 b
Urea+NBPT+DCD	40	18 d	6 c	4 b	5 c	8 c	6 bc	2 b	7 d	6 b	11 b

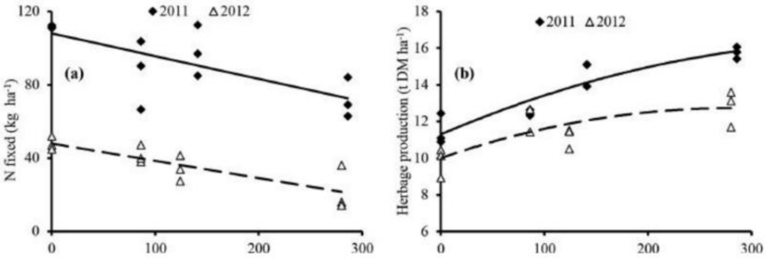
Treatments with different letters differ ($P < 0.05$) within columns. Moisture sampled at 0–5 cm on day after the application (%)

Comparison of annual ammonia losses at two sites

		Total NH_3-N loss (% of applied)		Change NH_3-N loss (% of urea 200)	
	Kg N ha-1yr-1	Johnston Castle	Hillsborough	Johnston Castle	Hillsborough
CAN	200	4.1 da	4.2 bc	-87	-83
Urea	200	30.6 c	25.1 a	Baseline	Baseline
Urea	400	40.0 ab	32.0 a	+31	+27
Urea+NBPT	200	8.2 d	4.0 c	-73	-84
Urea+DCD	200	41.6 a	13.7 b	+36	-45
Urea+NBPT+DCD	200	8.1 d	6.5 bc	-74	-74

Different letters within columns are different at ($P < 0.05$).

Impact of increasing N rates – N fixation by clover



Cut 6 times in 2011 and 7 times in 2012. This represents a grazing simulation management.

Proportion of nitrogen derived from the atmosphere (%Ndfa) by white clover.

Clover variety	Barblanca	Chieftain	Crusader
Fertiliser N input (Kg ha^{-1})	%Ndfa	%Ndfa	%Ndfa
0	85.6ab	84.9ab	88.6a
86	73.9a	73.2a	76.4a
140	70.3a	69.7a	73.1a
286	58.3a	57.7a	60.8a
Fertiliser N; SEM 1.29 P < 0.001)			

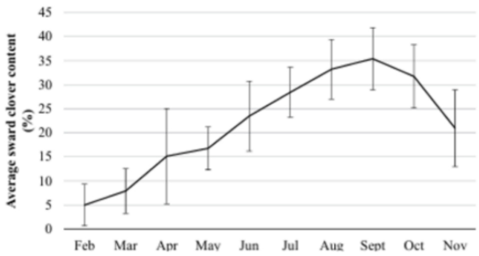
Burchill, W., James, E., Li, D., Lanigan, G., Williams, M., Iannetta, P., Humphreys, J., 2014. Comparisons of biological nitrogen fixation in association with white clover (Trifolium repens L.) under four fertiliser nitrogen inputs as measured using two 15N techniques. Plant and Soil 385.

Clover systems – 8 Year study – Moorpark

Benefits of clover in a grazing system

Comparison of grass alone and with white clover at different N rates

	Grass 250 kg N ha^{-1}	Grass-white clover 150 kg N ha^{-1}	SEM	P-value1
Total annual DM yield (kg DM ha-1)	13,467	13,396	397.5	ns
Annual silage yield (kg DM ha-1)	2,716	2,690	309.7	ns
Annual milk yield (kg cow-1)	6,068	6,311	253.2	0.0599
Annual milk solids yield (kg cow-1)	490	510	6.2	<0.05
Annual milk fat (%)	4.43	4.36	0.219	ns
Annual milk protein (%)	3.66	3.67	0.021	ns



Hennessy, D. 2022. Using white clover to reduce nitrogen fertilizer application - results from an eight-year study. Grassland Science in Europe, Vol. 27, 608-610. https://www.europeangrassland.org/fileadmin/documents/Infos/Printed_Matter/Proceedings/EGF2022.pdf

Manure N use efficiency – application timing

Historically in the NAP, N availability in slurry is assumed to be **40 %** available across all spreading dates. However, the recent revisions of the RB209 have included more precise figures on N availability from slurries depending on timing and method of application. If these revisions were adopted in the NAP it would have the following implications for N limits:

40 % availability = 68 kg N from slurry 310 – 68 = **242 kg chemical N/ha/yr**

35 % availability = 59.5 kg N from slurry 310 – 59.5 = **250 kg chemical N/ha/yr**

25 % availability = 42.5 kg N from slurry 310-42.5 = **267.5 kg chemical N/ha/yr**

Values are based on the most recent 310 kg N/ha limit.

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Conclusion - N Rates for Grassland

- $N_{opt\ (10)}$ was 245 kg/ha N for the 8 sites data and 340 kg/ha for Hillsborough dataset
- The region can consistently produce more grass on less applied N compared to the RB209
- This data supports the RB209 recommendations up to 15 t/ha dry matter
- Using the right fertiliser type in the right place at the right time can optimise nutrient use efficiency, and minimise gaseous emissions
- Nutrient management planning is critical to optimise nutrient status to maximise grass growth at any level of fertiliser applied farming intensity.
- Clover inclusion will be a key tool to support production.

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