Soil Tests for Predicting Nitrogen Supply for Grassland Under Controlled Environmental Conditions

Key Messages:

- Measuring mineralizable nitrogen (N) (MN) using the simple and robust Illinois Soil Nitrogen Test (ISNT) and/or a 7 day anaerobic incubation test (AI-7), Irish soils have a large variability in soil N supply across mineral grassland soil types.
- Evaluating the effectiveness of ISNT and other chemical soil N indices to predict plant N availability in these temperate soil types under controlled environmental conditions is necessary, in order to understand which measureable pools of N is provided to the plant within a growth period. This could eventually help to adjust fertilizer recommendations accordingly and therefore allow for improved fertilizer N use efficiency (N_fUE) and losses of reactive N to the environment.
- A model with the ISNT-N, the soil carbon (C) to N ratio (C:N) and total oxidized N (TON, as log transformed TON) best explained 55% and 79% of the variability in grass dry matter (DM) production and herbage N uptake, respectively, across 30 different Irish grassland soil types.
- Prior to fertilizer recommendations, routine analysis of field samples to gauge a field N supply is possible using these rapid soil parameters. However, further evaluation of these tests are needed from field studies across multiple and diverse growing conditions.

Synopsis

Estimating the quantities of N released can be difficult and many soil, climatic and land management factors affect the mineralization processes (Griffin, 2008). In temperate climates the temporal nature of N makes it difficult to predict long term supplies of soil N for uptake into the grass plant. The levels of N uptake in grass can vary considerably within and across different soil types. Across 15 Irish sites the herbage N uptake of unfertilized plots ranged from 74 to 212 kg ha^{-1} $year^{-1}$ (Humphreys, 2007). This corresponds with the findings of a recent laboratory study by McDonald et al. (2014a), where the mineralizable N (MN) of 35 temperate grassland soils ranged from 92 to 403 mg NH_4-N kg^{-1} using a 7 day anaerobic incubation test (AI-7). However McDonald et al. (2014a) also found that the more rapid

ISNT had a strong relationship with the AI-7 measure of MN (R^2=0.69), and therefore highlighting ISNT as a rapid chemical test capable of predicting MN. However, there was no validation from this previous study of ISNT predicting N recovery in grass herbage and its accuracy for making N recommendations across various soil types. Within this present study the effectiveness of chemical N tests: TON, ammonium (NH_4-N) TC, TC C:N and, in particular ISNT-N, to predict soil N supply for plant uptake through MN, in grass N uptake and dry matter (DM) yield, for a range of 30 Irish soil types under controlled environmental conditions (65% field capacity, 15^{o}C, 16 hour daylight and 80% humidity) across three successive 5-week growth periods were evaluated.

Mineral N in the form of TON (that was log transformed) had the strongest relationship with grass DM production (R^2=0.72, 0.87 and 0.57; P<0.0001; Fig 1*a*) and N uptake (R^2=0.82, 0.88 and 0.57 P<0.0001; Fig. 1*b*) in each of the growth periods (GR1, GR2 and GR3). The high proportion of variability explained by TON for both grass DM production and N uptake particularly in the first two growth periods (GR1 and GR2) can be credited to the varied but high initial levels of TON at the start of GR1 (10.8 to 153 mg kg^{-1}) in these 30 soils. These high concentrations can be attributed to increase in N mineralization following soil preparation handling and grass seeding similar to the effect generally observed after ploughing of grass swards (Whitehead, 1995).

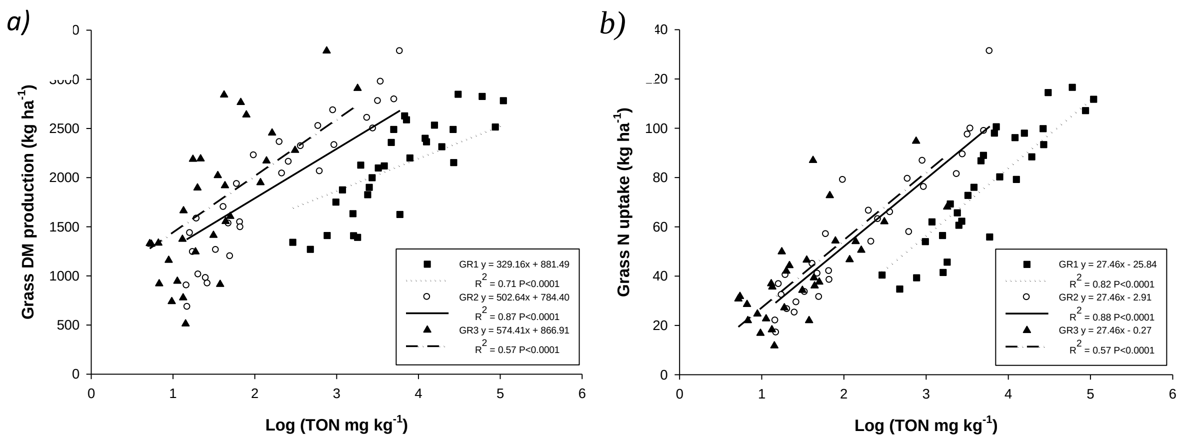

Fig 1. Relationship between log transformed total oxidized N (TON) and ***(a)*** grass dry matter (DM) production ***(b)*** grass N uptake for each growth period (GR1, GR2 and GR3). Fitted models account for the significant interaction of log TON X growth period.

Compared to TON, ISNT-N which cannot measure TON, had a poorer relationship with grass DM production (R^2=0.25, 0.32 and 0.34; P<0.05; Fig 2*a*) and N uptake (R^2=0.27, 0.33 and 0.35 P<0.05; Fig. 2*b*) at each of the growth periods (GR1, GR2 and GR3), respectively. Under the optimum growth conditions the plant would have consumed the readily available TON in the earlier growth periods (GR1 and GR2), but as the concentrations of TON declined over the growth periods, the grass plant seemed to assimilate a larger proportion of the N from the mineralized N pool.

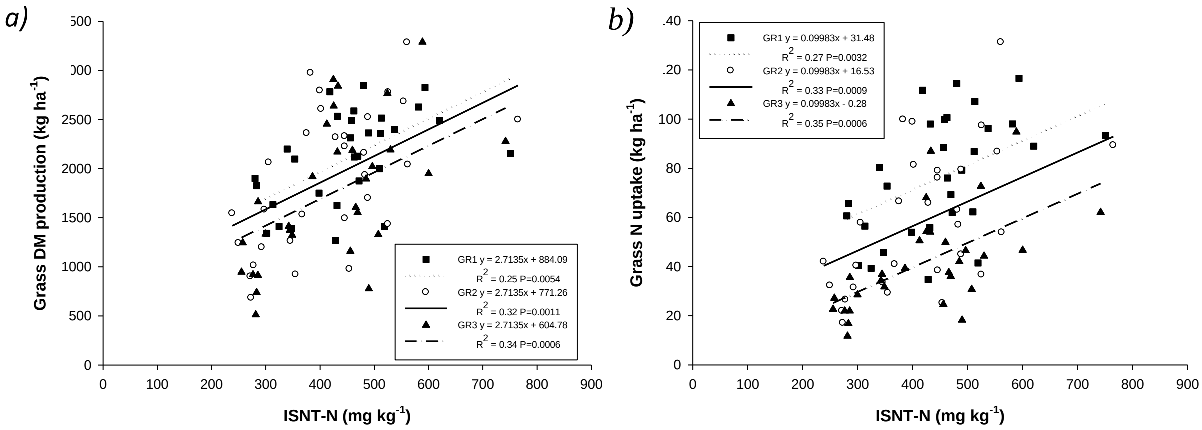

Fig 2. Relationship between Illinois soil N test (ISNT-N) values and ***(a)*** grass dry matter (DM) production and ***(b)*** N uptake for each growth period (GR1, GR2 and GR3). Fitted models account for significant main effect of growth period.

Following a multiple stepwise regression analysis, the combination of log TON, ISNT-N and C:N gave the best fit prediction models for both grass DM production and N uptake in each of the three growth periods. With the inclusion of the interaction of ISNT-N X C:N the best model explained 55% of grass DM production and 79% of herbage N uptake, where all growth periods combined (n=90) (Table 1 and 2). The interaction between C:N ratio and MN as measured by ISNT-N, found that as the C:N ratio increased the MN as measured by ISNT-N starts to become immobilized by microbes, therefore less N becomes available to the plant and vice versa. The C:N ratio seemed to act as a regulator for microbial assimilation and supply of amino sugars (Ding et al., 2010), a relatively stable fraction of organic soil N (Khan et al., 2001).

Table 1 Regression model of soil N indices for predicting grass DM production (kg ha^{-1}).

Growth period	Variable (X)	Parameter estimate	S E	P>t	95% Confidence limits		$RMSE^a$	Model R^2
GR1	intercept	1076.10	391.23	0.0043	270.35	1881.84	188.98	0.86
	log TON	498.34	62.88	<0.0001	368.83	627.85		
	ISNT-N	1.61	0.43	0.0029	0.71	2.50		
	C:N	–152.30	36.91	0.0004	–228.32	–76.28		
	ISNT-N × C:N	–0.41	0.23	0.0864	–0.88	–0.06		
GR2	intercept	873.39	441.88	0.0592	–36.68	1783.46	225.32	0.91
	log TON	647.27	59.97	<0.0001	523.77	770.78		
	ISNT	1.45	0.48	0.0058	0.46	2.44		
	C:N	–94.93	41.98	0.0327	–181.39	–8.47		
	ISNT-N × C:N	–0.47	0.25	0.0772	–0.99	0.05		
GR3	intercept	404.62	883.37	0.6509	–1414.71	2223.95	441.80	0.68
	log TON	661.48	162.92	0.0004	325.93	997.02		
	ISNT-N	2.36	0.91	0.0156	0.49	4.22		
	C:N	–60.30	85.40	0.4764	–232.07	111.47		
	ISNT-N × C:N	–0.92	0.53	0.0940	–2.00	0.17		
Combined growth periods (GR1-GR3)	intercept	–1156.51	1215.4	0.35	–3462.1	1329.31	308.37	0.55
	log TON	560.87	59.81	<0.0001	440.95	680.79		
	ISNT-N	7.56	2.58	0.005	2.38	12.75		
	C:N	121.64	114.58	0.29	–108.09	351.36		
	ISNT-N × C:N	–0.54	0.25	0.025	–1.02	–0.07		

Table 2 *Regression model of soil N indices for predicting grass N uptake (kg ha^{-1}).*

Growth period	Variable (X)	Parameter estimate	S.E	P>t	95% Confidence limits		$RMSE^a$	Model R^2
GR1	intercept	–0.401	16.89	0.98	–35.19	34.39	8.16	0.90
	log TON	29.07	2.72	<0.0001	23.48	34.66		
	ISNT-N	0.07	0.02	0.0017	0.03	0.10		
	C:N	–6.02	1.59	0.0009	–9.31	–2.74		
	ISNT-N × C:N	–0.12	0.01	0.25	–0.03	0.01		
GR2	intercept	6.92	18.11	0.71	–30.36	44.22	9.24	0.91
	log TON	26.83	2.46	<0.0001	21.76	31.89		
	ISNT-N	0.05	0.02	0.0109	0.01	0.09		
	C:N	–2.89	1.72	0.1049	–6.44	0.65		
	ISNT-N × C:N	–0.02	0.01	0.1305	–0.04	0.01		
GR3	intercept	–1.93	25.96	0.94	–55.39	51.53	12.98	0.64
	log TON	17.95	4.79	0.0009	8.09	27.81		
	ISNT-N	0.06	0.03	0.0240	0.01	0.12		
	C:N	–0.96	2.46	0.70	–6.01	4.08		
	ISNT-N × C:N	–0.02	0.02	0.18	–0.05	0.01		
Combined growth periods (GR1-GR3)	intercept	–59.39	41.02	0.16	–143.29	24.5	10.24	0.79
	log TON	17.17	3.32	<0.0001	10.51	23.84		
	ISNT-N	0.25	0.09	0.0049	0.08	0.43		
	C:N	4.77	3.84	0.22	–2.93	12.47		
	ISNT-N X C:N	–0.02	0.01	0.023	–0.04	0.00		

Equation formula for each growth period is constructed as follows: $Y=aX_1+bX_2+cX_3+d$, where X is the measured N indices (variable), a,b,c, are parameter estimates and d is the intercept
Equation formula for the combined growth periods is constructed as follows: $Y=aX_1+bX_2+cX_3+dX_4+e$, where X is the measured N indices (variable) or their interaction, a,b,c,d are parameter estimates and e is the intercept (intercept is for final harvest) [a]RMSE, Root mean square error.

The combination of three rapid soil N indices (TON, ISNT-N and C:N) into a model, where each represent the different soil N pools of available and potentially available N, gave the best prediction of grass DM yield and N uptake for each growth period and for all growth periods combined.

While this study was conducted under controlled environmental conditions, it does provide a method to assess the potential of a grassland soil to supply MN, and regardless of the future N losses that would be noticeable at field scale, it is still important to know the base N supply prior to making N management decisions which promote efficient and sustainable N use. This emphasises the additional need for these findings to be further validated across these soils under a varying seasonal environments of field trials, before a soil N testing system or recommendation system can be used on grassland farms.

This work is published in McDonald et al. (2014b)

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