NITROGEN RESPONSE EFFECT OF LESSN – A META-ANALYSIS

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Abstract

Donaghys LessN is a microbial bioactives product promoted as increasing nitrogen response in pasture offering potential economic and environmental benefits. The LessN system comprises 3 L/ha LessN product applied with 18.4 kg N/ha as dissolved urea. This was compared with the same rate of sprayed dissolved urea without LessN in 62 replicated (and 2 unreplicated) pasture trials throughout New Zealand, with capacitance probe pasture measurement at application and after a single grazing rotation duration (between 14 and 47 days, mean 25 days). The trials were subjected to meta-analysis (combined analysis).

The majority of the 52 trials (62%) showed a statistically significant ($p<0.05$) LessN effect when comparing the LessN system with the same rate of sprayed urea only. The meta-analysis on pasture growth effect of LessN system over sprayed urea at the same rate was also statistically significant at a mean 239 kg DM/ha ($p=3.3 \times 10^{-15}$).

The effect of soil temperature at start of trial, soil test levels and region were assessed. Soil temperature was significant ($p=0.002$), due to an apparent reduction of LessN effect when local soil temperature was below the product label minimum of 10^{o}C (four trials affected). One outlier trial commenced within 2 days of an over 200 mm rainfall flood event and showed no apparent LessN effect.

Further treatments in the trials included one or more of sprayed urea at 36.8 kg N/ha, solid urea at 18.4 kg/ha and solid urea at 36.8 kg/ha. Without low soil temperature trials and the one flooding trial, these treatments were compared individually with the LessN system for (18.4 kg N/ha and 36.8 kg N/ha) on a ratio basis for total kg DM grown above control. The calculated mean ratio of the LessN system over sprayed urea at 18.4 kg N/ha was 2.7 (1.9 for Independent trials only), over sprayed urea at 36.8 kg N/ha was 1.0 (1.2 for Independent), over solid urea at 18.4 kg N/ha was 2.2 (2.1 for Independent) and over solid urea at 36.8 kg N/ha was 1.1 (1.0 for Independent). These results were consistent with mean doubling (or more) of nitrogen response with LessN.

Introduction

Donaghys Industries Limited (Donaghys) recommends a LessN system of nitrogen fertiliser application. The system involves the spray application of 40 kg/ha urea fertiliser (18.4 kg N/ha) dissolved in 200 L total volume of water and incorporating 3 L/ha LessN. LessN is a microbial extract bioactives product that is designed to improve the uptake of and response to nitrogen of plant cells. One identified type of active ingredient is adenine compounds which share the same adenine base unit as the cytokinin plant growth regulators.

The LessN system is recommended by the manufacturers as being suitable for use when a nitrogen response can be achieved with a label proviso to apply when the soil temperature is at or above 10^{o}C.

A series of 65 trials on New Zealand pasture have been carried out by Independent and Donaghys researchers. All trials included a control (no nitrogen application and no LessN application) but in one independent trial the control was affected by herbicide contamination and this trial was excluded from the analysis in this paper.

Donaghys have claimed that the trial results show that, on average, urea use on pasture could be halved from 36.8 kg N/ha to 18.4 kg/ha while still achieving a similar pasture yield result. This claim is able to be tested with the main experimental design that was adopted in the pasture trials and has been supported by the findings of a Fertiliser Quality Council Review (report published on Donaghys Industries Ltd, 2012). This claim and also whether the nitrogen response ratio is doubled when comparing the LessN system with the same rate of nitrogen as urea can be tested by meta-analysis.

Meta-analysis is the combined analysis of a series of experiments to better derive the true effect size of a treatment and/or to better understand the set of data and potential reasons for variation in results. With any set of trials it can be expected that there will be a variation in response seen in each individual trial simply through natural variation and variation in sampling. There may in addition be reasons for variability between trials in terms of environmental conditions at the time of the experiment and in the paddock being tested and these can also be assessed for significance in a meta-analysis approach.

Edmeades and McBride (2012) attempted an analysis of the percentage effect of LessN and found that the mean LessN system result was approximately equal to the result achieved with double the amount of urea in both Independent and Donaghys trials, and that both Independent and Donaghys trials had statistically significant differences between the LessN system effect and the effect of urea at the same rate. They concluded, however, that in the Independent trials there tended to be a lower percentage effect for the LessN system treatment than in the Donaghys conducted trials. The analysis employed neglected to declare a large proportion of non-nitrogen responsive trials in the Independent trials and also failed to reflect on non-normal distribution of Independent trials which did not reflect the same range of responsiveness or environmental conditions as the greater number of Donaghys trials. The percentage calculation used by Edmeades and McBride was also poorly related to the actual effect on dry matter (linear regression R^2=0.23, i.e. just 23 % of variation in absolute dry matter effect was explained by the calculated percentage effect) and thus not useful for forming conclusions on the relative effect sizes in actual dry matter or nitrogen response difference. The percentages calculated were heavily skewed making them unsuitable for the construction of confidence intervals presented in the paper. The numerous apparent shortcomings in statistical technique in Edmeades and McBride (2012) are addressed in this paper with formal meta-analysis and a discussion of the Cumulative Distribution Function approach.

A good first step in formal meta-analysis is to combine all of the available trials together. This avoids the potential for bias in the inclusion or omission of relevant trials. In the case of the LessN trials, all trial results are publicly available (Donaghys Industries Ltd, 2013) and have been able to be included in the initial analysis.

Method

Trials were conducted from 2007 through to 2011 and trial design changed somewhat from trial to trial. The majority of trials included the main treatments of interest of "LessN40 (the LessN system as described earlier), and "Urea40" which was urea at 40 kg/ha (18.4 kg N/ha) dissolved in 200 L total volume of water. Most trials included "Urea80" at double the nitrogen rate of "Urea40", and some included "SoildUrea80" which was 36.8 kg N/ha applied as solid Urea prills. Some trials included a comparison treatment of SolidUrea40 with solid urea prills applied at 18.4 kg N/ha. A wide variety of other treatments were included but without sufficient numbers of trials in each case to provide reliable meta-analysis results for their effects. All data was included in the meta-analysis though to provide a better assessment of the variability in each trial.

The analysis focusses on the first grazing rotation after application of the treatments. The number of days involved varied between trials but averaged 25 days and ranged from 14 to 47. Longer term trial results are summarised on the Donaghys website (Donaghys Industries Ltd, 2013). Plots were grazed down low and even prior to a resting period of at least two days before application of treatments. Each plot was 3 m to 4m wide by at least 20 m (and as much as 50 m) long. The majority of trials included Grassmaster capacitance probe estimates along the length of the middle of each plot for kg DM/ha taken just prior to application of treatments and again at the end of the grazing rotation to provide a measurement of pasture growth over the course of the trial. In 24 of the trials, cuts were taken. The cut in one trial was with electric shear clipping to near ground level for a 0.2 m quadrat per plot in (using an initial probe measurement as the baseline from which to derive growth during the trial); cuts were with lawnmower in all other cases. With cuts, percentage dry matter was calculated using the oven-dried derived dry matter percentage of a subsample. Plots were assessed blind to avoid potential bias. All trials were conducted by experienced, trained personnel.

Application of liquid treatments was with fan jets on boom sprays mounted on a farm vehicle. In most cases this was a 4WD utility vehicle with a calibrated speed to deliver the desired spray volume while driving forward in idle (negating need for driver acceleration or braking and ensuring an even application based on constant speed and maximum nozzle flow rate). This method avoided the potential for unintentional bias between treatments.

Meta-analysis was performed with REML (Restricted Maximum Likelihood) procedure in Genstat Version 15.1 by independent statistician Dr David Baird of VSN Consulting. This included analysis of the absolute difference in dry matter production kg DM/ha between LessN40 and relevant comparison treatments and the analysis of ratios of response (growth above control) between LessN40 and the relevant comparisons. By way of comparison, a combined analysis of trials with simple t-tests on treatment comparisons and ratios was conducted by independent statistician Dave Saville. For further comparison the authors performed meta-analysis using multiple regression and cumulative probability functions to investigate and present the data (R Version 2.15.0).

Two measurements of the effect of LessN were of particular interest. One is the Response Ratio between LessN40 and urea only at the same nitrogen rate and the other is the Substitution Value of the LessN system which is the relative increase in nitrogen rate that is required to match the response of the LessN system. These two measurements have been described previously for New Zealand pasture fertiliser effect in Edmeades et al. (1991) with the Response Ratio and Substitution Value derived from the following equations (levels for 'Y' yield in kg DM/ha and 'X' urea amount in kg urea/ha are given in the Fig 1, for each of 0 control, S the standard of urea only and T the treatment of including LessN). The Substitution Value can be described as the horizontal relationship for where the yield of LessN40 is matched by the point on the nitrogen response curve and the Response Ratio can be described as the vertical comparison or the ratio between the LessN40 Yield over control divided by the yield over control for the same rate of nitrogen as urea only.

Response Ratio $= (Y_T - Y_0)/(Y_S - Y_0)$
Substitution Value $= X_S/X_T$

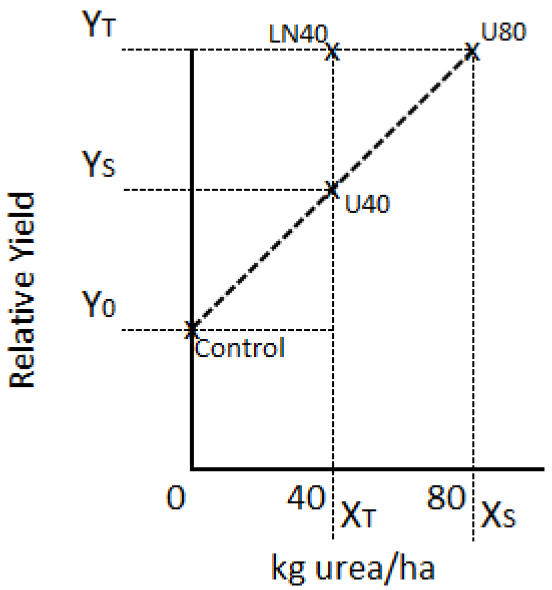

Fig 1. Parameters for Measuring Response Ratio and Substitution Value in LessN experiments (LN40 respresents LessN40 the LessN system at 40 kg urea/ha, U40 and U80 are urea only treatments at 40 and 80 kg urea/ha respectively).

Results and Discussion

Most analysis was based on the probe results as all nitrogen responsive trials had a probe measurement and only a subset had mowing measurements. Mowing results are presented later followed by analysis using the Cumulative Distribution Function graphs to illustrate some of the key findings.

Probe Results

The majority of the 52 trials nitrogen responsive trials (62%) showed a statistically significant ($p<0.05$) LessN effect when comparing the LessN system with the same rate of sprayed urea only. Six trials were non-nitrogen responsive in that there was no clear positive effect of nitrogen on pasture yields for the urea only treatments. To make sensible measurements of the effect of LessN on nitrogen responsiveness, these trials were excluded from some of the later meta-analysis and combined analysis. Their exclusion had little effect on the overall meta-analysis result but since all of the non-nitrogen responsive trials were independently conducted ones they affect the difference between Independent and Donaghys trial results. The non-nitrogen responsiveness may be related to low soil temperature (2.6^{o}C) in one case, recent heavy rainfall in another two cases (with flooding at one site), and onset of winter conditions in a further case.

In three independent but somewhat nitrogen responsive nitrogen trials, the local 9am 10cm soil temperature records in the week of application indicated levels below the LessN label level of 10^{o}C (Table 1). These trials should be excluded from the assessment of LessN effect as they are not representative of recommended use conditions. In one of these trials (4.4^{o}C on day of application), the Urea80 and LessN40 treatments both tended to grow less pasture than the Urea40 treatment and differences were not statistically significant. The other two trials (at 7.9^{o}C and 8.6^{o}C on the day of application), the LessN40 treatment was intermediate between Urea40 and Urea80 in both cases with no statistically significant difference from either Urea 40 or Urea80.

Table 1. Local 9am 10cm Depth Soil Temperature Records for Four Low Soil Temperature Trials (during cold snap of spring 2007).

Trial Name	Date	Day of Application (^{o}C)	7 day mean at Application (^{o}C)
Manawatu Sheep	27/8/2007	7.6	9.04
Manawatu Dairy	29/8/2007	8.6	9.24
Canterbury 07	05/9/2007	4.4	5.34
Rangiora 07	06/9/2007	2.6	4.69

In a further independent trial, the paddock had recently been flooded by an over 200mm rainfall event within two days of the experiment commencing. There was no apparent LessN response above Urea 40 in this trial and only a limited extra response from SolidUrea80 and it remains possible that a lag in growth post flooding may have limited LessN response in the days after application or that overall response was restricted due to soil mineral limitation.
Apart from the non-nitrogen responsive trials, the low soil temperature trials and the recent flooding trials, there was generally a linear response to nitrogen from 0 to 18.4 kg N/ha to 36.8 kg N/ha. In just two further trials was there an apparent inability of the pasture to respond reasonably linearly to nitrogen above 18.4 kg N/ha. In these two trials, LessN40 (18.4 kg N/ha) approximately matched urea only at 36.8kg N/ha (estimated substitution value of 18.4 kg N/ha) but the response ratio of LessN40:Urea40 was less than 2:1.

The overall means for each treatment were consistent with a generally linear response to nitrogen up to the tested 80 kg urea (36.8 kg N/ha) level. The light grey bars in Fig 2 presents the comparative means for the 52 nitrogen responsive trials using simple t-test comparison only for experiments that contained all four relevant treatments (in three trials where SolidUrea80 and Urea80 treatments were both present the solid urea treatment value was used in the calculation for this graph). The dark grey bars represent the mean effect sizes for the overall meta-analysis including all trials regardless of nitrogen response or treatment combinations. An advantage of the Maximum Likelihood method is that mean effect sizes relative to control are calculated in such a way as to take advantage of every trial with an allowance account for weighting of trials according to size of effects in each trial as well as trial variability and level of replication.

The error bars given in Fig 2 are the Tukey HSD (Honest Significant Differences) calculated from an ANOVA of the trial means. The meta-analysis REML approach calculated the confidence intervals for the difference between mean effects. For LessN compared to Urea40 this was 239 kg DM/ha (95% CI of 216 to 263 kg DM/ha) in favour of the LessN system which was statistically significant ($p=3.3 \times 10^{-15}$). For LessN compared to Urea80 the difference was -16 kg DM/ha (95% CI of -41 to +8.4 kg DM/ha) which was not statistically significant (p=0.168). For the comparison of LessN 40 with the solid application of the same amount of urea (SolidUrea40 representing a subset of 15 of the overall trials) the mean difference was 174 kg DM/ha (95% CI of 129 to 221 kg DM/ha) in favour of the LessN system. Compared to SolidUrea80, LessN40 had a mean effect of +14.8 kg DM/ha (95% CI of -30.8 to +60.5). These effects sizes put the LessN system as approximately equivalent to urea at twice the N rate (consistent with a substitution value of around 2 in ratio terms and 40 kg/ha in urea terms) and as having over twice the response of Urea40 on average (consistent with a Response Ratio of over 2 or a more than doubling of nitrogen response rate).

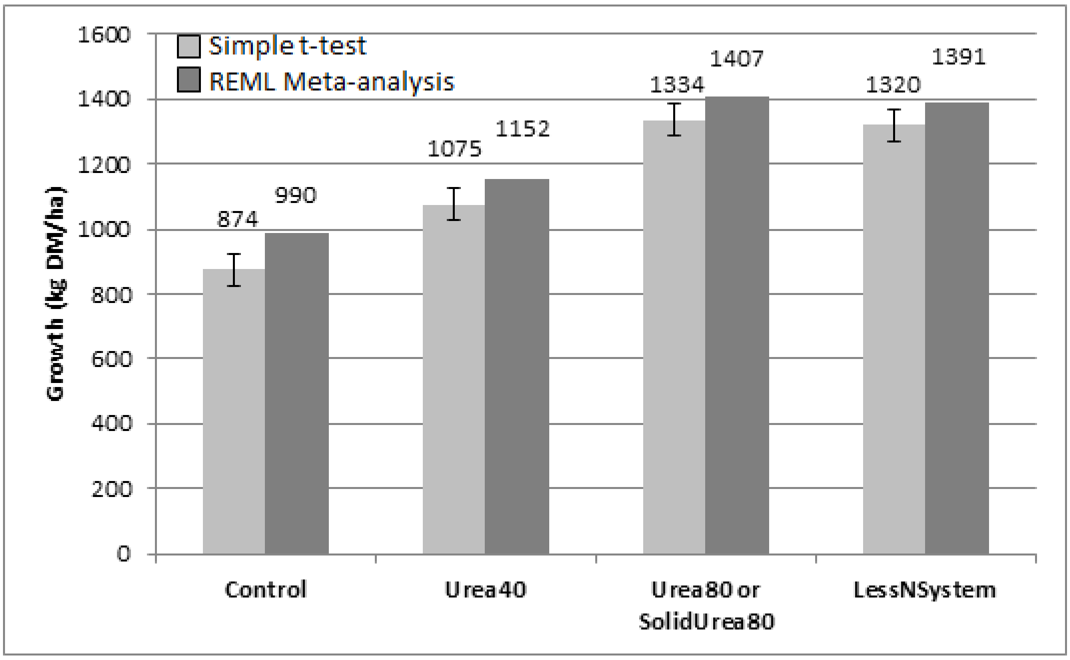

Fig 2. Mean Pasture Yield Results for Key Treatments over Combined Trials. The meta-analysis includes all trials, the t-test analysis includes nitrogen responsive trials with all four treatments represented in each trial.

The REML meta-analysis was also used to construct confidence intervals for the ratio between LessN40 response (LessN40 yield – Control yield) and the response of either solid and liquid forms of urea at either application rates. The results are given in Table 2 with 95% confidence margins. For the comparison with Urea40 (liquid), the mean effect was more than a doubling of response while for the smaller subset of trials that compared LessN40 with SolidUrea40, the mean effect was 1.77 with a doubling of effect still in the 95% confidence interval. It should be noted that these comparisons are still with the inclusion of non-nitrogen responsive trials (though these would have higher variability in ratio calculations and so carry less weight in the REML meta-analysis) and low soil temperature trials and the recent flooding trials. In both solid and liquid urea only comparisons, the ratio with the double rate of urea was quite precise at around 1:1 with LessN40.

Table 2. Meta-Analysis Results. Ratio of LessN System response (LessN40 – Control) to the response of Urea Only treatments.

Urea Form	Urea Application Rate	
	40 kg urea/ha (18.4 kg N/ha)	80 kg urea/ha (36.8 kg N/ha)
Liquid Urea	2.47 $\pm$ 0.29 (55 trials)	0.96 $\pm$ 0.06 (51 trials)
Solid Urea	1.77 $\pm$ 0.34 (15 trials)	1.04 $\pm$ 0.12 (15 trials)

There was a high amount of variation and positive skew in the ratio of LessN40 response to Urea40 response. This was found to be highly correlated with the variation in the ratio of Urea80 response to Urea 40 response on a 1:1 basis (with the exclusion of the non-nitrogen responsive trials, one trial where Urea40 performed below control, one trial where Urea80 performed below Urea 40, three below label soil temperature trials and the one recent flooding trial, the slope was 1.08 with origin of 0.0 and a R^2 of 0.97). The relationship between the ratios was the same for both independent trials (large circles in Fig 3) and for Donaghys trials (small circles). To account for the skew, a regression of the log transformed ratios was also performed this was found to still account for 90% of the variation in LessN40:Urea40 responses (slope = 0.99, origin 0.0, R^2=0.90). There was no statistically significant different in the relationship for Independent compared to Donaghys trials (p=0.556). With just the exclusion of the non- nitrogen responsive trials the relationship was still approximately 1:1 (slope of 0.97, origin 0.2). These results are all consistent with the ratio of LessN40 response to Urea 40 response being approximately equal to the ratio of Urea80 response to Urea40 for both Independent and Donaghys trials.

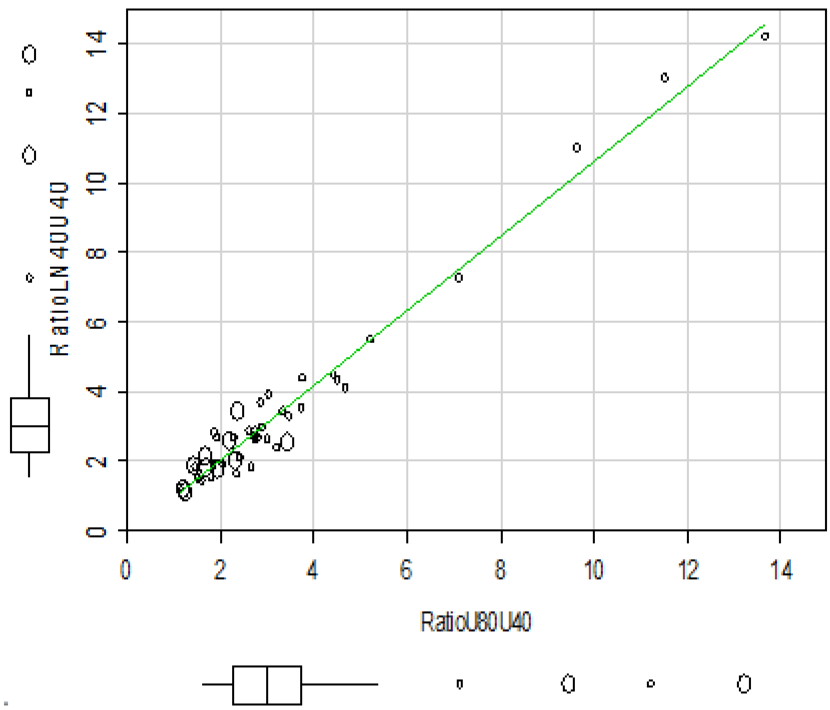

Fig 3. Relationship between the Ratio of LessN40 Response:Urea40 Response and the Ratio between Urea80 Response:Urea40 Response

Testing the relationship between LessN40 response and the response for urea only at the 80 kg urea/ha rate for the same selection of trials, the mean ratio was 1.02 (1.01 if log transformed and back-transformed). The mean of Donaghys conducted trials was 1.02 and the mean for Independent trials was 1.06 with no statistically significant difference (p=0.569, simple t-test of trials). With only the non-nitrogen responsive trials excluded, the Donaghys trials had a mean of 1.02 and the Independent trials 0.91, still not statistically significant (p=0.149, simple t-test of trials). Meta-analysis of the complete set of trials found the ratio of LessN40 response to Urea80 response was 0.96 (95% CI 0.90 to 1.02) and the ratio of LessN40 response to SolidUrea80 was 1.04 (95% CI 0.92 to 1.16), quite precisely consistent with a substitution urea value of around 40 kg urea/ha on top of the 40 kg urea/ha added with the LessN system.

In most nitrogen responsive trials there was an approximately linear response to nitrogen right up to the 80 kg urea/ha (36.8kg N/ha) rate. This is consistent with the approximately linear responses expected for modern dairy farm pastures at the N application rates employed in the trials (see Cameron et al, 2005).

The Independent trials were typically conducted in batches which did not represent the full range of nitrogen responsiveness of trials and were biased by four trials commencing at below label soil temperatures and seven being conducted in a summer with a heavy rainfall event (three such trials being non-nitrogen responsive). The majority of nitrogen responsive and label soil temperature Independent trials conformed to an approximate Response Ratio of 2. The three exceptions presented in Fig 4 where the ratio was significantly less than two appeared to also have a curvilinear nitrogen response above the 40 kg urea/ha rate. In two cases the LessN40 response matched the Urea80 response and it remains possible that there was a limitation in ability to respond in these pastures beyond the maximum reached. In the third trial (Reporoa) there was no apparent LessN response and the LessN40 result was similar to the Urea40 result; flooding two days prior to this trial commencing may have impacted on the ability of the pasture to respond to the LessN at the time of application and it could be considered non-representative of normal conditions.

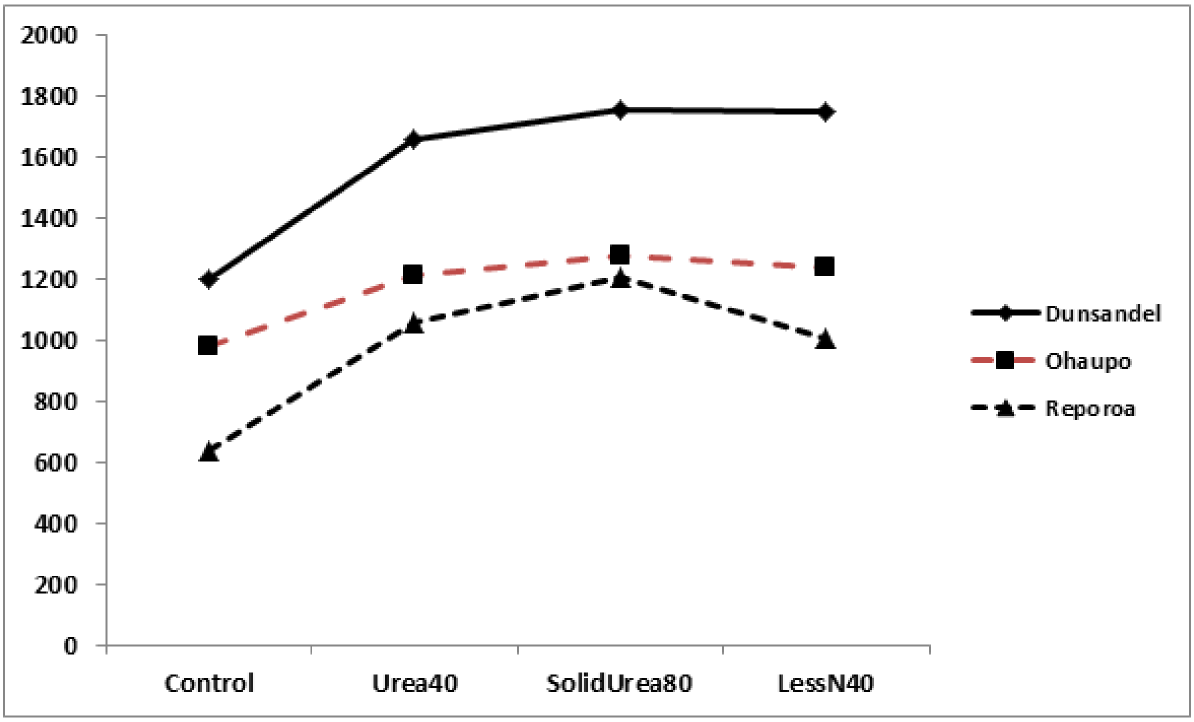

Fig 4. Three nitrogen responsive trials with an apparent non-linear (curvilinear) nitrogen response. Extra nitrogen response and response to LessN appeared to be limited above 40 kg urea/ha. The Reporoa trial had flooding two days prior to the trial commencing.

Best subsets (Cp) testing on multiple regression of the measured environmental factors at the time of application found that both "soil temperature below 10°C label recommendation in the week of application" (p=0.0005) and "recent flooding" (p=0.0998) were useful for explaining variation in the Response Ratio (LessN40 response divided by Urea40 response). This supports the exclusion of the affected trials from an assessment of the Response Ratio effect.

The combined analysis results for trials excluding non-nitrogen responsive trials, three below label soil temperature trials and one recent flooding trial is presented in Table 3 for overall and for Independent only trials. The results are consistent with a doubling or more of nitrogen response and with LessN40 response being similar to the response from urea at twice the N rate. The tight confidence intervals from the t-distribution analysis show good precision in these estimates for the overall trial result.

Table 3. Mean ratio of LessN System response (LessN40 – Control) to the response of Urea Only treatments from combined analyses for trials (without three below label soil temperature trials and without recent flooding trial). Means and simple t-distribution confidence intervals calculated on log transformed data.

	Overall Data				Independent Only Data			
Treatment	**No. of Trials**	**Lower CI 95%**	**Mean**	**Upper CI 95%**	**No. of Trials**	**Lower CI 95%**	**Mean**	**Upper CI 95%**
Urea40	47	2.28	2.71*	3.21	10	1.51	1.94	2.47
Urea80	39	0.95	1.01	1.07	2	0.52	1.11	2.37
SolidUrea40	11	1.46	2.24	3.44	8	1.16	2.13	3.89
SolidUrea80	11	0.92	1.06	1.23	8	0.83	1.02	1.24

* The high mean for this ratio was affected by three trials with very high ratio calculations (even log transformation did not fully assist in gaining an approximately normal distribution); without these three highest trial results, the mean was 2.4 similar to the mean effect derived from REML meta-analysis.

Mowing Results

Sixteen of the nitrogen responsive, label soil temperature and non-flooding trials included mowing measurements to assess dry matter yield. In t-distribution calculations of the ratios between treatments (using log transformed data to improve normality assumption), the results were consistent with a Response Ratio of 2 and an equalling of the response at double the nitrogen rate and thus broadly consistent with the probe results. The confidence margins were wider than for probe results partly due to the lower number of trials involved.

The mean ratio between LessN40 response and the response of urea only applied as either liquid or solid was 1.99 (95%CI of 1.24 to 3.18) and 2.24 (95%CI of 1.48 to 3.39) respectively. Comparing LessN40 response to urea only at the 80 kg urea/ha rate applied as either liquid or solid resulted in the ratios 1.07 (95%CI of 0.73 to 1.56) and 1.02 (95%CI of 0.70 to 1.49) respectively.

Cumulative Distribution Function Approach

In any statistical analysis it is useful to present the data visually in order to convey trends and perhaps identify underlying variation that might not be simply due to normal random error. The Cumulative Distribution Function approach may be useful as an exploratory data analysis technique. The technique presents data in order of effect size for each trial. The Y axis is the cumulative proportion (or percentage) of trials represented up to that level with the top of the axis being 1 (or 100% of trials). The X axis is the effect size. A horizontal line at the 0.5 (or 50%) value on the Y axis would show the median value.

Normally distributed data will typically give a sigmoidal shape when there are sufficient trials represented as a normal distribution tends to have the majority of results around the mean and a lower density of results at the extreme high or low levels. It is important though not to assume that a sigmoidal distribution implies an approximately normal distribution. The distribution may suffer from positive or negative kurtosis or from significant skew to the left or to the right. If confidence intervals are calculated from the data, these may be badly affected by a strong skew to one side. The percentages for the effects in LessN trials calculated by Edmeades and McBride (2012) suffered from strong positive skew affecting the proper calculation of a mean and the confidence intervals on either side.

A further problem with the way data is sometimes presented in the Cumulative Distribution Function method is that two treatments on the same graph sorted in increasing order of effect size will not show the relationship between the treatments in each individual trial as the trials are often not labelled or easily identifiable. This can result in a loss of important information.

A more full approach to the presentation of Cumulative Distribution Functions is the display of error bars for each individual trial. This gives an indication of how reliable each trial is and also if there was statistical significance in some individual trials as well as some apparent variation between certain trial that is not simple random error.

A fundamental concern should also be how meaningful the measurement being tested is. As stated earlier, the percentage calculation for the LessN system in Edmeades and McBride (2012) was a poor predictor of actual dry matter yield increase. The calculation was:

LessN System Percentage = 100 X (LessN40 – Urea40)/Urea40

This calculation takes the actual kg DM/ha effect (LessN40 – Urea40) of LessN which is economically meaningful, practically meaningful (e.g. in terms of kg DM per kg N) and approximately normally distributed, and converts it into a percentage (ratio) that is non-normally distributed, highly positively skewed and has little meaning economically or practically (R^2 of 0.23 for linear relationship with absolute kg DM effect size). Percentages can be useful for comparing results from trials on different crops or if the effect is one proportional to the denominator of the calculation; neither is the case for the set of LessN pasture trials.

A further problem with the Edmeades and McBride (2012) approach was to present the percentage LessN40 effect for Independent and Donaghys trials in a graph without also presenting the double urea percentage results which are known to be matched on average by the LessN40 results. The Urea80 results can help put the trials in context. High LessN40 results that may appear to be outliers are generally seen to be matched with high percentages for urea only at 80 kg urea/ha. And similarly the poorer LessN40 percentage results are generally matched by poor results for urea at 80 kg urea/ha. This indicates a similar urea Substitution Value in most trials for the LessN system and a difference in measured responsiveness of trials that is predictable by the urea only response at 80 kg urea/ha.

Results from the LessN trials excluding non-nitrogen responsive trials and low soil temperature trials are shown using the percentage calculation and the actual dry matter difference in each trial in Fig 5 and 6 respectively. It can be seen that while the Independent trials tend to be at the lower end of the range for the percentage calculations (Fig 5), the absolute dry matter effects (Fig 6) are more evenly distributed and the scale of absolute effects of both independent and in-house results are centred around an economically meaningful level of response. The close correlation between percentage response of urea only at the 80 kg urea/ha rate with the LessN40 percentage response is also apparent helping explain the generally low LessN percentage responses in independent trials as being representative of low percentage response trials (this then is tied to the Urea40 denominator performance and that some trials appeared to have limited capacity to respond to more than 40 kg urea/ha).

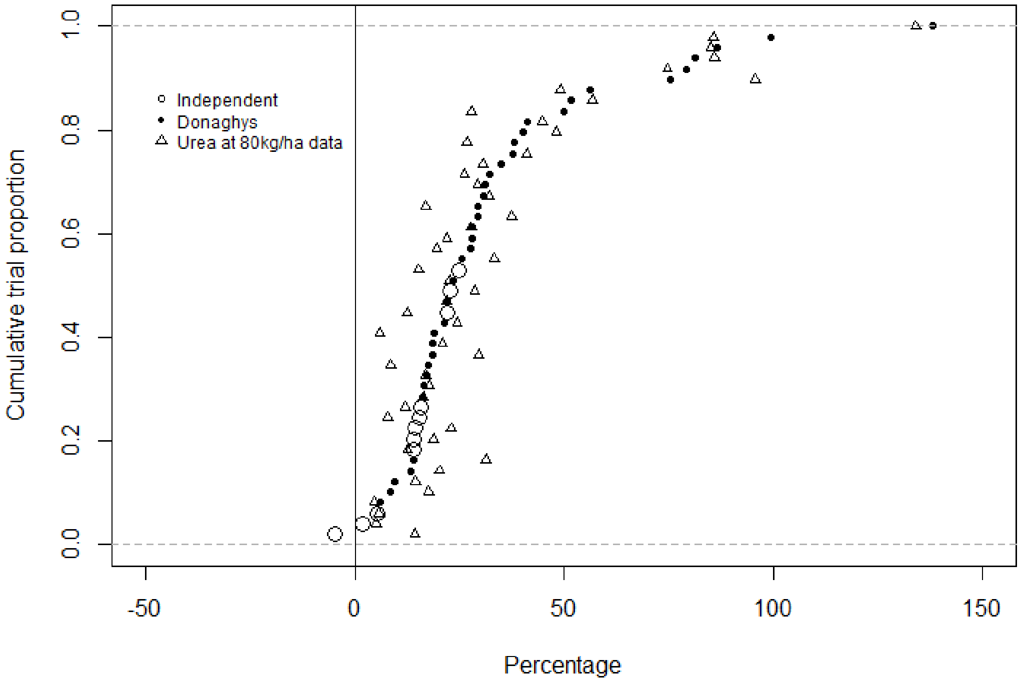

Fig 5. Cumulutaive Distribution Function graph of Percentage (calculated by the method of Edmeades and McBride, 2012) effect of LessN40. Urea only at the 80 kg urea/ha rate data is included for each trial.

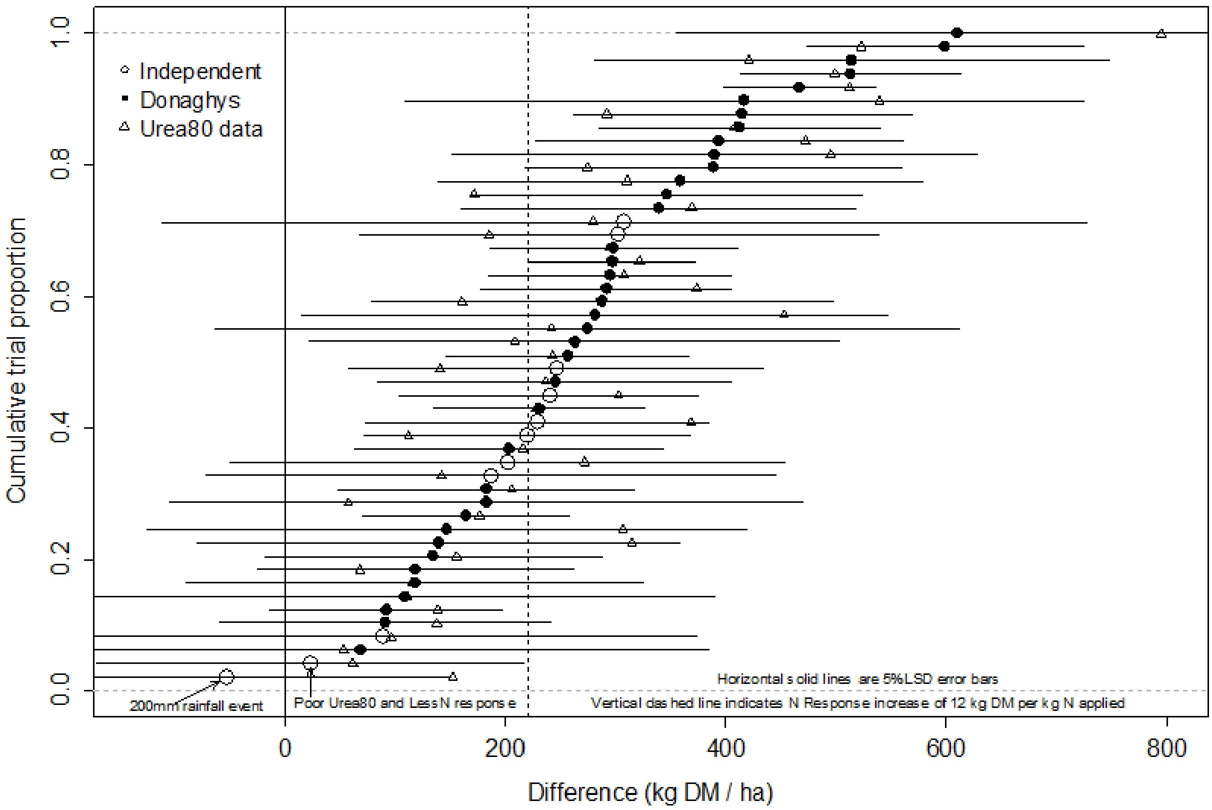

Fig 6. Cumulative Distribution Function graph of Difference between LessN40 and Urea40 treatments (in absolute kg DM/ha).

Individual trial error bars were included in the absolute dry matter graph (Fig 6) and show that in the majority of cases, the LessN system treatment was statistically significantly greater than the urea only treatment at the same nitrogen rate and that there was no statistically significant difference between the LessN40 treatment and the urea only treatment at the 80 kg urea/ha rate). Error bars are not given in Fig 5 as the calculations were so non-normally distributed but not able to be transformed to give meaningful confidence intervals for each trial. Variability was in any case much greater than with the absolute dry matter readings which give a clearer indication of practical effect and statistical significance.

Conclusion

The mean effect of the LessN system was consistent with a doubling or more of the Response Ratio or in other terms a doubling of nitrogen response compared to urea only at the same rate. Mowing gave similar results to probe estimation of dry matter yield gains though the response ratio had a mean of 2.0 rather than statistically significantly higher than 2 as measured by probe. The Substitution Value of the LessN system (at the 40 kg urea/ha rate) was reasonably consistently 2 (equivalent to an additional 40 kg/ha of urea) since LessN40 gave generally similar results to Urea80 and SolidUrea80.

It is hypothesised that for optimal Response Ratio (LessN40 response compared to the response of urea only at the same N rate), pasture needs to be in a reasonable state of growth at the time of application. This may explain the reduced Response Ratio in three otherwise nitrogen responsive trials where soil temperature was not at label temperature at the time of application and when there was flooding two days prior to application in a further trial.

In two trials unaffected by low soil temperatures or flooding, there appeared to be a limited addition response above Urea40 for either additional urea or LessN inclusion. This may point to a requirement to ensure that soil mineral nutrient requirements and other factors are not limiting full response. Nevertheless in the majority of trials and in the analysis of every trial combined, the mean effect of the LessN system was consistent with a doubling of nitrogen response (or more) with tight confidence intervals.

Extended trials past the first grazing rotation were beyond the scope of this paper but results are presented in Donaghys Industries Ltd (2012).

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