Evaluating the Agronomic Effectiveness of Fertiliser Products

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Abstract
One of the problems which arises when analysing and interpreting results from field trials designed to test the efficacy of fertilisers and fertiliser-type products on pastures and crops is the conundrum of Type 1 and Type 2 statistical errors: is the product having literally no effect, or is the trial not "powerful" enough to detect small differences. This problem can be objectively and pragmatically solved, when sufficient trial data are available, by using cumulative frequency distribution functions. In this paper we explain what cumulative frequency distribution functions are and their usefulness for determining the agronomic effectiveness of products. This technique is then applied to field trial data testing the effectiveness of a number of fertiliser and fertiliser-type products used in agriculture today. It is concluded that this approach provides a more objective basis for determining the efficacy or otherwise of fertilisers.
Keywords: fertilisers, agronomic effectiveness, testing, field trials, cumulative frequency distribution**.**

Introduction
Many new products have been introduced into the agricultural market in New Zealand in recent years as alternatives to, or to increase the effectiveness and efficiency of, traditional solid fertiliser products. Field experiments are required to determine the effectiveness of these products, and such experiments should be sufficiently powerful to detect treatment differences against a background variability in pasture or crop production of between 5 to 10% (Sinclair *et al.* 1994). For example, Johnstone & Sinclair (1991) have shown that between 9 and 28 treatment replications would be required to detect a 10% difference in yield at a 95% level of probability.

Most field experiments do not meet this standard and, furthermore, the predicted effects of some products on plant yields are often small (see Results). It is not surprising therefore that the effects of these products, as measured in individual field experiments, are frequently not statistically significant.

The interpretation of such results is problematic – is the product having an effect but the experiment is not sufficiently accurate to detect it, or is the product having no effect and the observed treatment effect due to the background biological variation? The converse situation also arises when an individual result is statistically significant – is the effect due to the treatment or is it due to the small but finite probability that the product is having no effect and the observed effect is due to the background variability? These possibilities give rise to the classic Type I and II errors associated with statistical testing (Snedecor & Cochran 1967).

Reynolds (1987) has suggested a pragmatic solution to this problem that can be used when a given product has been tested many times. This enables the frequency distribution of the measured treatment effects to be examined and compared with a normal distribution with a mean of zero. For convenience this is achieved by converting the distribution frequency and plotting the cumulative distribution function. Any displacement of the distribution, either positive or negative, relative a control, can be taken to indicate a real treatment effect. For example, the data in Fig. 1 are from a set of experiments conducted by Wadsworth (1987) in which the effect of a small application of water (225 L/ha) on crop yields was measured relative to a nil treatment (no water). Such an input of water would not be expected to have a sustained or substantial effect on crop yield. This is indicated by the fact that the observed effects of water are distributed normally around a mean of -0.6% with a confidence interval of 2.3%. The range in the observations is -22% to 32%, consistent with the variability normally associated with experiments of this nature, allowing for the odd intrusion of other experimental errors.

Methods
General
A complete description of the methodology used throughout this paper is given elsewhere (Edmeades 2002). Briefly, for any given product the results from published and unpublished field trials are recorded on a site × year × crop (or pasture) basis and the measured yield differences between the control and the product treatments are calculated as a percentage of the control, either positive or negative. Only results from replicated and randomised field trials are used. The rank and distribution, and hence the cumulative frequency

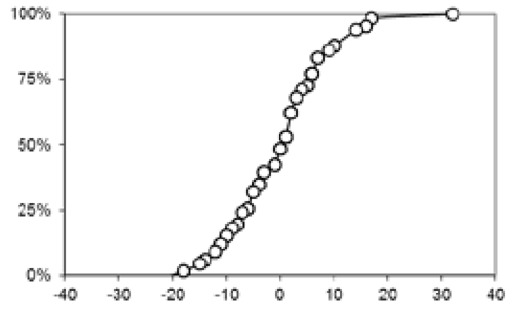


Figure 1. Frequency distribution (y-axis) of crop responses (%) (x-axis) to water (225 L/ha) relative to control (data from Wadsworth 1987).

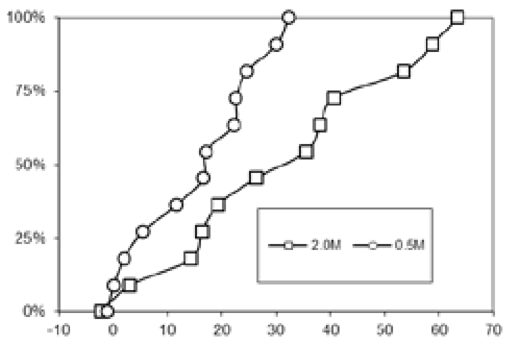


Figure 2. Frequency distribution of pasture responses to fertiliser P (triple superphosphate) applied at 2 rates (2 × maintenance and 0.5 × maintenance) (data from Sinclair *et al.* 1994).

distribution, of the observed product responses are then determined, together with the descriptive statistics of the distributions.

In formal meta-analyses it is normal to give each trial a weighting dependent on the accuracy of the particular measurement of interest. For example in the trials discussed in this paper the primary focus is on the effect of a given product on the relative crop (or pasture) production. The trials could then be weighed based on, say, the LSD determined for each trial, or some other metric indicating the accuracy of the measurement. If this were done one could imagine in Fig. 1 horizontal LSD bars of varying width associated with each trial, indicating whether that specific trial result was statistically different from zero. However, the quandary arising from Type I and II errors would still remain. By plotting the cumulative distribution of the responses the focus is on the distribution of *all* of the observed responses relative to zero and providing there is sufficient data (i.e. a sufficient number of trials) the weighting of any given trial is of secondary concern.

In any case in any set of trials which use the same trial design on the same crop (or pasture) it is likely that the trial CVs will be similar, in which case it is reasonable to assume all trials have a similar weight. This is the situation in most of the data discussed in this paper. The exceptions are the trials on liquid fertilisers and with the products Avail and Nutrisphere. In the former case different crops were tested using a range of trial

Table 1. Descriptive statistics of the population of observed effects of the four product-types on the production of crops and pastures expressed as the percentage increase or decrease in production relative to the control (from Edmeades 2002).

Product type	Number of trials	Mean Response (%)	Confidence interval (95%)	**Distribution by quartile**		
				25	50	**75**
Fish-based	67	-1.4	1.44	-3.9	-0.9	2.6
Seaweed-based	543	1.48	0.88	-4.0	0.8	5.4
Animal-based	93	-1.24	1.69	-4.1	-1.1	3.6
Vegetable-based	107	-0.72	1.52	-5.1	0.4	2.6

Table 2. Descriptive statistics of the measured pasture responses to urea40, urea80 and urea40+LessN for the independent and in-house trials (data from Donaghys 2012).

Source of trials	Treatment	Number of trials	Mean response (%)	Confidence interval	**Range**
Independent	Urea40	20	24	7	5–66
	Urea80	27	32	8	11–90
	Urea+LessN	27	38	8	15–100
In-house	Urea40	41	26	8	-6.5–132
	Urea80	41	72	21	20–443
	Urea+LessN	41	76	21	21–453

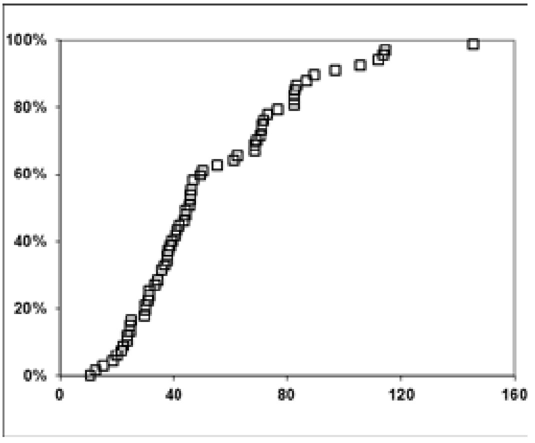


Figure 3. Frequency distribution of pasture responses to fertiliser N (80 kg urea/ha) relative to control (data from Donaghys Industries 2012)

designs. However all the trials were properly replicated and the treatments randomised thus reducing between-trial weightings. Furthermore, the large number of trials used in this case minimises the possibility that the overall distribution of responses is distorted with data from a few (it is assumed) anomalous results. The trials with Avail and Nutrisphere were categorised into three classes based on the reported quality of the trial design and data (see later), in effect weighting the trials into three groups. Only the most reliable set of data, and one assumes a subset of trials of similar weight, was used to draw firm conclusions.

A final comment is required in respect to the interpretation of the cumulative response functions. The results in this paper all relate to products that are promoted to and used by farmers who would normally expect, as a minimum, to get a return on his/her investment. Thus small product responses of say <5%, while perhaps interesting to a research scientist developing a product, are likely to be of little consequence to a practical farmer. It is in this context that the results in this paper are offered.

P and N Fertilisers

Many field trials have been conducted in New Zealand examining the effects of fertiliser phosphorous (P) and nitrogen (N) on pasture production. Sinclair *et al.* (1994) reported the results from a national series of replicated trials in which the effects of applying phosphate fertiliser (triple superphosphate), at two rates (0.5 × maintenance and 2.0 × maintenance) on pasture yields, on a series of P deficient soils were measured. Similarly, Donaghys Industries (2012) have published the results from a set of replicated trials in which the effects of N (80 kg urea/ha) on pasture production have been measured. The relative pasture responses to P or N have been extracted from these data sets.

Liquid Fertilisers

There are several liquid fertilisers sold in New Zealand. These can be classified as products derived from natural materials such as seaweed, fish, animal and vegetable products by various chemical and biochemical processes. These products may also contain added inorganic nutrients and/or other biological materials and are recommended to be applied at low rates (2–20 L/ha). Their primary mode of action is claimed to arise from the presence of plant growth substances (PGSs such as auxins, cytokinins and gibberellins), acting alone or in combination with the other components of the product (nutrients, proteins or enzymes), which stimulate the biological processes in the plant. Some also claim to have beneficial effects on the soil. The general claims made for this type of liquid fertiliser include: increased plant yield and quality, improved nutrient use efficiency, greater tolerance to stress (drought, cold, insect pests etc.) and increased root growth or activity. Some also claim to have beneficial effects on the soil biological activity and nutrient availability.

A database comprising the results of over 800 replicated field trials internationally was established (Edmeades 2002) from which the relevant data was extracted.

Avail and Nutrisphere

These products are not yet sold in New Zealand but large volumes are manufactured (by Speciality Fertiliser Ltd) and sold (by Simplot Ltd) in America. Both products are polymers, which are either added to N fertilisers (Nutrisphere) or coated onto P fertilisers (Avail). They are claimed to increase the efficiency of either N or P fertiliser and to increase crop production by 10%.

For these trials a database was established (Edmeades & McBride 2011) recording the results of 210 trials with Avail and 121 with Nutrisphere. Most of this research was unpublished. These trials were then ranked as either: very reliable (trial design and full statistical analysis were available), reliable (no information about the trial design but the statistical significance of the treatment effects was available) or not reliable (trials which were either non-replicated or with less than three replicates, or the trial design was not known or no statistical information or analysis was available or there was doubt as to whether the entire data set was presented).

Gibberellic Acid

Gibberellic acid is one of three recognized plant growth regulators and is used either alone or with fertiliser to stimulate pasture production. For a review on the use of gibberellins on pastures see Matthew *et al.* (2009). Nufarm Ltd has developed a water-soluble formulation of gibberellic acid which is sold under the trade name

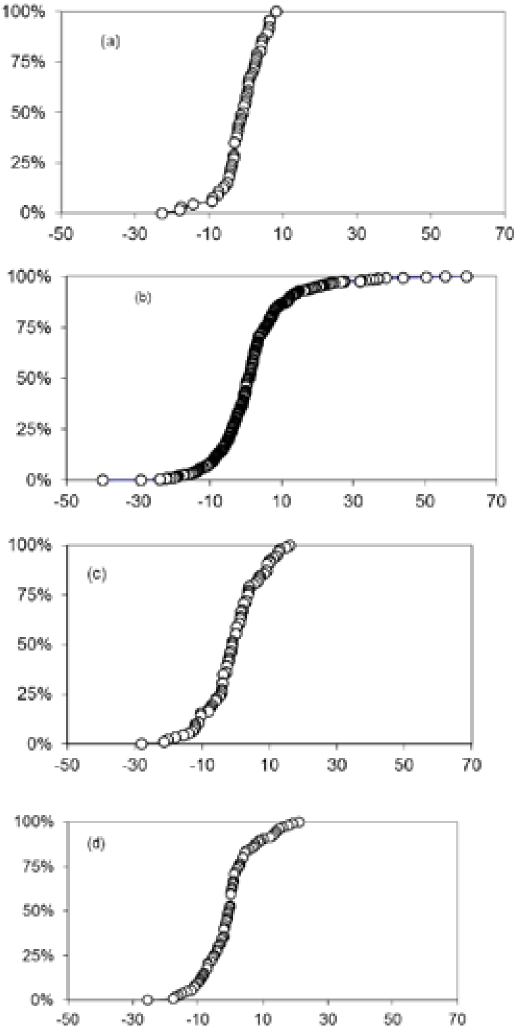


Figure 4. Frequency distribution of crop and pasture response to a) fish-based (n = 67) b) seaweed-based (n = 543) c) animal-based (n = 107) and d) vegetable-based (n = 93) liquid fertilisers relative to control (Edmeades 2002).

ProGibb® and it is recommended to be applied within 5 days of grazing and that the pasture is utilised within 40–50 days. The company has conducted 35 trials replicated trials nationally examining the effect of ProGibb on pasture production in New Zealand. Nufarm Ltd commissioned agKnowledge Ltd to review this body of research (Edmeades 2009).

EcoN

EcoN is a proprietary formulation of the nitrification inhibitor DCD marketed by Ravensdown Fertiliser Cooperative Ltd. It is claimed to reduce nitrate leaching, nitrous oxide emissions and increase

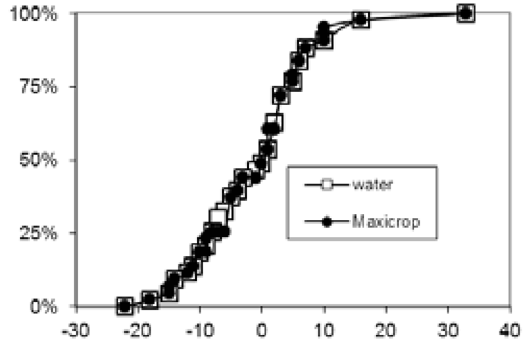


Figure 5. Frequency distribution of crop responses to Maxicrop compared with the response to the same rate of application of water (data from Wadsworth 1987).

pasture production. It is sprayed onto pasture and is recommended to be applied during the winter, typically in May and again in August. Ravensdown Fertiliser Cooperative commissioned agKnowledge Ltd to review all the relevant research on the effects of DCD on pasture production (Edmeades 2008).

LessN

LessN is marketed by Donaghys Industries. It is a "natural microbial based nitrogen utilisation enhancer formulated and trialled specifically for use in combination with dissolved urea fertiliser". LessN is said to contain "high levels of beneficial compounds to stimulate plant growth." In fact the active ingredient in LessN has not yet be identified but may be one of the plant growth regulators (Dr Rainer Hoffman, Lincoln University, pers. comm.).

The company has reported results from pastures for 41 in-house trials and 27 trials conducted by independent researchers (Donaghys Industries 2012). All these replicated trials have the same design: control, urea40 (18.6 kg N/ha), urea40+LessN, urea80 (36 kg N/ha).

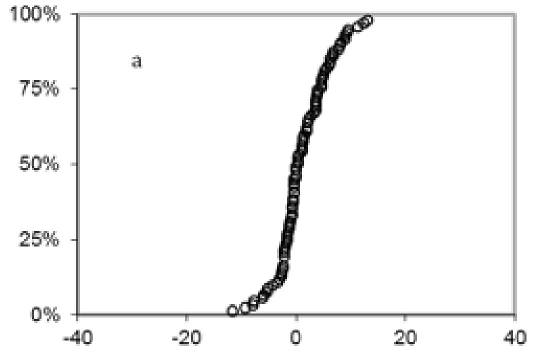
SustaiN

SustaiN is a proprietary formulation of urea and the urease inhibitor agrotain. It is marketed by Altum Ltd, a subsidiary of Ballance AgriNutrients Ltd. It is known that agrotain slows the hydrolysis of urea to ammonium and it is claimed that this results in a reduction in ammonium volatilisation, thereby increasing urea N efficiency. Data from the published literature were summarised for this paper.

Results and Discussion

Fertiliser P and N

The cumulative distributions of the observed pasture responses to P at both rates are given in Fig. 2. The



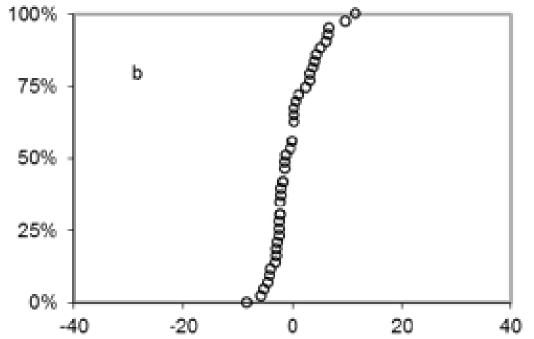


Figure 6. Frequency distribution of response to a) Avail (n = 95) and b) Nutrisphere (n = 44) including all very reliable trials (see text) and omitting outliers. (Edmeades & McBride 2012).

distributions are moved to the right and all the observed responses are greater than zero, indicating that fertiliser P is effective at increasing pasture production on P deficient soils. This is of course consistent with much other research worldwide. In this case the range of the observed responses reflects not only the background variability in pasture production but also the initial P status of the soils. In these examples the population of results is not large enough to clearly define the expected S-shaped cumulative frequency distribution (for examples see Fig. 4b).

Similarly, Fig. 3 shows the cumulative distribution function of the pasture response to fertiliser nitrogen (80 kg urea/ha) relative to the control. Once again the well-documented effectiveness of N fertiliser on pasture production is reflected in the cumulative distribution; all the observed responses are greater than zero and the average response is 57% with a range of 10%–145% (confidence interval CI = 7%).

Liquid Fertilisers

The cumulative distributions of the observed crop yield responses to the four types of liquid fertilisers (*viz*. seaweed, vegetable, animal or fish-based) are shown in Fig. 4 and the relevant descriptive statistics

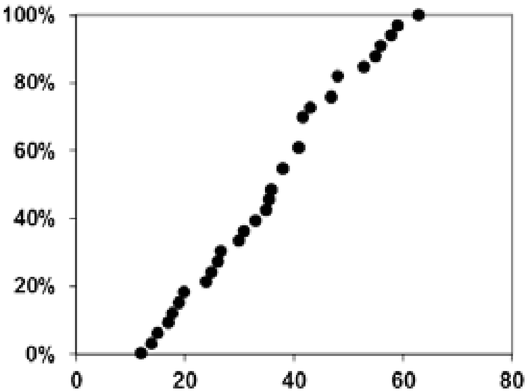


Figure 7. Frequency distribution of pasture responses to Progibb when applied as recommended (see text) (data from Edmeades 2009).

for each subset of data are given in Table 1. The observed crop responses are approximately normally distributed about zero, consistent also with the hypothesis that these product-types are having no effect on crop yields. Of particular interest to New Zealand is the product Maxicrop. Many trials (302) have been conducting world wide on a range of crops, including pastures, on this one type of seaweed product and the average responses is 1.6% (confidence interval 1.4%) (Edmeades 2002). Indeed this product has been shown to be no better than water (Fig. 5) (Edmeades 2002).

Avail and Nutrisphere

For the product Avail there were 95 very reliable trials. The results were distributed around zero with a mean of 1.4% and confidence interval of 1.1% (Fig. 6a). The results from the 44 very reliable trials with Nutrisphere indicated and average crop response of 0.05% (confidence interval 1.3%) (Fig. 6b). These results are inconsistent with the claim that these products increase crop production by 10–12%.

Giberellic Acid

The distribution of the response to ProGibb is shown in Fig. 7. The mean response is about 36% (confidence interval 5%) with a range of 13% to 63% indicating that ProGibb is effective when used as recommended (i.e. applied within 5 days of grazing and harvested within 50 days).

EcoN

The cumulative distribution of pasture responses (n = 28) to EcoN, when applied as recommended, is given in Fig 8. The mean response is 2% (SE = 1%) with a range of -17% to +17%. These results are consistent with those reported by Gillingham *et al.* (2012) from four

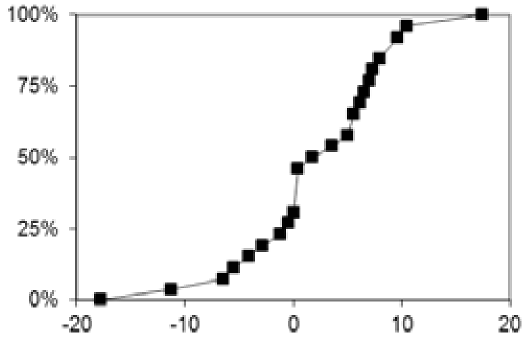


Figure 8. Frequency distribution of pasture responses to EcoN when applied as recommended (data from Edmeades 2008).

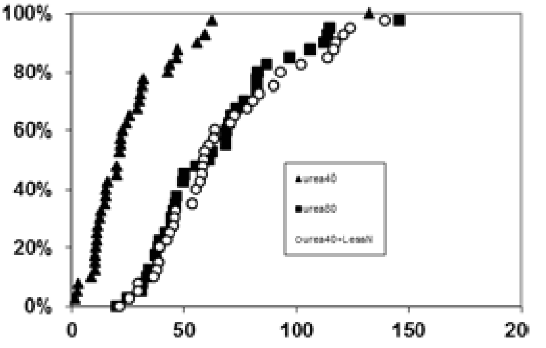


Figure 9. Frequency distribution of pasture responses to urea40 (40 kg urea/ha), urea80 (80 kg urea/ha) and LessN (40 kg urea/ha + LessN) from the in-house trials (data from Donaghys 2012).

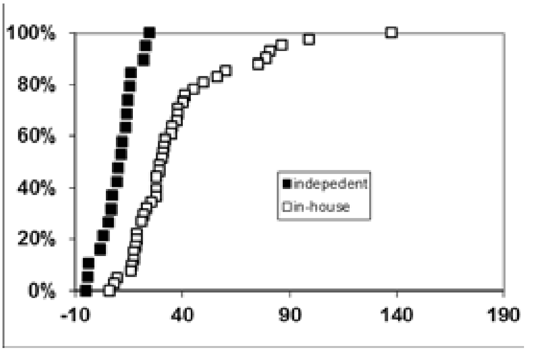


Figure 10. Frequency distribution of the differences (%) between the urea40+LessN treatment and the urea40 treatment for the in-house trials and the independent trials (data from Donaghys 2012)

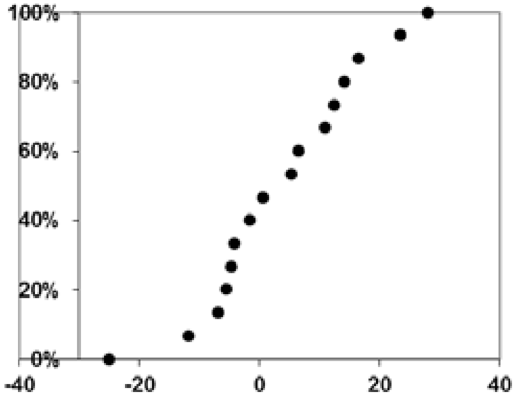


Figure 11. Frequency distribution of pasture responses to SustaiN (data from Stafford *et al.* 2008; Martin *et al.* 2008).

sites over 3 years. It is important to note that in these trials EcoN was applied, as recommended, to the whole pasture, which includes a mosaic of urine patches of varying ages. Thus these trials reflect the situation and conditions in which a farmer would use the product.

Ravensdown justify their claim that EcoN increases pasture production by up to 20% based on a) research from Lincoln University (for example see Di & Cameron 2004) and b) farmer demonstration-type trials (Carey et al. 2012). All of the research at Lincoln employed the same trial protocol: the effects of EcoN were measured in the presence of large inputs of urine N (1000 kg N/ha) and fertiliser N (200 kg N/ha). These results therefore cannot be extrapolated to the field situation where normal N loadings in pastures are much less than this. Furthermore, the results from the farmer demonstration trials, while interesting, should be set aside when they conflict with the results from properly designed scientific trials conducted by independent science organisations.

LessN

The distribution of the responses to the three treatments, relative to the control, is given in Fig. 9 for all the in-house trials. These results suggest that urea40 (18.6 kg N/ha) increases pasture production by 26% (n = 41, range -6.5% to 132%, CI = 8) and urea80 (36 kg N/ ha) by 72%, (n = 41, range 20% to 443%, CI = 21). Taken at face value the responses to urea40+LessN were similar to those for the urea urea80 (76%, n = 41, range 21%–453%, CI = 21). However, these in-house results are not consistent with the trials conducted by the independent researches. The average responses to urea80 and urea40+LessN from the independent results were much less than those recorded from the in-house trials (Table 2).

The key question is: does LessN when added to urea have an effect on pasture production over and above that of the same rate of urea. Fig. 10 shows the distribution of the differences between urea40+LessN and urea40 alone, for the independent and in-house experiments. For the independent trials the average difference was 10% (CI = 4%, range -5 to 25%). For the in-house trials the difference was 38% (CI = 9%, range 6–137%). Further independent research is clearly required before the effects of LessN, when added to urea, can be unequivocally quantified.

More importantly, these results cannot be interpreted to mean that adding Less N to urea halves the need for fertiliser urea, as the company claims. For example if the treatment urea80 was replaced by say urea60 or urea90 it is likely that these treatments would have given pasture yields similar to that of urea40+LessN, given the precision of the trials. Further trial work is required where the effect of LessN is measured in the presence and absence of many rates of urea to determine the true substitution value of Less N with respect to urea.

SustaiN

Fig. 11 shows the differences in pasture production between urea and SustaiN as measured in 16 field trials (see Stafford *et al.* 2008 and Martin *et al.* 2008 for the individual trial results). The results are approximately evenly distributed around zero (range -25%–53%) with an average of 4% (CI = 7%). Because the confidence interval includes zero this result is consistent with the conclusion that SustaiN has no consistent effect over and above urea when applied at the same rate of N. Given the small number of trials results available in the published literature, for this type of analysis, this conclusion is tentative and subject to further trial work. However it is nevertheless corroborated by independent research, which indicates that the losses of N from ammonium volatisation are small (0–5%) when urea is used at normal rates (< 50 kg urea) on pastures in New Zealand.

Conclusions

The results discussed above demonstrate the usefulness of cumulative frequency distribution functions for determining the efficacy of fertilisers and fertiliser-type products. Providing sufficient data are available the frequency distribution of the responses relative to an appropriate control can be assessed against a normal distribution centered on zero. This approach obviates the need to know whether the results from an individual trial are statistically significant or otherwise and provides a readily comprehensible picture of all of the available evidence.

ACKNOWLEDGEMENTS

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