A comparison of pasture responses to applications of granular or fine particle fertiliser formulations

Milestone 2 report

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1. Executive Summary

Fine Particle Application (FPA) of fertiliser is achieved by fine grinding solid granular fertilisers to typically between 100-200 µm particle size and dampening the powder with water. This damp mix of fine particles and water is then spun on through specially designed encapsulated spinners via aerial or ground application.

FPA Ltd have completed over 200 farm monitoring trials of the FPA technology for the application of a range of fertiliser nutrients, established to demonstrate the even spread by the FPA method and also to measure the effects on pasture performance. Good records have been kept of these trials, and a consistent methodology has been applied. Given the limited amount of experimental data on the agronomic effects of fine particle application of fertilisers in the public domain, it was thought that these data should be summarised and made public.

The final database comprised 250 field trials from around 170 properties. 54% of the sites were on the South Island, 46% on the North Island. No trials were located north of Taranaki. 74% of the sites were classed as dairy farms, the remainder as mixed livestock. Similarly, the terrain of 74% of sites was classed as 'Flat', the remainder in the rolling to hill terrain categories. Sites generally comprised of three plots of 9 m^2 each with the following treatments: (a) an untreated 'control', and a fertiliser mix of the host farmer's choice applied either (b) in granular form (by hand) or (c) as fine particle application through a calibrated spreader. Fertiliser mixes varied but generally contained some N with other macro- and/or micro-nutrients. Pasture dry matter yields were measured by rising plate meter (RPMP) at all sites, and also at a selection of sites by mowing, weighing the cuttings and converting to dry matter using a standard 20% DM conversion factor.

As well as calculating pasture DM yields, fertiliser response was calculated and expressed in units of kg DM/kg N applied. Clearly, we would expect that the response was not only due to the N component where a fertiliser mix was applied. However, as the same mixes were applied by the two methods, this is a reasonable comparison to make between methods (but still recognising other nutrients could also contribute to an observed effect). Our analysis focused on harvest 1, where most of the response would occur, and a subset of data was used to assess the effects across multiple harvests after a single application.

Our starting hypothesis was that there should be no difference in pasture yield or response to applied fertiliser given that both fine particle-applied and hand-applied granular fertiliser forms would be applied evenly on the small experimental plots. However, the analysis of the data from the FPA monitoring sites showed a consistent difference in pasture response to the two fertiliser application methods. We found that:

- Overall, the fertiliser N response from FP-applied fertiliser was statistically significantly higher than from granular-applied fertiliser: 40 vs 16 kg DM/kg N, as an average of both measurement methods for harvest 1.
- Similar trends in response were found when including subsequent harvests (standardised to a period 110 days after application).
- There was no evidence of regional differences in response to FP-application
- Generally, FP-application out-performed granular applications at application times throughout the year, the exceptions being June, July and January when there was no difference.

The overall result is in line with some other trials, although others have also shown no benefit. Furthermore, there is no firm established mechanism to explain the size of differences that were measured. This lack of certainty over mechanism is a potential barrier to acceptance of the data. However, trial protocols were established and followed, and data were well documented. We have therefore analysed the data in good faith and suggest the results warrant further debate and experimentation to elucidate a mechanism of action that could explain the observations.

Note: this report was originally submitted October 2019 and has been updated with more methodological detail of the field sites (January 2020)

2. Background

Fine Particle Application (FPA) of fertiliser is achieved by fine grinding solid granular fertilisers to typically between 100-200 µm particle size and dampening the powder with water (30-40% by weight). This damp mix of fine particles and water is then spun on to pastures through specially designed encapsulated spinners via aerial or ground application. Thus, it is a solid fertiliser application system: the role of the water is to dampen any dust and facilitate even spreading. The water evaporates soon after spreading.

Thus, FPA is a method of application and it can be used with any fertiliser mix (single fertilisers, compound fertilisers or blends); FPA is not a fertiliser. While there are similarities between suspension fertiliser systems used overseas and FPA, there are also differences, namely (Morton et al. 2019):

- More water added (40-60% water by weight)
- Resulting in a saturated solution plus suspension as fine particles
- As suspension fertilisers are delivered to the farm already made-up, there is inclusion of clay or bentonite to keep particles in suspension

A major difference with FPA, therefore, is that FPA converts granular fertiliser into fine particles on-site during the application process. It is a solid fertiliser application process, not a liquid fertiliser.

FPA was originally developed to achieve an even spread of fertiliser across the spreading width on challenging terrains, often with blended combinations of fertiliser of different size and spreading ballistics; first by helicopter-based technology and then by designing an add-on to a ground spreader.

More even spreading at a paddock scale and accuracy of spreading (e.g. avoiding water courses) formed the original value proposition for FPA. At a paddock scale, more even spreading could theoretically result in a more cost-effective use of the applied fertiliser. The size of the benefit (if any) would depend on the evenness of spread achieved by other application methods. However, Horrell et al. (1999) indicated that for N on pasture, significant financial loss in dairy and sheep/beef systems occurs at a CV of approximately 40%-50% and concluded that Spreadmark standards are a satisfactory basis for defining the evenness requirements of fertiliser applications in most circumstances.

Despite the main reason for FPA development cited as evenness of spread at the paddock scale, to date, most research on yield effects has focused on evaluating FPA at a scale much smaller than a paddock: several m^2. Intuitively, we would not expect a pasture growth benefit from the FPA method at this scale compared with granular fertiliser because evenness of spread is not an issue on small plots with hand-spread fertiliser. Shepherd (2018) stated that, although a couple of journal papers suggest enhanced foliar N uptake from FP-application, no definitive mechanism has been confirmed as to why FPA should offer a pasture yield benefit at this small (m^2) scale. On this basis, our starting hypothesis was:

> *On small plots, FPA should not give a larger pasture growth response to applied fertiliser than granular fertiliser applied by hand.*

The most authoritative assessment to date has been by Morton et al. (2019) who concluded from their assessment of small plot trials that there was "insufficient experimental evidence to recommend the use of FPA fertilisers over the standard granular form of application". Nevertheless, rigorous testing of our hypothesis is made difficult by the lack of published data, further compounded by different methodologies and often no reported statistics.

However, FPA Ltd have completed over 200 farm monitoring trials of the FPA technology for the application of a range of fertiliser nutrients, established to demonstrate the even spread by the FPA method and also to measure the effects on pasture performance. Good records have been kept of these trials, and a consistent methodology had been applied. Given the general lack of experimental data on FPA in the public domain, it was thought that these data had potential to test our hypothesis that the FPA method would not convey a yield benefit above the granular fertiliser applied by hand on small plots.

AgResearch therefore worked with FPA Ltd. to establish a complete database of these trials, which we then used to independently evaluate the results. Our reason for suggesting that the results are more widely reported was to stimulate a debate, based on a more detailed dataset of application methodologies.

3. Field trial methodology

3.1 Overview of approach

Each fertiliser comparison trial was unreplicated but there were over 200 sites of the same design, thus comprising a good dataset to statistically analyse to test our hypothesis. Trials were run by FPA Ltd, using local contractors to do the experiment. Contractors were provided with detailed protocols. Training on the execution of these protocols was provided. Detailed records were kept for each trial site and provided to FPA Ltd for collation in a central data store.

Each site comprised of three treatments: a granular mix of fertiliser; the same mix of fertiliser applied at the same rate as the granular by the FPA method; and a nil fertiliser control. The fertiliser mixes varied between sites depending on the preferences of the host farmer. The majority of sites had a single application followed by several harvests. Some sites had multiple applications (2-9), with multiple harvests.

Typical plot size was 9 m^2 (3m x 3m). Granular applications were made by hand. Manual application would not be able to replicate the FPA method, so the application was achieved by calibrating the spreader to the same application rate as granular, covering non-FPA plots with plastic sheeting and then driving the spreader adjacent to the plot to apply fertiliser to the FPA treatment(s). More details on this are given below.

Pasture yields were always estimated by a rising plate meter (RPM) - 10 measurements per plot - and then the pasture was cleared by mowing. In addition, at some sites, individual plots were mown and the grass cuttings weighed as another (direct) method of assessing fresh yield.

Our final database comprised c. 250 field trials from around 170 properties. 54% of the sites were on the South Island, 46% on the North Island (Table 1). No trials were located north of Taranaki. 184 of the sites were classed as dairy farms (74%), the remaining sites as mixed livestock. The terrain of sites was classed as 'Flat' for 184 of the sites, and the remainder as rolling to hill terrain categories.

Table 1. *Location of trial sites*

Region	Count
CANTERBURY	13
OTAGO	5
SOUTHLAND	117
MANAWATU	47
TARANAKI	67
Total	249

3.2 Fertiliser treatments

A range of fertiliser mixes was used across the 250 sites, ranging from urea alone to mixes that supplied N with other macronutrients, micronutrients and lime. However, within a site, the same fertiliser mix was applied as 'granular' or by the FPA method. Only one site recorded 'ProGibb' as an additive: this was excluded from the analysis, being a growth stimulant rather than a fertiliser nutrient.

We have checked with FPA Ltd about the use of gibberellic acid and they categorically state that, apart from this one anomaly, it was not used in the field trials in the compiled database.

The analysis and interpretation of results in this report is based on that assurance.

3.3 Field trial methodology

3.3.1 Site selection

Sites were selected in conjunction with farmers to represent average pasture quality and ease of access for monitoring. Sites were normally setup adjacent to a fence line to allow the trial site to be fenced off to exclude stock from the trial site.

There was no randomisation of treatments; they were always set in the same order so that the control and granular plots could be covered with a single plastic sheet when fertiliser was applied by the FPA method.

Plot boundaries were marked with glyphosate, and the control treatment was always identified with a triangle in the left-hand corner. The plot size was a standard 9 m^2.

3.3.2 Fertiliser application

Both fertiliser treatments at a site were applied on the same day. Granular fertilisers were hand-applied after being pre-mixed, pre-weighed and bagged per plot. In order to exactly replicate the FPA methods, the FPA treatment was made using the ground spreader, covering non-FPA plots with plastic sheeting.

The plastic sheeting served as a check that application rates were achieved by the spreader. The intercepted fertiliser was allowed to dry on the sheet and then swept, collected and weighed. This was standard procedure at all sites and records have been kept. Application rates were generally ±10% of planned application rate.

Furthermore, Appendix I provides examples from independently run trials that these levels of accuracy can be obtained by this method.

3.3.3 Measurements

Two methods of estimating yield were used. Neither directly measures dry matter (DM) production, so there are assumptions built in to the subsequent calculations of DM production:

- **Rising plate meter** – this is a common tool for assessing ‘compressed height’ of pasture (Anon 2008a). A regression equation converts the compressed height (i.e. “clicks”) to an estimated kg DM/ha. This equation is a ‘guide’ and not an absolute measure of quantity as the DM composition will change due to seasonal variations (Anon 2008a). At the very least, however, the plate meter will give relativity between treatments at the same site, as well as providing an estimate of kg DM/ha. The following approach was used:
    - Each 9 m^2 plot had 10 placements of the RPM
    - Two average calibrations for the RPM were used. For dairy, DM/ha = RPM clicks x 140 + 500; for Sheep and beef, DM/ha = RPM clicks x 158 + 200
    - Pasture height measurements in CM were also recorded on the field monitoring plot report forms

- All plots were fenced off to exclude stock and mown to around 1500 - 1700 kg DM/ha, with all grass clippings removed
- For multiple harvests all residuals were measured using the RPM and recorded

- **Mowing plots** – At some sites, fresh yield was also weighed after cutting to a standard height equivalent to the height an animal would leave post-grazing. These harvests were taken from mowing a 2 m^2 area in the middle of the plot. Fresh weight was adjusted to an assumed constant DM content of 20% to estimate DM production.

As well as calculating pasture DM yields, fertiliser response was calculated and expressed as kg DM/kg N applied. Clearly, we would expect that the response was not only due to the N component where a fertiliser mix was applied. However, as the same mixes were applied by the two methods, this is a reasonable comparison to make between methods (but still recognising other nutrients could also contribute to the observed effect).

The **extra kg DM per kg applied fertiliser N** is a standard industry measure and typically ranges for N fertiliser applied 'conventionally' from <5 kg DM/kg N in winter to >20 kg DM/kg N in late spring/early summer (Anon 2008b).

This value was calculated from plate meter DM estimates and fresh yield estimates. However, the two methods were not used in the same analysis because absolute values will differ between methods, due to the different assumptions described above. Calculations made were as follows:

Rising plate meter:

kg DM/kg N = (Plate meter $DM_{N\ fertiliser}$ - Plate meter $DM_{Nil\ N\ control}$) / kg $N/ha_{fertiliser}$

Plot mowing:

Mown kg fresh yld/ha = Fresh harvest yield (kg) x 10000 / harvest area (m^2)

Mown kg DM/ha = kg fresh yld/ha x 0.2, assuming DM content is 20% of fresh yld

kg DM/kg N = (Mown $DM_{N\ fertiliser}$ - Mown $DM_{Nil\ N\ control}$)/ kg $N/ha_{fertiliser}$

Consequently, we removed trial sites where the applied fertiliser did not contain an N source. We also excluded any measurements where a control measure was not provided.

Subtracting a control yield from fertiliser-treatment yields, inevitably result in some negative values due to errors associated with measurements. Consequently, data distribution was positively skewed and required transformation (in this case square root transformation) before analysis of variance could be undertaken to test for statistical significance.

3.3.4 First harvest vs multiple harvests

Analysis of pasture N response first focused on the first harvest after fertiliser application, given that this is when most of the response would be expressed. This also allowed all sites to be included in the analysis.

Thereafter, the effect of residual growth in subsequent harvests was examined to see if this altered the trends we observed with pasture response in harvest 1 only. This was done by identifying a subset of sites where there were multiple cuts after a fertiliser application and then re-comparing pasture response over these harvests, as affected by fertiliser application method.

4. Database and statistical analysis

4.1 Database development

AgResearch worked with FPA Ltd to develop a consistent format for the records from each trial. As a result, FPA Ltd provided us with Excel workbooks that included:

- Farm property details: client i.d., farm i.d., plot i.d., plot size
- Fertiliser application details: types of application (generally 'granular' and FP applications), composition of fertiliser mixes applied, application dates, application rates and cost estimates of the nutrients
- Yield data: harvest dates and estimates of fresh yield (always included a rising plate measurement of fresh yield, and sometimes also a harvested plot weight of mown pasture)

These workbooks were then combined to generate a single database for statistical analysis. Inevitably, as the data were combined some inconsistencies were identified, for example in spelling of nutrients, client names, etc. This therefore required some additional data cleaning to arrive at a finalised database.

4.2 Statistical analysis

The DM estimates were transformed to help resolve issues with the assumptions for a linear model. The transformed pasture responses were based on a square root transformation:

Transformed pasture response = (sqrt($DM_{fertiliser}$) – sqrt($DM_{control}$)/N applied

This transformation allowed for negative values after correcting for the control and reduces the influence of large positive values.

Linear mixed effects were used where Fertiliser treatments were included as fixed effects and Client ID (Site) as random effects. For the effects models (e.g. region, enterprise type) the interaction between the effect and the Fertiliser treatment was included as fixed effects.

5. Results

5.1 Yield response, as estimated by rising plate meter (harvest 1)

5.1.1 Comparison of fertiliser application methods

Appendix II shows the yields estimated by rising plate meter for both fertiliser application methods and control treatments for the 161 sites and each harvest. The graphs show a reasonably consistent trend of control yield < granular application yield < FPA yield.

Here, we have focused on response at harvest one. Based on these rising plate meter measurements there is evidence that, overall, the estimated pasture response to fertiliser mixes applied by FPA was larger than that of granular forms of fertiliser (Table 2). On average, the response was about 2.5 times that of granular application.

***Table 2**. Estimated yield response to applied fertiliser N (kg DM/kg N applied) from the two fertiliser application methods (first harvest after application), calculated by rising plate meter. Lettering indicates significant pairwise difference on the sqrt scale at the 5% level. The untransformed means, sd, min and max values and number of plots within the treatment are presented.*

Treatment	Mean	Standard deviation	Min value	Max value	No. of plots
Granular	17.7 b	23.4	-47.4	170	572
FPA	43.7 a	40.4	-16.3	353	585

Table 3 shows the estimated pasture response to fertiliser application methods by region. This is supported by the statistics in Figure 1, which show the square root-transformed fertiliser response. The larger response from the FPA method is consistent across all regions. Therefore, the FPA method performs better than granular application regardless of region. All the lines in Figure 1 are approximately parallel, which implies that the additional response to FPA is consistent across regions.

Statistical analysis showed that response to FPA, relative to granular application, was consistent across enterprise type (dairy, mixed livestock) and landscape (flat, rolling, etc) (data not shown).

5.1.2 Seasonal response

Calculated fertiliser responses from granular applications followed the expected seasonal trends, peaking at around 25-30 kg DM/kg N in early summer, with another smaller rise in autumn. A similar pattern is shown with the FPA method, albeit with much higher rates of DM response, in line with results described earlier.

For most months there was evidence that the FPA method resulted in a statistically significant larger pasture response than granular application. The exceptions are June, July and Jan (Figure 2); however, there were few sites with applications during these months (3 in June and July, 7 in January), so it is necessary to interpret findings for these months with caution. Traditionally, these would be months where fertiliser applications are avoided: winter applications in June and July are against fertiliser codes of practice due to risk of leaching and small responses; January is often drought-affected so fertiliser applications are often avoided then.

Table 3. *Estimated yield response to applied fertiliser N (kg DM/kg N applied) by Region from the two fertiliser application methods (first harvest after application), calculated by rising plate meter. Lettering indicates significant pairwise difference on the sqrt scale at the 5% level. The untransformed means and number of plots within the treatment/region are presented.*

Region	Treatment	Mean	P value	No. of plots
CANTERBURY	Granular	17.9 b	<0.001	31
	FPA	48.0 a		31
MANAWATU	Granular	21.5 b	<0.001	103
	FPA	69.4 a		106
OTAGO	Granular	21.1 b	<0.01	7
	FPA	50.3 a		7
SOUTHLAND	Granular	16.0 b	<0.001	302
	FPA	35.2 a		313
TARANAKI	Granular	18.3 b	<0.001	129
	FPA	41.8 a		128

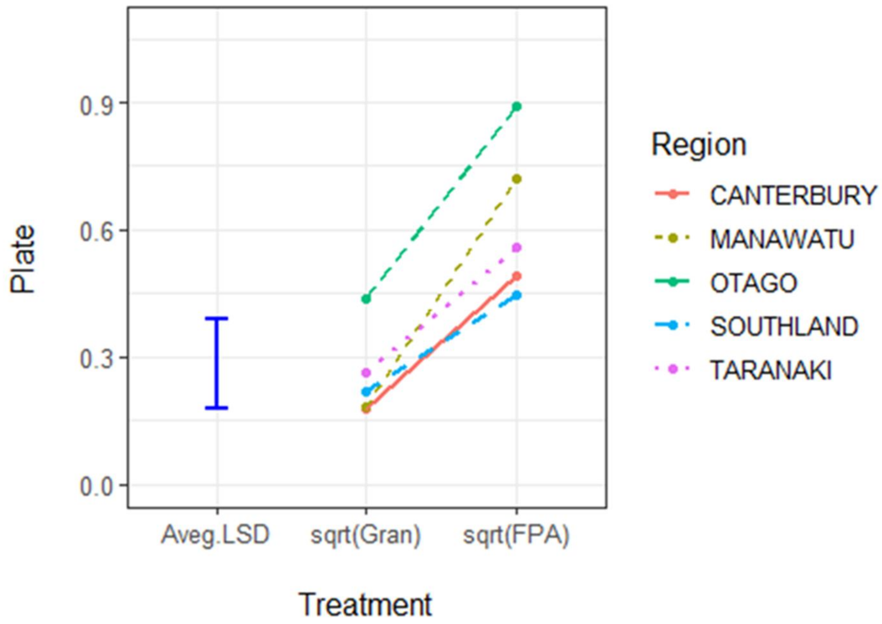

Figure 1*. Mean values of square root-transformed yield response to applied fertiliser N, by treatment and region.*

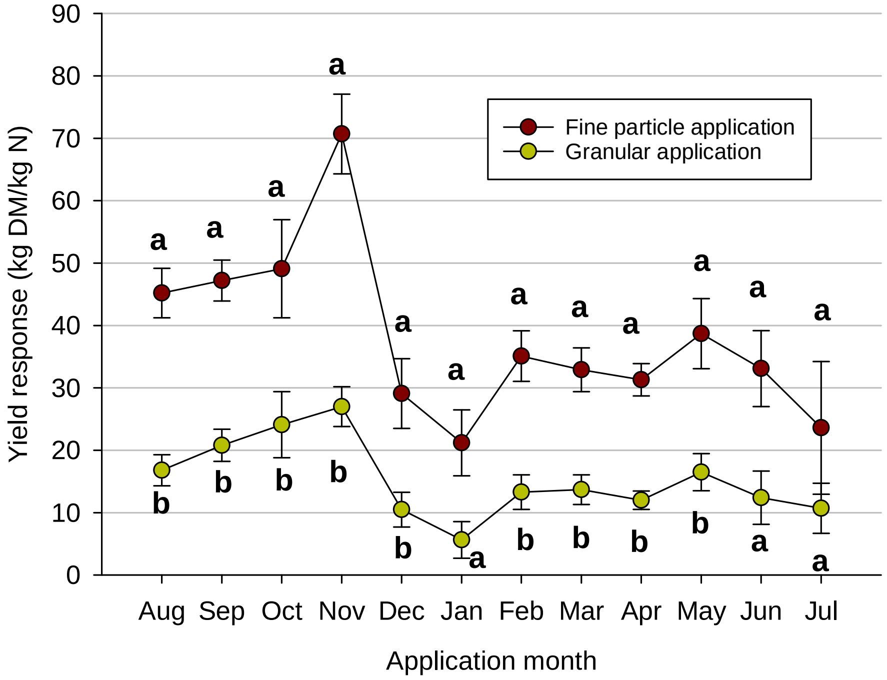

***Figure 2**. Effect of application month on yield response to fertiliser N (with standard error), as estimated by rising plate meter. Different letters within a month indicate significant differences (P<0.001) within a month.*

Figure 3 shows the variation in average estimated response each year. With the exception of 2011 (2 sites only) and 2017 (3 sites only), there was a highly significant difference between application methods (P<0.001). The number of comparisons was much higher in other years ranging from 65 in 2014 and 2015 up to >190 in 2014. 2011 and 2017 aside, the relativity between application methods appeared consistent.

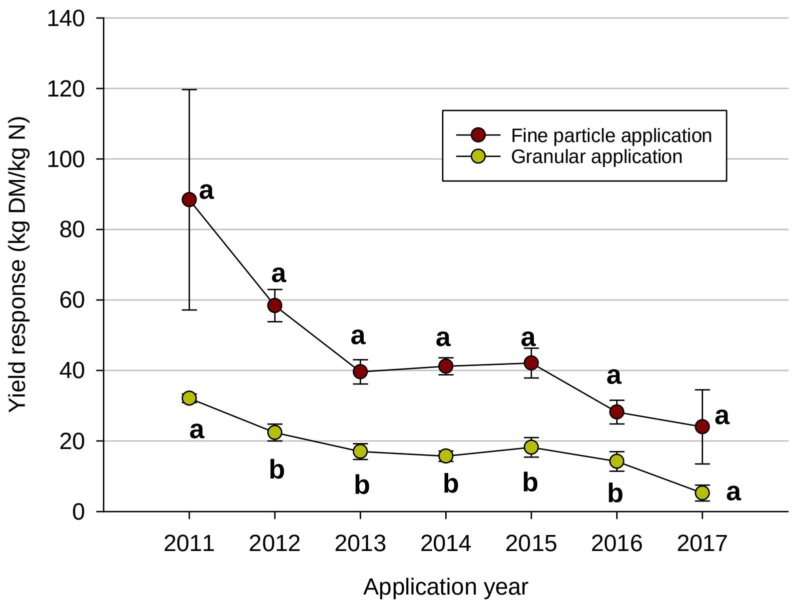

***Figure 3**. Effect of application year on yield responses to fertiliser N (with standard error), as estimated by rising plate meter. Different letters within a year indicate significant differences (P<0.001) within a month.*

5.2 Comparison of yield assessment methodologies

Figure 4 shows the relationships between estimated pasture dry matter yield from rising plate meter and mown fresh yield measurements, where both methods were used at a site. While there is general agreement, there is considerable scatter.

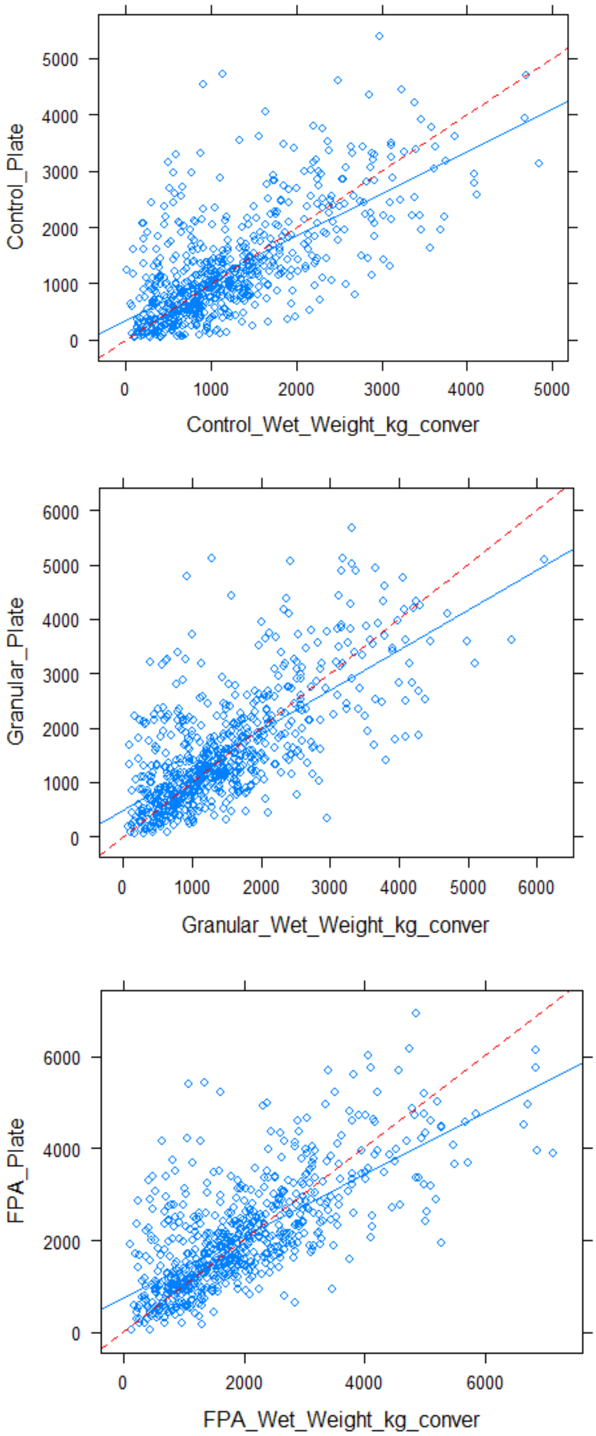

Figure 4. *Relationship between estimated DM yield of pasture based on rising plate meter and mown fresh yield where the two methods were used at the same site. Control, granular and fine particle application method treatments are presented. Red dotted line represents the 1:1 relationship while the solid line represents the fitted line.*

5.3 Yield response, as estimated from mown fresh weights (harvest 1)

5.3.1 Comparison of fertiliser application methods

Appendix III shows the yield estimates derived from mown plot fresh weights for both fertiliser application methods and the control for the 133 sites and each harvest. As with the rising plate meter estimates, the graphs show a reasonably consistent trend of control yield < granular application yield < FPA yield. Absolute values differ from plate meter estimates, though not all sites used both methods so we are not comparing like with like.

As for the RPM data, we have restricted our main analysis to harvest 1 for simplicity but also because this is where we would expect most of the response. There is evidence that, overall, the estimated pasture response to fertiliser mixes applied by FPA was larger than that of granular-applied fertiliser (Table 4). On average, the response was about 2.8 times that of granular application; of the same order as estimated by rising plate meter.

Table 4*. Estimated yield response to applied fertiliser N (kg DM/kg N applied) from the two fertiliser application methods (first harvest after application), calculated from mown fresh yields. Lettering indicates significant pairwise difference on the sqrt scale at the 5% level. The untransformed means, sd, min and max values and number of plots within the treatment are presented.*

Treatment	Mean	Standard deviation	Min value	Max value	No. of plots
Granular	12.6 b	15.8	-36.2	115	416
FPA	35.9 a	35.2	-14.1	230	423

Table 5 shows the estimated pasture responses to fertiliser application methods by region. This is supported by the statistics in Figure 5. This shows the square root-transformed fertiliser response. The larger response from the FPA method is consistent across all regions. Therefore, the FPA method performs better than granular application regardless of region. The possible exception is Otago where the difference was marginally significant at P=0.6 but there were only 7 site comparisons. All the lines in Figure 5 are parallel, which implies that the benefits from FPA method were consistent across regions.

Statistical analysis did not show that enterprise type (dairy, mixed livestock) or landscape (flat, rolling, etc) affected the response to FPA relative to granular application (data not shown).

5.3.2 Seasonal response

Calculated yield responses from granular applications follow the expected seasonal trends, peaking at around 25-30 kg DM/kg N in late spring, with another smaller rise in early autumn (Figure 6). A similar pattern occurred with the FPA method, albeit with much higher rates of DM response, in line with results described earlier.

For most months there was evidence that the FPA method resulted in a larger pasture response than granular application. Exceptions were July and January; however, there were few sites with applications during these months (1 in July, 5 in January), so it is necessary to interpret findings for these months with caution.

Table 5. *Estimated yield response to applied fertiliser N (kg DM/kg N applied) by Region from the two fertiliser application methods (first harvest after application), calculated from mown fresh yield. Lettering indicates significant pairwise difference on the sqrt scale at the 5% level. The untransformed means and number of plots within the treatment/region are presented.*

Region	Treatment	Mean	P value	No. of plots
CANTERBURY	Granular	7.2b	<0.01	27
	FPA	19.3a		27
MANAWATU	Granular	13.3b	<0.001	45
	FPA	44.6a		47
OTAGO	Granular	6.9a	<0.06	7
	FPA	16.9a		7
SOUTHLAND	Granular	11.4b	<0.001	221
	FPA	31.0a		227
TARANAKI	Granular	18.3b	<0.001	116
	FPA	41.8a		115

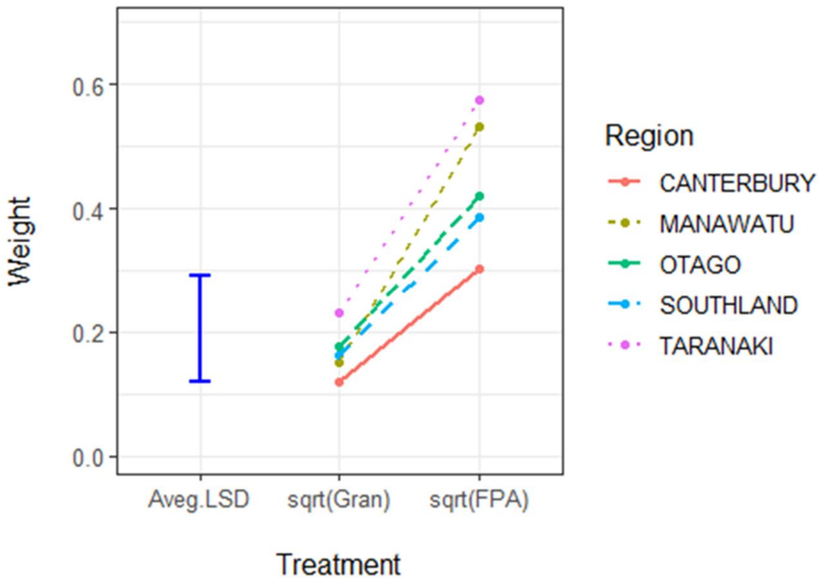

Figure 5*. Mean values of square root-transformed yield responses to applied fertiliser N, by treatment and region.*

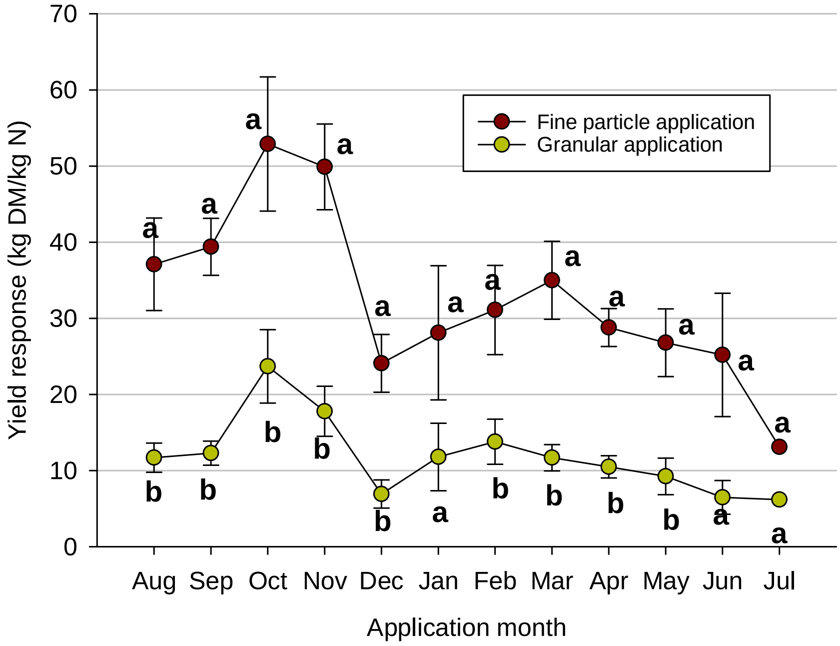

Figure 6. *Effect of application month on yield response to fertiliser N (with standard error), as estimated from mown fresh yield. Different letters within a month indicate significant differences (P<0.001) within a month.*

Figure 7 shows the variation in average estimated response each year. With the exception of 2011 (no data) and 2017 (3 sites only), there was a highly significant difference between application methods (P<0.001). The number of comparisons was much higher in other years ranging from 46 in 2015 up to 170 in 2014. The relativity between application methods appeared consistent.

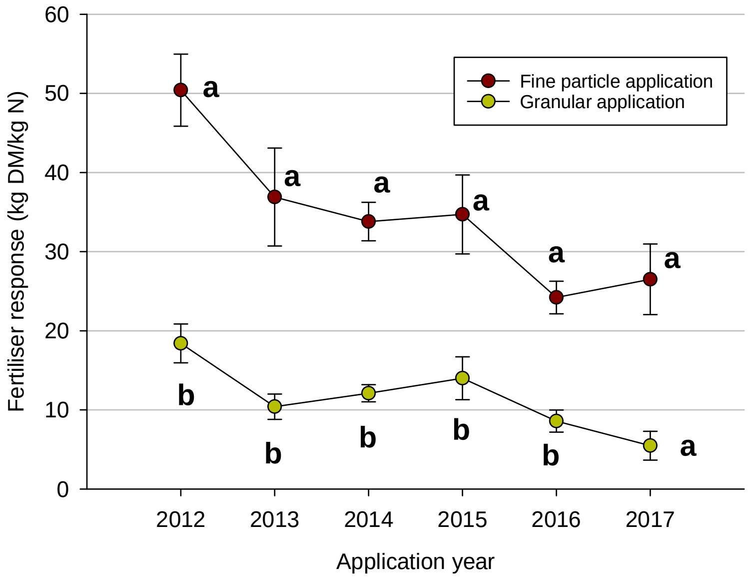

Figure 7. *Effect of application year on estimated fertiliser N response, using rising plate meter. Different letters within a year indicate significant differences (P<0.001) within a year.*

5.4 Results beyond harvest 1

All of the results reported above focused on Harvest 1 after fertiliser application. Here, we extend the analysis to the first three harvests post a fertiliser application to explore the residual effects from fertiliser applications. We used a subset of the data, focusing on the first fertiliser application at a site and sites with 3 or more harvests after this application.

Figure 8 shows the square root-transformed pasture responses by harvest (for both measurement methods). Linear trends were fitted to the transformed data and was used to normalise a pasture response at sites to a standard 110 days.

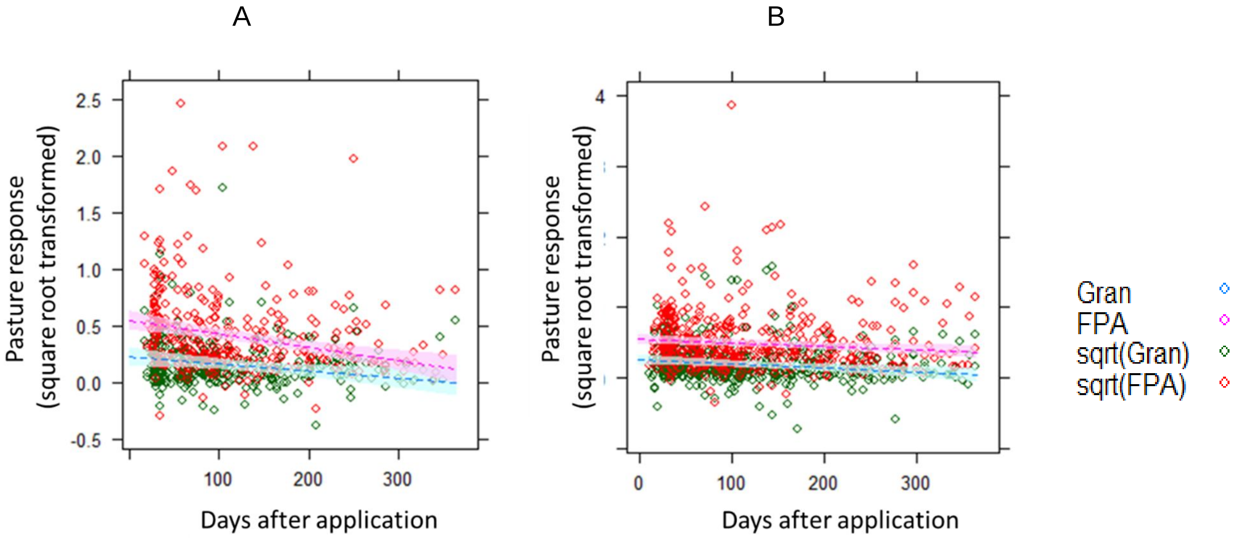

Figure 8. *Multiple harvests after a single fertiliser application (square root-transformed data), with fitted lines to estimate longevity of effect. A = DM estimated by mown fresh yield; B= DM estimated by rising plate*

Table 6 shows the average fertiliser response across these sites, for both pasture yield measurement methods. Overall, calculated fertiliser responses were similar for both methods and in line with observations for single harvest measurements. There a larger response, on average from FPA. Absolute values were also similar to those calculated from harvest 1 only, suggesting much of the response was from that harvest.

Table 6*. Estimated yield responses to applied fertiliser N (kg DM/kg N applied) from the two fertiliser application methods (calculated at 110 days, equivalent to c. 3 harvests). Calculated from rising plate and mown fresh yields. Lettering indicates significant pairwise difference on the sqrt scale at the 5% level.*

Treatment	Mean	Standard deviation	Min value	Max value	No. of plots
Plate meter method					
Granular	13.8b	19.8	-66.3	162	489
FPA	37.9a	35.8	-16.3	230	495
Plot mowing method					
Granular	12.2b	16.3	-17.6	115	355
FPA	34.0a	36.9	-14.1	238	361

6. Discussion

Fine Particle Application - the development of a solid fertiliser application method to apply fertiliser materials with different spreading ballistics – should be considered at two scales:

- Spreading performance at the paddock scale and assessment of whether (a) fertiliser is applied more evenly than by other application methods, and (b) if so, does this translate to a yield or other benefits?
- Sub-metre scale: are there additional benefits to pasture growth arising from application of fine particles of fertiliser, compared with granular application?

This report aims only to address the second bullet point. Differences in evenness of application at a paddock scale between application methods is proposed by FPA Ltd as a benefit of FPA, but this has not been independently verified.

6.1 Assessment of results

At the sub-metre scale, our starting hypothesis was that there should be no difference in pasture yield given that both fine particle-applied and hand-applied granular fertiliser would be applied evenly on small experimental plots.

However, *the analysis of the data from the FPA monitoring sites showed a consistent difference in pasture response to the two fertiliser application methods*. This was consistent across regions and across seasons. Two methods of indirectly estimating DM production gave similar results, both in terms of trends and in absolute values of response (kg DM/kg N). Although our analysis first focused on harvest 1, analysis of sites with multiple harvests after a fertiliser application showed similar results.

The findings support the results from the replicated field trial in the Waituna catchment in 2017/18 (Crossley 2018). There have been other studies also completed but few have undergone peer review. Morton et al. (2018) identified 13 trials (using small plots) that aimed to mimic the FPA method and compare with granular application of N-based fertilisers. These were characterised as: journal papers (3); experiment reports with statistics (5); or experiment reports without statistics (5). In most cases, N application rates were 30-60 kg N/ha. One study used 100 kg N/ha. Two of these trials applied 2-6 kg N/ha as DAP so, unless there was expected to be a large response to non-N nutrients, we might expect it to be difficult to measure yield differences at these N rates. If we focus on the other 11 reported trials, Morton et al. (2018) show that:

- Two journal papers show statistically significant yield increases from FPA
- Four reports with statistics show no significant treatment effect
- Five reports without supporting statistics infer a significant treatment effect of FPA

Interpretation is further confounded by differing application methodologies – or lack of details of application methodologies. In short, previous results have been conflicting and confusing. This is further confounded by insufficient insight to explain the causes of differences between results. Although a range of possible mechanisms has been identified in the literature, none have been investigated in depth or proven (Shepherd 2018; Morton et al. 2019). These include:

- Denser nutrient coverage (smaller, more closely spaced, particles) across the paddock enabling greater pasture access to applied N (and other nutrients)
- Reduced ammonia volatilisation
- Reduced losses to the environment (other than ammonia volatilisation)

- Foliar uptake bypassing the soil processes

Morton et al. (2018) provide a detailed critique of all of these mechanisms, so there is no point restating them too much here. Their conclusion was that, of the four options described above, foliar uptake is the most credible mechanism. Foliar urea is rapidly taken up by turf grasses (Stiegler et al. 2011; Stiegler et al. 2013) and perennial ryegrass (Bowman & Paul, 1992). In the latter case, it was demonstrated that urea was assimilated by the plant twice as rapidly as foliar nitrate. Castle et al. (2007) also showed with clover that plants supplied with urea to foliage or to roots plus foliage had significantly larger leaf areas than did clover receiving N only to the roots. It was argued that at low temperatures, N transport from the root becomes a rate limiting step.

Dawar et al. (2012) used ^{15}N labelled urea and demonstrated significantly greater ^{15}N recovery by pasture under FP-application compared with granular application. In this paper, the authors also cite that previous work showed that "*approximately 70% of the applied urea is seen in small particles on pasture leaves during the first 12 h of application*". The success of foliar application would also be dependent, we assume, on sufficient time for the fertiliser to reside on the leaf to enable transfer into the leaf. Two mechanisms might work against the opportunity for foliar uptake:

- Application of a powder: the fertiliser is finely ground and we are told that the water soon evaporates after application, leaving the dry fertiliser sticking to the leaves. It would need to be solubilised to be taken up by the leaf
- Following weather: given the wide range of sites and application times, it is probable that rain will wash the fertiliser from the leaf at least at some sites

In short, enhanced foliar N uptake is one possible mechanism, but more work is required to confirm it as a definite method for increased fertiliser response.

Results also indicate a longevity of effect, so focusing on harvest 1 does not bias results in favour of one fertiliser application method or the other. The longevity of the effect was unexpected. Possible reasons could include a change to the sward structure that for some reason is having longer-term benefits (anecdotal observations suggest a change in sward architecture after FPA application at some sites) or continued response from the macro-nutrients, other than N, that were also applied in many cases. However, both of these suggestions are speculative at this stage. And as with all things related to FPA, more detailed research is required.

6.2 Assessment of the experiment approach

We have no reason to doubt the methodology employed in the monitoring trials but obviously we did not undertake the experiments ourselves. There is evidence of SOPs, field operators were trained and there are good data records for each trial. One weakness is possibly lack of randomisation, with plots always organised in the same order to make FP-application by machine easier. We also assume there was no bias in selecting the site itself, expecting that the sward was even across all three plots at the start of the experiment. On this point, sites were selected in conjunction with the host farmer. The only constraint was that they had to be adjacent to a fence to make animal exclusion easier. The Waituna demonstration plots showed similar results using this methodology. We discuss other methodological aspects below, which need to be considered in interpreting the results.

- *FPA fertiliser mix*: Our interpretation of the results is based on the assurance that gibberellic acid was not applied to the sites included in the database. One trial where this was documented as an addition was omitted from the analysis. Clearly this is an important assumption and is based on the assurances given to us by FPA. Otherwise, we are not comparing like with like.
- *Yield measurements* – assessment of DM production was based on a plate meter and a calibration to convert readings to dry matter, or relied on harvesting fresh yield and applying a 20% conversion factor. While neither of these involved direct measurement of dry matter yield, they allow the relativity to be compared between treatments. Furthermore, both methods give reasonable approximations of pasture production based on expected values. It was also encouraging that calculated fertiliser responses were reasonably similar between methods. And yield estimates by both methods were strongly correlated.
- *Confirmation of application rates* – whereas the granular fertiliser was applied by hand and it was therefore easy to calculate and check the application rate, FPA was applied through a calibrated spreader. Collection of the fertiliser from the plastic sheets covering non-FPA treatments allowed the application rate to be checked. We also suggest below that application rate would need to be the order of at least 50% higher than reported to reproduce these results.

  One result of covering the non-FPA plots with sheeting could have possibly been that the fertiliser bounced off the sheet onto the FPA plot, thus increasing effective application rate. However, we were assured that with FPA the fertiliser mix lands on the covers "*in the consistency of wet cement, so it sticks to the plastic cover on contact; only after the water dries out of it can the FPA fertiliser be swept off the cover. No chance of bouncing off*".
- *Plastic sheeting affecting non-FPA sward* - plastic was down for the minimum time to apply the plots, a maximum of 10-15 minutes to avoid any heating of the pasture under the covers on a hot day.

The FPA method required the fertiliser to be applied by calibrated machine. Measurements established that actual applications were generally ±10% of target. Even so, all response rates were calculated based on the target (rather than actual application rate). We investigated the size of the effect of this assumption on calculated N response rates.

To do this we took the published pasture response results from spring-applied urea at Tokanui farm, Waikato (Shepherd et al. 2015). These authors demonstrated that soils with a high soil total nitrogen content had reduced responses to fertiliser N. Therefore, we selected a subset of 11 sites with soil N in the range 0.3-0.7% so that there was a large response to applied N. We took the average of these 11 sites to produce a standard fertiliser N response curve and fitted a polynomial response function (Figure 9).

Based on this response function, we calculated the % change in calculated fertiliser response from applying a target of 50 kg N/ha based on two scenarios: a spreading error of ±10% or ±50%. For the scenario tested, a ±10% error in spreading suggests close to a ±10% error in calculated N response rate; a ±50% error in application rate resulted in a c. 40-50% error in calculated N response rate (Table 7). We conclude that even if the spreading error was consistently >50%, this is unlikely to explain the yield differential we have observed between application methods.

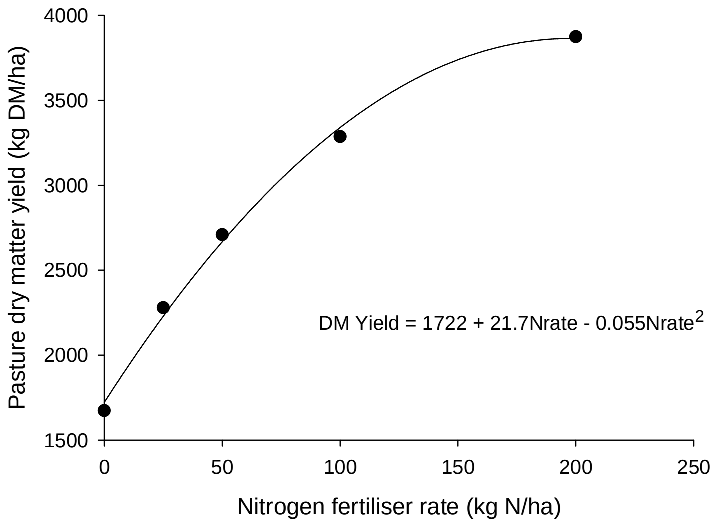

Figure 9. *Standardised pasture fertiliser N response curve based on three harvests after a single fertiliser N application in spring (adapted from Shepherd et al. 2015).*

Table 7. *An example of the effect of a spreading error on calculated pasture responses, assuming the response is based on target application rate rather than actual application rate.*

Target rate (kg N/ha)	**Scenario**	**Actual rate (kg N/ha)**	**Calculated response (kg DM/kg N)**	**Variation (%)**
50	No error	50	18.9	
50	±10%	45-55	17.3 to 20.5	-9 to +8
50	±50%	25-75	10.1 to 26.3	-46 to +39

7. Conclusion

We have analysed data from an extensive set of monitoring trials. We did not undertake the field trials but a detailed protocol was followed, the field operatives underwent some training and data curation was good. We have therefore analysed the data in good faith and suggest the results warrant further debate and experimentation to resolve the question around FP-application once and for all.

We say this because the monitoring sites overall showed a consistent and large difference in pasture response to the two fertiliser application methods: FP-application and granular application. This was consistent across regions and across seasons. Two methods of indirectly estimating DM production gave similar results, both in terms of trends and in absolute values of response (kg DM/kg N).

The results we present from the monitoring sites add more results to suggest advantage of the FPA methodology but provide no insight into why this occurred. Foliar uptake of N has previously been suggested as one mechanism. However, more in-depth investigation to confirm the effect and conclusively identify the cause(s) of the effect is required if the yield benefit arising from FP-application is to be widely accepted.

We provide this report as part of the on-going debate.

8. References

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9. Appendix I – Evidence of application rate testing

The first is the WINTON TRIAL conducted in 1993 which was the first independently run replicated FPA versus Granular trial (7 replicates) set up as a public trial to which we invited all the local consultants and fertiliser companies to be involved in. It was run for 12 months with 1 application of a fertiliser mix at two different rates; 65 Kgs and 130 Kgs/ha. (DAP, Potash, elemental Sulphur) which was the average of what we were applying at the time. Page 3 of the report, explains how the application rates of FPA where tested by sweeping the fertiliser off the covers and weighing them after application (averaged within 12% of target application rate) which is the same technique we use for calibration of the equipment to test application rates (like Fertmark certification for suspension fertiliser) = testing rate of application (kg/ha) and evenness of coverage.

The second study is the work done by Summit Quinphos which was the first time FPA was used to apply NITROGEN ONLY, as previously we had been used for fertiliser blend application. This was a nationwide series of replicated trials (5 replicates) set up using the same design as the WINTON TRIAL and also using the same technique of sweeping and weighing the nitrogen particles off the covers to check that the FPA application rates were correct.:

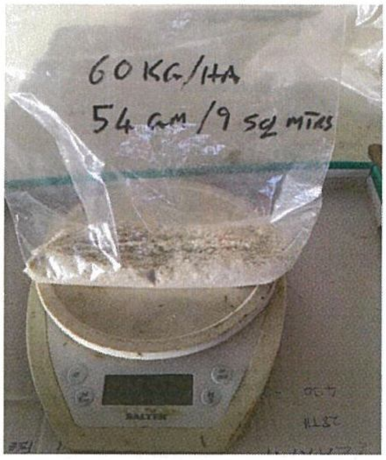
Third Study - 2017/2018 Living water final report of Waituna study

The third study is the Living Water (Waituna) demonstration which incorporates all the same trial design and techniques as the other trials. The same sweeping and weighing of the plot covers was used which is reported, with supporting photos showing the procedure in the report.

See over for photographs…

Photo 2: The FPA truck applying the fertiliser to the plots

P 7: Photo showing the uniformity of spread of fertiliser under the FPA system.

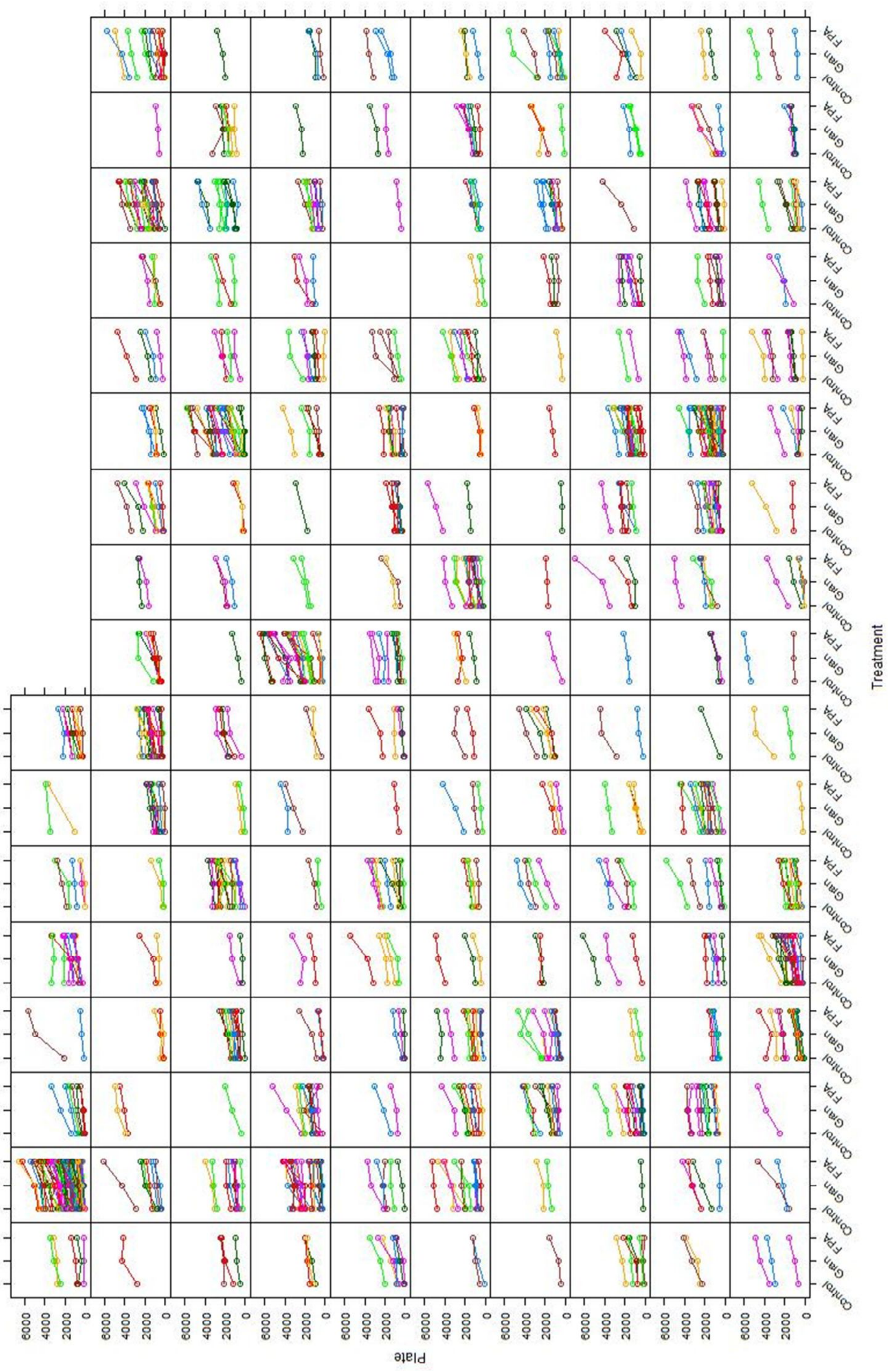


P 6: The scale recording the sweepings of fine particles to confirm the truck calibration

Left 4: Covers from plots being swept to recover the fine particles for weighing to confirm the calibration of the truck application.

10. Appendix II – Summary of dry matter yield estimates (by rising plate meter) at all sites

Yield estimates for each harvest at each site (kg DM/ha). Sites with multiple harvests include 1st, 2nd, 3rd etc harvests after application, indicated by different line colours. Some sites received multiple applications of fertiliser.



11. Appendix III – Summary of dry matter yield estimates (based on fresh yield measurements) at all sites

Yield estimates for each harvest at each site (kg DM/ha). Sites with multiple harvests include 1st, 2nd, 3rd etc harvests after application, indicated by different line colours. Some sites received multiple applications of fertiliser.