LIVING WATER

Project

Literature Review of the Use of Fine Particle Fertilisers and Application Methods

Site

Waituna

Project Purpose

This literature review supports a demonstration project commissioned by Living Water on the fine particle application of fertilisers being carried out from March 2017 and May 2018. The demonstration project is assessing the effects of the application of nitrogenous fertiliser (urea) using a fine particle application (FPA) method compared to conventional application of granular fertiliser. Living Water's particular interest is to see if nitrogen fertiliser application use can be reduced without compromising pasture growth.

The literature review will assess the body of research work done on fine particle fertilisers (FPF) as well the application technology of fine particle fertilisers (FPA), with the purpose of establishing what benefits there may be in using FPF and FPA. The review covers both New Zealand and international research.

Principal Consultant

Living Water has commissioned Chris Crossley, Agricultural Consultant, to undertake the literature review and the FPA demonstration project.

Timeframe

Start Date: May 2017 Finish Date: September 2017

A LITERATURE REVIEW

OF THE USE OF FINE PARTICLE FERTILISERS AND APPLICATION METHODS

A REPORT PREPARED FOR

LIVING WATER

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EXECUTIVE SUMMARY

Farmers in New Zealand are facing mounting pressure to reduce nitrate leaching from their farm systems as well as phosphate runoff risk. While attempting to achieve reduced nitrate leaching, farmers are also concerned with increasing productivity of their farm system output. These two aims appear to be at loggerheads with each other which is driving technological advances in agriculture to achieve both aims.

The literature review is being undertaken to assess the body of research work done on fine particle fertilisers (FPF) as well the application technology of fine particle fertilisers (FPA – fine particle application), with the purpose of establishing what benefits there may be in using FPF and FPA. The review covered both New Zealand based and international research.

There are distinct benefits to be found in this fertiliser technology that fall into three main groups of benefits; these being the additional pasture grown compared to other forms of fertiliser and their mode of application, as well as environmental and economic benefits. Pasture production is a key competitive advantage that New Zealand has and therefore the pastoral industry needs to be pushing the competitive edge all the time.

Fine particle applications technology is one of these technologies that can help farmers achieve both their aims. FPA has the advantage that it is known to create greater pasture dry matter responses than other forms of fertiliser, such as granular fertiliser, and bulk spreading methods. For example, in the Winton Trial, FPA applied DAP, the nitrogen content produced 10% more grass than the granular DAP at the same nitrogen N application rates. Pasture growth achieved had been as high as 10%.

Environmentally, granular urea fertiliser has some serious issues with nitrate use efficiency of N (or NUE) and have a lower N response efficiency compared to other chemical fertilisers. The implications of this from an environmental perspective are faster hydrolysis which temporarily raises soil pH around the urea granule creating a hot spot for N Losses via NH_3 volatilisation.

From an economic point, if a fertiliser has a low response efficiency then this would mean that the economics of applying granular urea would lead to less profit. However, as the FPA has reported response rates to urea N applied have been significantly superior to granular applied urea N, this creates the possibility for additional profit for farmers due to FPA's good NUE.

CONTENTS

1. INTRODUCTION

Living Water (10 year partnership between the Department of Conservation and Fonterra) has commissioned this literature review of both published and unpublished research and publications that address the fine particle application (referred to as FPA) fertiliser application method.

The on-going use of inorganic fertilisers has been critical to the growth in productivity of New Zealand's agricultural sector. The increasing use of fertilisers, particularly nitrogenous fertilisers, has come with an unexpected negative impact on the environment and more specifically the waterways of New Zealand.

Nitrogen is an essential plant nutrient and key to maintaining higher yield production and worldwide economic viability of agricultural systems. Nitrogen is removed in large quantities by livestock and harvested materials and is mobile and susceptible to gaseous losses and leaching. As a result, most agricultural systems are N-deficient. Farmers apply different N fertilisers such as urea, ammonium phosphate, ammonium sulphate, di-ammonium phosphate and potassium nitrate to increase yields and this has led to increasingly intensive livestock operations in many regions of the world. However, this increase in N use, with N-response efficiency reported to be between 33 and 50%, is contributing to higher worldwide N losses via volatilisation and NO_3^- leaching that impact air and water quality (Raun, 1999; V.C, Fageria, & He, 2001; Follett, 2001; Howarth et al., 2002; Nosenga, 2003).

Purpose of the Literature Review

This Literature Review will source and review national and international literature in relation to the Fine Particles Application (FPA) method of nitrogen fertiliser application.

The FPA Literature Review will:

1. Collate and summarise national and international literature and scientific trials (published and unpublished) of the FPA method

2. Review data from the literature and trials to clarify results achieved regarding the efficacy of the FPA method compared to other fertiliser application techniques.

2. WHAT ARE FINE PARTICLE AND SUSPENSION FERTILISERS?

It appears that in New Zealand there is no single clear definition of these two types of fertiliser. The Fertiliser Association of New Zealand does not define a suspension fertiliser but rather implies it to be a fine particle fertiliser with a specific mode of application. However, this does not sufficiently clarify the difference between fine particle fertiliser and suspension fertiliser. Fine particle fertilisers (FPF) excludes both granular and liquid fertilisers, but it may include suspension fertilisers.

Technically, the definition of a suspension fertiliser should indicate that it is pre-manufactured and consists of a fluid containing dissolved and undissolved plant nutrient compounds. Suspension of the undissolved materials is usually produced with the aid of a suspending agent of non-fertiliser properties (clay, e.g., bentonite). Mechanical or air

agitation may be necessary to facilitate uniform suspension of undissolved plant nutrients,
(AgGatewayAgGlossary;agglossary.org/wiki/index.php?title=Suspension_fertilizer).

A precise definition of fine particle fertiliser is also not readily available but the label alludes to the fertiliser, often granular, being ground up into small particles which are normally less than 200 microns, to which water is added. This results in a wet "paste" type consistency. Part of the reason for there been no accepted homogenous definition of fine particle fertilisers and application, is more than likely due to the number of competing operators in the industry who use slightly different methods of preparation and application to achieve a fine particle fertiliser and application. Some are patented and others not, but the majority use the term "fine particle".

Both liquid fertilisers and suspension fertilisers, are factory manufactured products. Liquid fertiliser is sold in plastic 200 ltr drums or 1000ltr cube type containers, as a dissolved solution of 80% water:20% fertiliser, with a set NPKS rating, as opposed to a custom made fertiliser for each individual farm.

Suspension fertiliser can also be made in a factory by grinding up granulated fertiliser or the raw fertiliser material, which is then mixed with water and delivered to farms for spray application in tankers. To slow down the rate of solid fertiliser settling during transport, Bentonite clay is normally added as a suspension additive. This process is quite costly as the product is delivered to the farm with the water already added, adding significantly to the cost of the cartage. Suspension fertiliser blends have a minimum of 30% to 50% water added. The cost of suspension fertiliser is normally at least twice the cost of the granulated NPKS fertiliser that it is made from. Suspension fertilisers can also be combined for reasonably long periods of time before being applied. Often fine lime is used in suspension fertiliser to help as a suspension additive. Other options have been the use of prills to apply fertilisers but these also cannot be considered as a fine particle fertiliser, (B. Emeny, pers. comm.)

Throughout the United Kingdom, it appears that there are fine particle fertiliser producers and applicators, also using different methods of working fertiliser into fine particles and similar modes of application, although they are not precisely the same.

3. WHAT IS FINE PARTICLE APPLICATION?

Within the domain of the discussion on fine particle and suspension fertilisers, falls the method of application of the fertiliser to land. Fine particle application (FPF/FPA) encompasses both the fertiliser product processing and the application or spreading technology, to create a "suspension" fertiliser and the dispersion mechanism. FPF/FPA is not a product and it cannot be classified as a liquid fertiliser application method or as a normal suspension fertiliser application method.

The fertiliser used in fine particle fertiliser applications, is normally, but not necessarily, in granular form which is then ground up while the application vehicle is moving and applies the fine particles immediately. As a comparison, fine particle application is a mechanical application process which is carried out on the moving fertiliser spreading vehicle, while topdressing the farm, which applies the granulated fertiliser blends that have been recommended by consultants for the farm and purchased by the farmer. These are loaded into the fine particle spreading truck directly from the local bulk store. There is no fine particle fertiliser product. The fertiliser that results from the fine particle application process is a grind of the granulated product, the actual product being that which is recommended by the fertiliser company's consultants, (B. Emeny, pers. comm.).

Regarding the use of water with fine particle applications, the water is only in contact with the fertiliser for a few seconds to dampen down the dust during the application of the finely ground fertiliser to the ground. (It is not mixed together at the local bulk store). It is not mixed with the fertiliser for long periods of time as in the case of liquid or suspension fertiliser products. As an example, the final mix of any product that is processed and applied through the FPANZ® system is a maximum of 30% water and 70% solids. FPANZ® has patented technology to grind up granular fertiliser as well the spreading system that enables it to deliver the applied fertiliser more precisely at a high standard of distribution of the fine particles, (B. Emeny, pers. comm.).

There are a small number of operators applying fertilisers using the fine particle application method with a range of particle size and grind that would result in differences in fine particle distribution patterns of the various methods. In the application of fine particle fertilisers, it is critical that the grinding of the fertiliser to a consistent optimum size, and the spreading system, that results in a good consistent distribution pattern of the applied fertiliser, is essential to the success of fine particle application technology, (Zaman and Blennerhassett, 2009) as quoted in the "Nutrient Management in a Rapidly Changing World" Workshop Proceedings.

The efficiency of FPF/FPA can be easily compared with any other application system, i.e., granular, liquid or suspension, by comparing the response ratio to the applied nutrient using these different technologies. Furthermore, this can be done by comparing the total applied cost per kilogram of the fertiliser nutrient to the ground as well as the total cost per Kilogram of Dry Matter produced.

Fine particle fertiliser and application operators claim that fine particle fertilisers and the methods they use to apply the FPF, have numerous benefits over the normal granular fertilisers and bulk spreading applications. These claimed benefits include the following:

- Evenness and better distribution of fertiliser spreading that leads to improved fertiliser efficiency. This results in all pasture plants receiving the same ratio of nutrient, resulting in a more even pasture sward with a higher plant density/unit area which results in greater dry matter production.

- As the fertiliser particle size is reduced, FPF provide a greater surface area per kilogram of applied fertiliser than granular fertilisers. This results in greater availability of the nutrients to the plants, allowing for more rapid uptake of those nutrients into the plant and the soil system, resulting in a faster growth response. As an illustration, in the grinding process of the fertiliser granule, the exposed surface area of a coarse 2mm chip increases exponentially from 24 mm^2 to almost 10,000 mm^2, thus increasing the availability of nutrients for plant nutrient uptake.

- FPF enables nutrient uptake by plant foliage through cuticular absorption. This make the nutrients more readily available resulting in faster growth response.

- Both macro-nutrients and trace-minerals can be applied at the same time resulting in a cost saving in the application of the fertiliser as well as time savings. Other products can be applied at the same time such as herbicides.

- FPF and applications allow for the proportions of nutrients being applied to be varied from standard granular fertilisers available.

- FPF and applications promote environmental sustainability as less fertiliser can be used with more accurate placement. The risk of run-off of fertiliser is lower due to the accuracy of placement. As nutrients are more rapidly available there is also the benefit that less of the nutrient is lost through leaching and volatilisation, particularly with nitrogenous fertilisers.

- FPF and applications result in better dry matter response rates and thereby resulting in a lower cost per kilogram of dry matter produced being more economical than regular fertilisers.

4. RESULTS FROM REVIEWED PAPERS AND ARTICLES

4.1. AgConsult. Winton Trials: Report detailing twelve-month results of the Winton Trials. November 1993.

The report detailed results of trials conducted at the Winton Experimental Farm in Southland, with oversight by AgConsult. Its main purpose was to assess the Dry Matter responses to different application methods of fertiliser and different fertiliser mixes, limiting the focus of the trial to the agronomical aspects supported by soil and herbage tests. This was to be done be comparing the application of fertiliser with the FPA system against normal granular applications. FPA applications were done by helicopter.

A replication of seven was chosen for the trials, i.e., each treatment was replicated in seven plots of 4x4 m, 42 plots in all, including one control plot in each set. Three different application rates were tested, being 50 and 100kg/HA of DAP respectively applied in granular (GR) and fine particle (FPA) form, and one application of SSP (Single Superphosphate). There were also some mixes of small amounts of other fertiliser components such as trace elements, limeflour, potassium and magnesium, lifting the total application rates to 65kg/HA and 130kg/HA respectively of the DAP 50 and the DAP 100.

Results

With the assumption of a pasture D.M. level of 3% Nitrogen (considered a low estimate), the application of 1kgN could theoretically boost Dry Matter production by 1/0.03=33 kg/Ha of additional Dry Matter. Therefore, the GR50/FPA50 and GR100/FPA100 treatments could be expected to grow up to 297 and 594kg/Ha of additional Dry Matter maximum.

The FPA response was said to be more than a simple response to applied nitrogen, with the possibility of the FPA application increasing the mineralisation rates of N. Although in both cases (GR50-FPA50 and GR100-FPA100) the amount of N in the DAP applied was the same, the FPA application resulted in an appreciable shift towards ryegrass dominant sward in the G100-FPA100. Furthermore, the difference in response rates when comparing the GR50 and FPA50 and the GR100 with FPA100, showed the N response was stronger in the FPA plots. The authors supposition is the FPA application led to increased N mineralisation due to increased biological activity.

They commented that the FPA treatment response was more than a simple response to the applied nitrogen, even though these are still aspects of a nitrogen response, e.g., a shift in pasture composition and higher soil N levels. The one explanation offered was that the FPA application increased mineralisation rates of N. They did however qualify their comments with the statement that although these explanations seem to be supported by the soil nitrogen test results, it was too early to draw firm conclusions as to which mechanism could be at work and that research is necessary to confirm this supposition.

The table below indicates the soil nitrogen levels (NO3 and HN3) after 12 months. The results show that both FPA treatments had elevated nitrogen levels, even after 12 months. The writers expressed their expectation that a relatively clear relationship exists between the amounts of N applied, the amount of Dry Matter produced (assuming there are no limiting factors), and finally the residual soil N level. Furthermore, although the relative response differences at this stage were large (up to 136% extra DM grown by the FP100 plots) it was important to be realise that the absolute differences were less than 500kg/ha extra D.M. grown, due to the generally low daily growth rates.

Table 1:

Total Pasture Dry Matter Production

Accumulated Dry Matter Production. Winton Trials from 11/11/93 to 19/10/94

	Control	Super	G50	G100	FP50	FP100
Dry Matter (kgDM/ha)	9735	9951	9990	10330	10920	11463

Table 2:

Relative Dry Matter Responses

	8/12/1993	13/01/1994	6/03/1994	12/04/1994	31/05/1994	19/10/1994
Control	0%	0%	0%	0%	0%	0%
Super	1%	7%	-2%	-1%	32%	5%
G50	18%	7%	6%	4%	21%	9%
G100	32%	6%	-8%	7%	40%	5%
FP50	46%	7%	-5%	3%	126%	15%
FP100	55%	10%	1%	7%	136%	18%

These are relative responses. In absolute terms the biggest differences occur in the first periods.

Table 3:

FPA response relative to corresponding Granular response.

	11/11/1993	8/12/1993	13/01/1994	6/03/1994	12/04/1994	31/05/1994	19/10/1994
FP50	1	2.48	1.00	0.79	-0.17	6.04	1.43
FP100	1	1.73	1.61	-0.15	1.01	3.36	3.52
G50	1	1	1	1	1	1	1
G100	1	1	1	1	1	1	1

These are relative responses. In absolute terms the biggest differences occur in the first period.

Table 4:

Dry Matter Response to different Fertiliser treatments and application methods

	% increase over control	% increase of FPA over granular at the same rate	% increase of 100 kg/ha rate over 50 kg/ha rate FPA over granular at the same rate
SuperPhosphate at 250 kg/ha	2.2%		
Granular DAP mix at 50 kg/ha	2.6%		
FPA DAP mix at 50 kg/ha	12.2%	9.6%	
Granular DAP mix at 100 kg/ha	6.1%		3.5%
FPA DAP mix at 100 kg/ha	17.7%	11.6%	5.5%

Table 5:

Table showing actual kgs Dry Matter response for each replication

Control	N applied	Max. N response based on fert. N	Actual D.M. Response
SuperPhosphate	0	0	128
G50	9	297	255
G100	18	594	595
FPA50	9	297	1185
FPA100	18	594	1728

Table 6:

Winton FPA Trial 1994

Soil Nitrogen levels after twelve months (N ppm)

	Control	S/F	G50	F50	G100	F100
NO_3	11.32	10.46	10.88	10.88	10.88	14.37
NH_3	31.19	24.56	27.75	32.44	31.19	38.42
Total Av N	42.51	34.14	38.63	43.32	42.07	53.29

Conclusion

- Over the twelve-month period, the nitrogen content of the FPA applied DAP treatments grew approximately approx. 4.6 and 2.9 times more Dry Matter than their granular equivalents.

- An observation made was that the increased soil Nitrogen levels were reflected in increased rye-grass content of the pasture and a decreased "clover" and "low fertility grasses" content. A visual assessment was undertaken throughout the first six months period. The results of the visual assessment indicate that there was a shift towards an increase in ryegrass content on all treated plots but particularly where nitrogen containing fertiliser mixes were applied.

- The superphosphate plots resulted in an increase in both the clover content and the ryegrass content.

- They go on to point out that although the nitrogen content of applications was the same on the granular and FPA plots, on the FP100 plots, there was an appreciable shift towards ryegrass compared with the GR100.

4.2. M. Zaman and JD Blennerhassett, Summit-Quinphos. 2009. Can Fine Particle Application of Fertilisers improve N-use Efficiency in grazed Pastures? Nutrient Management in a Rapidly Changing World; Fertiliser & Lime Research Centre; Massey University, Palmeston North, New Zealand.

These trials were conducted on permanent pasture in Ashburton, Lincoln and Canterbury, during 2007 and 2008. The Dry Matter (DM) results of these trials and their economic evaluation can be found in the Trial summaries, within this section below.

The Ashburton trial had two experiments; the first had 4 replicates of 3 fertiliser treatments: urea, urea plus the urease inhibitor NBPT (Agrotain[1]), and 75% Agrotain treated urea plus 25% sulphate of ammonium, each applied at 30kg N/ha. The second experiment had 4 replicates of 2 treatments: urea, urea plus Agrotain, each applied at 25 or 50kg N/ha. The third experiment was comprised of applications of urea plus Agrotain at 25kgN/ha to 2 pasture heights (5cm and 10cm) and 10cm pasture height with 10mm spray irrigation after 1 day of fertiliser application. There was also a Control treatment (no N).

Results

- In all three experiments, fertilisers applied in FPA form performed better by producing significantly more pasture dry matter and exhibiting higher N response and response efficiencies compared to their corresponding treatments applied in granular form.

- The report commented that this was probably due to the even spread of the fertiliser, delayed urease activity of the leaves and soil, and providing pasture with the opportunity to absorb added urea directly through their leaves/cuticles. Nitrogen response efficiencies decreased by applying fertiliser in FPA form at a

[1] Agrotain® or NBPT, a nitrogen stabiliser, is a coating applied to urea granules. It is a patented urease inhibitor developed in the United States. Its main function when applied to soils is to block urease enzyme activity, thereby reducing the conversion rate of urea to ammonium which in the volatilisation of ammonia. The benefit of this is reduced volatilisation, improved nitrogen use efficiency (N.U.E.) and higher uptake of nitrogen.

high rate of 50kgN/ha. Their comment was FPA is a good management tool for enhancing N response and has greater potential for improved economic returns if applied in the right conditions. The report states that the climatic conditions under which the FPA performed in this trial,were not optimal, in that the soil conditions were extremely dry and high soil temperatures (25°C) and air temperature (32°C) on the day of fertiliser application caused moderate to severe pasture burning. These hot dry conditions were likely to inhibit N uptake through the leaves due to a lack of sufficient solute to transport it.

- As with any fertiliser application, unless done under optimal conditions, less than the best economic returns will result. However, in practice, this is difficult to consistently achieve as other factors will sometimes determine the decisions to apply nitrogen, such as a feed deficit.

- Other observations from the trial, reported that FPA delivers an even spread of applied fertiliser on a per plant basis. This was supported by observing that a significant proportion of the applied fertiliser was found adhering to the pasture leaves. Urea improves the permeability of the cuticle and thereby facilitates diffusion in the leaf, providing the plant with a short opportunity to absorb some urea directly through their leaves/cuticles. They go on to comment that urea and Ammonium are known to require less energy to metabolise and to convert to plant protein than Nitrate-N (Watson and Millar, 1996). This energy saving enhances the plant growth. This is related to the fact that significant numbers of the fine particles end up adhering to the leaves enabling the plant to take up the Urea-N and Ammonium-N directly. It is the improved spreading benefit that comes from FPA that allows for this direct uptake.

- In the second trial in Ashburton, two rates were applied for both FPA and granular, those being 25kgN/ha and 50kgN/ha. FPA25 exhibited a 52% improvement in N response over its urea treatments applied in granular form while such improvements were only 15% for the higher FPA50 rate. The FPA50 resulted in lower responses compared to the FPA25. These applications were made under conditions of extremely dry soil conditions and high soil temperatures (25°C) and air temperatures (32°C). This caused moderate to severe pasture burning. Hot dry conditions are likely to inhibit N uptake through the leaves due to lack of sufficient solute to transport it. Carlier et al., 1990, have demonstrated that excessive uptake as urea can result in transient leaf tip burn, caused by either the increase in pH in the plant as urea is hydrolysed to ammonium by plant urease, and/or the toxicity of subsequently released ammonia. The reason for this outcome proffered by the team was the plants had perhaps reached their maximum uptake potential through the leaves therefore decreased N efficiency. At this high rate, the plants suffered leaf tip burn, caused either by the increase in pH in the plant as urea was hydrolysed to ammonium, and/or the toxicity of subsequently released ammonia.

- In the third experiment, on the day of the fertiliser application, dry soil conditions and high soil temperatures affected N responses from urea with Agrotain in FPA form. However, applying FPA to higher pasture covers and then applying light irrigation significantly improved N response and response efficiencies in these conditions. This would assist with uptake through the leaves.

It would reduce the risk of volatilisation as the uptake of N applied would be faster under conditions of moisture and high soil temperature.

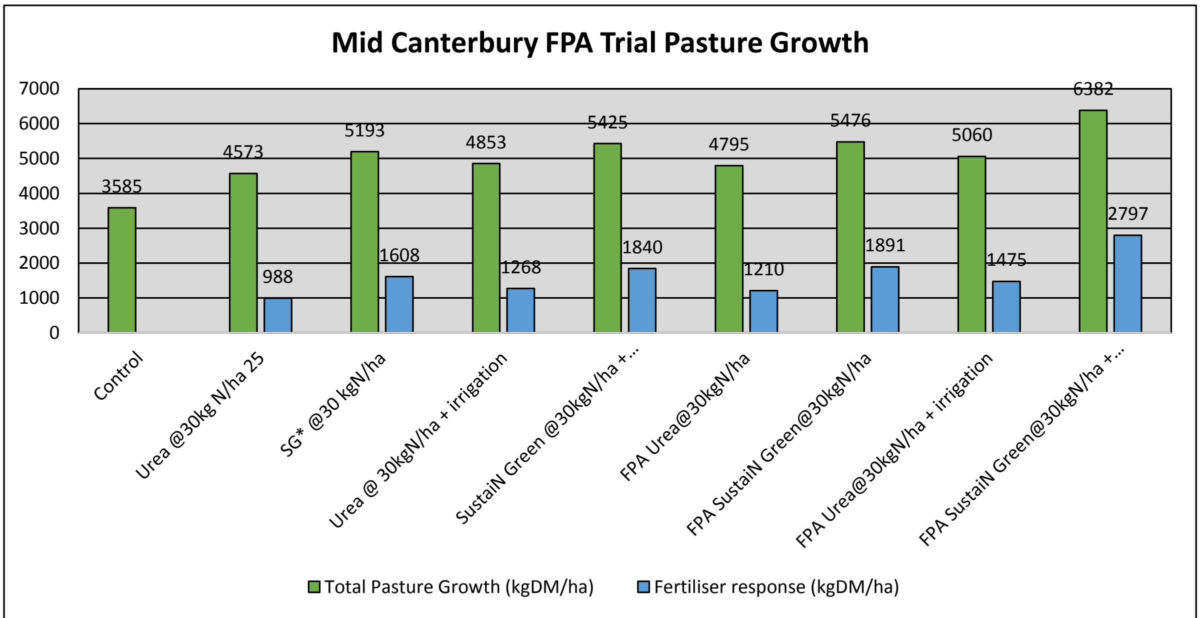
- Applying urea with Agrotain in FPA form showed significantly improved pasture growth, N response and response efficiency compared to urea alone. Nitrogen response and response efficiency decreased with higher rates of fertilise applied in FPA form. The overall results indicate that FPA is a good management tool for enhancing N response and has a greater potential for improved economic returns when applied in the right conditions.

Trial Summary

Applications: Ashburton 2007
30kg applied
Initial application: 25th August 2007
Cut 1: 6/10/2007 - 42 days growth
Cut 2: 4/12/2007 -59 days growth

	Total Pasture Growth (kgDM/ha)	Fertiliser response (kgDM/ha)	N Response Efficiency (kg DM/kg N Applied)	Extra kg DM/kg N over Urea
Control	3585			
Urea @30kg N/ha 25	4573	988	33	
SG* @30 kgN/ha	5193	1608	54	21
Urea @ 30kgN/ha + irrigation	4853	1268	42	9
SustaiN Green @30kgN/ha + irrigation	5425	1840	61	28
FPA Urea@30kgN/ha	4795	1210	40	7
FPA SustaiN Green@30kgN/ha	5476	1891	63	30
FPA Urea@30kgN/ha + irrigation	5060	1475	49	16
FPA SustaiN Green@30kgN/ha + irrigation	6382	2797	93	60

* SG is SustaiN Green



Trial Summary

Lincoln FPA

Applications: Lincoln 2007

30kg applied

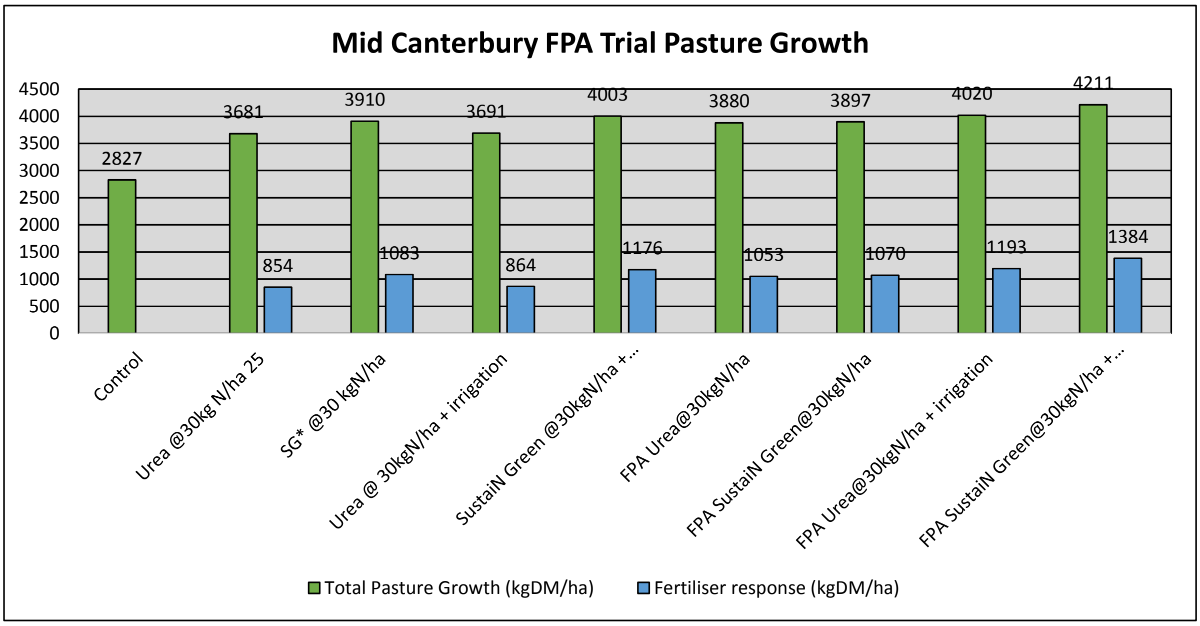
Initial application: 18th August 2007

Cut 1: 22/09/2007 - 35 days growth

Cut 2: 21/10/2007 -29 days growth

	Total Pasture Growth (kgDM/ha)	Fertiliser response (kgDM/ha)	N Response Efficiency (kg DM/kg N Applied)	Extra kg DM/kg N over Urea
Control	2827			
Urea @30kg N/ha 25	3681	854	28	
SG* @30 kgN/ha	3910	1083	36	8
Urea @ 30kgN/ha + irrigation	3691	864	29	0
SustaiN Green @30kgN/ha + irrigation	4003	1176	39	11
FPA Urea@30kgN/ha	3880	1053	35	7
FPA SustaiN Green@30kgN/ha	3897	1070	36	7
FPA Urea@30kgN/ha + irrigation	4020	1193	40	11
FPA SustaiN Green@30kgN/ha + irrigation	4211	1384	46	18

* SG is SustaiN Green

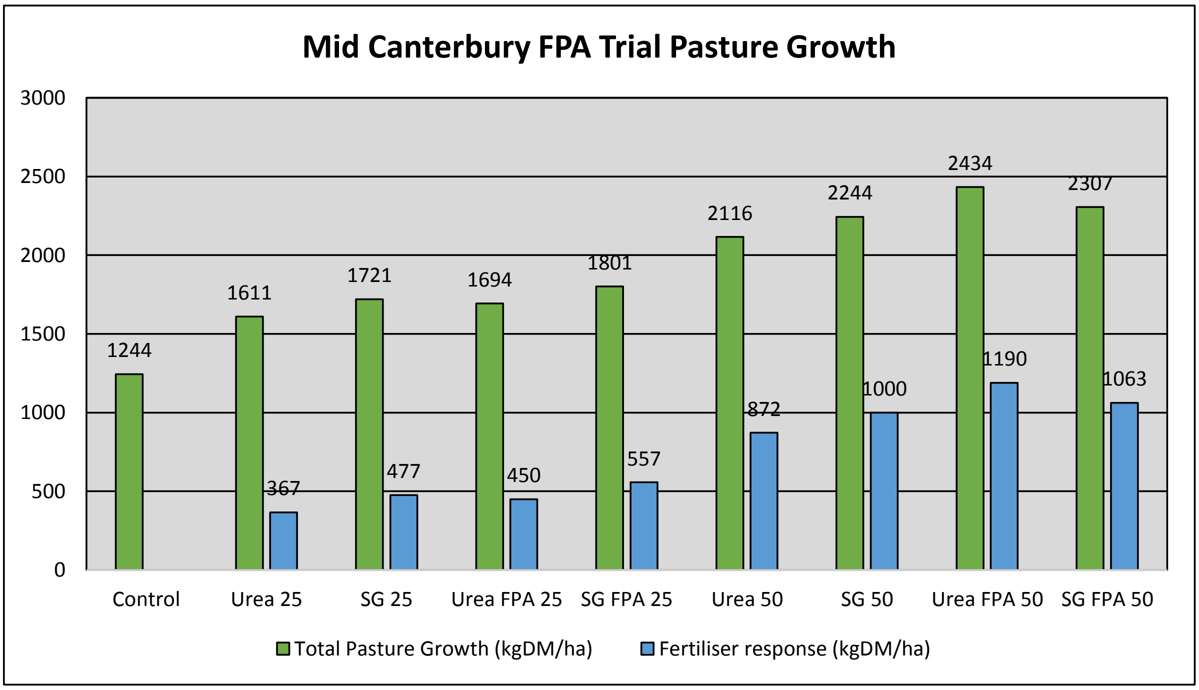


Trial Summary

Mid Canterbury FPA

Applications: Mid Canterbury 2007
30kg applied
Initial application: 26th Feb 2007
Cut 1: 21/3/2006 - 23 days growth
Cut 2: 5/05/2007 -42 days growth

	Total Pasture Growth (kgDM/ha)	Fertiliser response (kgDM/ha)	N Response Efficiency (kg DM/kg N Applied)	Extra kg DM/kg N over Urea
Control	1244			
Urea 25	1611	367	15	
SG 25	1721	477	19	4
Urea FPA 25	1694	450	18	3
SG FPA 25	1801	557	22	7
Urea 50	2116	872	17	
SG 50	2244	1000	20	3
Urea FPA 50	2434	1190	24	6
SG FPA 50	2307	1063	21	4



Conclusion

- Granular applied urea has been reported to have a lower N response efficiency compared to other chemical fertilisers. The implications of this from an environmental perspective are faster hydrolysis which temporarily raises soil pH around the urea granule creating a hot spot for N Losses via NH_3 volatilisation (Mulvaney and Bremner, 1981; Watson et al., 1994; Zaman et al., 2008).

Lowering efficiency of applied N fertiliser pose a potential environmental threat via eutrophication of lakes, rivers and may add to nitrous oxide (N_2O) in the atmosphere.

- Response efficiency of applied urea improved further if urea is applied in fine particle application (FPA) form (Quin et al., 2005, 2006). FPA results in a more even distribution of the applied urea on a per plant basis, which is likely to minimise localised hot spots for N losses.

4.3. K. Dawar, M. Zaman, J.S. Rowarth, J. Blennerhassett, M.H. Turnbull. Agriculture, Ecosystems and Environment, Vol 139 Issue 4, 2010. Urease inhibitor reduces N losses and improves plant-bioavailability of urea applied in fine particle and granular forms under field conditions. New Zealand.

This experiment was set up to run from October to December 2009. It was established on permanent grazed ryegrass/white clover pasture on a site near Lincoln, Canterbury. The experiment area was fenced off twelve months prior to the treatment application to avoid N deposition from grazing cows. There were five replicates of the following treatments:

- N-labelled urea with or without NBPT a urease inhibitor called Agrotain, which is effective in delaying urea hydrolysis as well as increasing productivity under a range of cropping and pasture systems; and
- N-labelled urea with or without NBPT applied in either granular form to the soil surface or in FPA form (with 40% water by weight) through a spray at a rate equivalent to 100kgN/ha; plus
- An additional control treatment that received no N.

Lysimeters were also put in place to capture and measure any leachate. Furthermore, separate plots of 1m2 were set up to measure herbage production and N uptake in intact pasture with each plot receiving the same treatments as those of the lysimeter plots (Table 7).

A field lysimeter/mini plot experiment was established in a silt loam soil near Lincoln, New Zealand, to investigate the effectiveness of urea fertilizer in fine particle application (FPA), with or without the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT – “Agrotain”), in decreasing nitrogen (N) losses and improving N uptake efficiency.

The five treatments were: control (no N) and 15N-labelled urea, with or without NBPT, applied to lysimeters or mini plots (unlabelled urea), either in granular form to the soil surface or in FPA form (through a spray) at a rate equivalent to 100 kg N ha−1.

Gaseous emissions of ammonia (NH3) and nitrous oxide (N2O), nitrate (NO3−) leaching, herbage dry-matter (DM) production, N-response efficiency, total N uptake and total recovery of applied 15N in the plant and soil varied with each urea application method and with the addition of NBPT.

Urea with NBPT, applied in granular or FPA form, was more effective than in application without NBPT: N_2O emissions were reduced by 7–12%, NH_3 emissions by 65–69% and NO_3^- leaching losses by 36–55% compared with granular urea. Urea alone and with NBPT, applied in FPA form increased herbage DM production by 27% and 38%, respectively. The N response efficiency increased from 10 kg DM kg^{-1} of applied N with granular urea to 19 kg DM kg^{-1} with FPA urea and to 23 kg DM kg^{-1} with FPA urea plus NBPT. Urea applied in FPA form resulted in significantly ($P < 0.05$) higher ^{15}N recovery in the shoots compared with granular treatments and this was improved further when urea in FPA form was applied with NBPT.

These results suggest that applying urea with NBPT in FPA form may well prove to be a good management tool under variable field conditions (soil moisture, pH, daily temperature and sunlight) and they conclude that combining FPA urea with urease inhibitor is likely to be a significant step toward improved N-use efficiency and herbage DM production in intensive grassland systems.

They do mention that their recommendation is for further field research under different environmental conditions to better evaluate and understand FPA versus granular fertilisation of pasture systems.

Highlights of the experiment

In investigating the effectiveness of urease inhibitor on urea application to pasture the results indicated the following:

- N losses, pasture production and N-response efficiency responded to addition of inhibitor.
- Urea applied with inhibitor in FPA form, reduced N_2O and NH_3 emissions and NO_3^- leaching losses.
- Urea applied in **FPA form alone**, also reduced N_2O and NH_3 emissions and NO_3^- leaching losses.
- The same application increased herbage DM production and N-response efficiency.
- This approach has potential to mitigate N losses and improve N-response efficiency.

Results

- Total NH_3 losses from applied urea did not differ between granular and FPA treatments in the absence of NBPT (Table 7). Daily as well as total, NH_3 losses were significantly ($P<0.05$) reduced when urea was applied with NBPT, either in granular or FPA form. Total NH_3 losses were 18.7% and 16.9% of the applied N in granular urea and FPA urea treatments, respectively. In contrast, urea applied with NBPT in granular or in FPA form lost only 6.2% and 5.4% of the applied N as NH_3, respectively.

- Nitrate leaching was the predominant form of N in the leachate and varied significantly ($P<0.05$) with time and some N treatments (Table 8) with only trace amounts of NH_4^+, ranging from 0.004kgN/ha to 0.035kgN/ha. Nitrate-N leaching events occurred on three occasions after irrigation and rainfall events. Nitrate concentrations in leachate ranged between 11.66mgN/L and 5.22mgN/L. Nitrate concentration in the first leachate was significantly (P<0.05) higher from the granular urea treatment compared with the other treatments and decreased in successive leaching events. **Cumulative NO_3^- leaching losses during the 63 days were significantly (P<0.05) reduced when urea was applied in FPA form (0.92% of applied N) compared with granular form (2.1% of applied N).** Over the same leaching event period, NBPT-treated FPA urea reduced NO_3^- leaching losses by 55% compared with granular urea, **while FPA urea without NBPT reduced NO_3^- losses by 31% compared with granular form of urea**.

- Cumulative herbage growth, N-response efficiency and total N uptake varied significantly with urea application method and with addition of NBPT. With urea applied in FPA form without NBPT, **cumulative herbage DM was significantly (P<0.05) greater at 27% relative to granular urea.**

- Total N uptake by the herbage was also significantly (P<0.05) greater when herbage was supplied with N in FPA form rather than in granulated form. **This uptake was 136kgN/ha with urea applied in FPA form without NBPT as opposed to only 107kgN/ha with urea applied in granular form.**

- N-response efficiency (kgDM/kgN applied) was also significantly (P<0.05) higher when urea was applied in FPA form than when it was applied in granular form.

- The total recovery of applied N in herbage differed significantly (P<0.05) amongst treatments, and was 26, 28, 56 and 67% for granular urea, NBPT-treated granular urea, FPA urea and NBPT-treated FPA urea, respectively.

- Total N recovery was significantly (P<0.05) greater when urea (with or without NBPT) was applied in FPA form than in granular form.

- **Fine particle application of urea without NBPT resulted in significant (P<0.05) increases in herbage DM, total N uptake and N-response efficiency compared with corresponding granular treatments.**

Such improvements in response efficiency by urea and urea + NBPT in FPA form could be attributed to a number for factors including:

- Uniform distribution of applied urea – FPA results in uniform distribution of applied urea on a per plant basis (approximately 70%), therefore a significant proportion of the applied urea is seen in small particles on pasture leaves during the first 12 hours of application. These deposited urea particles may enable pasture plants to absorb urea directly through their leaves/cuticles (Franke, 1967; Watson et al., 1990b) and this facilitates efficient conversion of urea into plant protein. Other researchers have found that urea is more easily absorbed through leaves/cuticles than NO_3^- and NH_4^+ (Bowman and Paul, 1989,1990,1992; Riederer and Muller, 2006).

- Under field conditions, plants take up most of their N in NO_3^- form because of the ubiquitous presence of urease enzymes and nitrifying bacteria. Being an uncharged particle, urea can also be taken up by roots as an intact molecule without releasing any charge (H^+ or OH^-) to the rhizosphere. Direct absorption of urea and its subsequent conversion to plant protein, leaves the plant with extra energy (Middleton and Smith, 1979), which could be used for additional growth. In contrast, NO_3—N must be reduced before assimilation, which requires additional energy (Raven, 1985; Ullrich, 1992) that the grass cannot allocate to growth.

- The greater response efficiency of NBPT-treated FPA urea over FPA urea alone indicates that urea hydrolysis was delayed. This gives a longer opportunity for plants to take up urea through the leaves/roots.
- This study provides evidence for a higher N-response efficiency of urea applied with NBPT in FPA form under variable field conditions (daily temperature, soil moisture, sunlight) and is therefore a significant step toward improved urea N-use efficiency.
- Easier N uptake through both leaves and roots.
- Efficient N metabolism.

Table 7:

Total NH_3-N loss, the proportion of applied N lost as NH_3-N and % changes during 14 days of the experiment from plots with uream with or without the urease inhibitor (NBPT) applied in granular or FPA forms.

Treatments	NH_3-N losses (kg/ha)	N lost as NH_3-N (% of the aplied N)	% Changes in NH_3 relative to urea (G)
Control (no N)	0.6[a]		
Urea (G)	19.3[b]	18.7[a]	
Urea+NBPT (G)	6.8c	6.2[b]	-65
Urea (FPA)	17.5[b]	16.9[a]	-9
Urea+NBPT (FF	6.0[c]	5.4[b]	-69

Within columns, means with the same letters are not significantly different at the p <0.05 level where n=4

Table 8:

Individual and total NO_3^--N loss (kgN/ha) during leaching events and % difference in NO_3^--N loss relative to granular urea from plots treated with or without the urease inhibitor (NBPT), applied in granular or FPA form.

Treatments	Nitrate-N lost each time period (kg/ha)			NO_3^--N losses	N lost as NO_3^--N	% difference in
	D-35	D-49	D-60	(kg/ha)	(%of the applied N)	NO_3^--N loss
Control	0.76[a]	0.56[a]	0.36[a]	1.68[a]		
Urea G	1.67[b]	1.36[b]	0.8[b]	3.83[b]	2.15[a]	
Urea+NBPT (G)	1.14[c]	0.8[c]	0.52[c]	2.46[c]	0.78[b]	-36
Urea (FPA)	1.07[c]	0.96[c]	0.57[c]	2.6[c]	0.92[b]	-31
Urea+NBPT (FPA)	0.75[a]	0.5[a]	0.48[c]	1.73[a]	0.05[c]	-55

Within columns, means with the same letters are not significantly different at the p <0.05 level where n=5

Table 9:

Total herbage dry-matter (DM) (kg/ha), % difference relative to urea-G, total N uptake (kgN/ha), % difference relative to urea-G, response efficiency (kgDM/ha of applied N) and the recovery above ground (%) from plots treated with urea, with or without the urease inhibitor (NBPT), applied in granular of FPA form.

Treatments	Herbage dry-matter (kg/ha)				% difference relative to urea-G
	D-21	D-42	D-63	Cumulative	
Control	865a	705a	843a	2412a	
Urea G	1403b	958b	1079b	3439b	
Urea+NBPT (G)	1625c	1203c	1175c	4003c	16
Urea (FPA)	1648d	1540d	1171c	4359d	27
Urea+NBPT (FPA)	1724d	1642c	1366d	4731c	38

Within columns, means with the same letters are not significantly different at the *p* <0.05 level where n=7

Treatments	Response efficiency (kgDM/kg of applied	Total N uptake (kg N/ha)	% difference relative to urea-G	Total N recovery (%)
Control		81a		
Urea G	10a	107b		26
Urea+NBPT (G)	16b	129c	20	48
Urea (FPA)	19c	136c	27	56
Urea+NBPT (FPA)	23d	148d	38	67

Statistical analysis was applied using ANOVA to determine the effect on measured parameters using Minitab. General linear model analysis was carried out at individual times when specific times x treatment interactions were statistically significant. Least significant differences (LSD) were calculated only when the treatment effect was significant at *P*<0.05.

Conclusion

- Dawar et al., 2010, concludes that urea with NBPT applied in FPA form resulted in further reductions in N losses via NH_3 and N_2O emissions and NO_3^- leaching, and resulted in higher herbage dry-mater production, N-response efficiency, N uptake and recovery of applied N. (See Tables 7, 8 and 9 above). This outcome would be expected; however, what Table 8 also indicates, is that **FPA applied urea (without NBPT) delivers essentially the same reduction in nitrate N leaching as granular applied urea with NBPT**. This clearly and strongly indicates the effectiveness of urea applied FPA is on its own when it comes to reducing nitrate N leaching.

- Furthermore, the small particles resulting from FPA adhere to the leaves/cuticles which allow for direct absorption by the leaves and roots. This direct uptake in addition to reductions in soil and plant urease activity, appears to provide the plant with an opportunity to convert the absorbed urea into protein more efficiently. Applying urea in FPA form may well prove to be a good management tool under variable field conditions (soil moisture, pH, temperature and sunlight).

4.4. M. Mahoney; Small plot nitrogen trial comparing various nitrogen topdress fertiliser options for pasture and different rate and frequencies of application. Australia. Agronomy Field Trial Report, Incitec Pivot, February 2010.

The trial's aim was to demonstrate the differences in efficiencies of the different fertilisers and application methods on an established ryegrass sward dairy pasture under centre pivot irrigation, in the Western Districts of Victoria.

There were ten treatments including a control. The treatments included the following:

- A Control
- Urea
- Green urea – urea coated with a specific trademark urease inhibitor.
- Easy N – a liquid fertiliser of Urea and ammonia nitrate with1L EasyN + 1L Water
- Easy N + Urease Inhibitor (Agrotain)
- Experimental method (FPA) with 1kg Urea + 0.7kg water.
- Easy U-sol + Agrotain – with Easy U-sol being solubilised urea in water

The experimental fertiliser application method used FPA was adopted from New Zealand technology to establish if, as suggested, the technology would be able to significantly improve pasture production per unit of nitrogen input when compared to conventional urea application methods.

Plots were arranged in a randomised plot design of ten treatments replicated twice, once in each block. The plots were 2 metres wide by 20 metres in length aligned parallel. Plots either side of the treatment strip were covered with a tarpaulin to prevent spray drift from falling on the wrong plots. All the plots were separated by a sprayed-out strip demarcating their individual boundaries. There was also a 4m buffer strip between the blocks.

All treatments were applied at the initiation of the trial on 13th February 2009. Only on every second harvest was the higher double rate of nitrogen applied whereas the half rate was applied after every harvest. By the end of the trial, all treatments had received the same amount of applied nitrogen, approximately 382kgN/ha. Rates were as follows:

- 84kgN/ha every second grazing, 1 day after grazing;
- 42kgN/ha applied after each grazing, 1 day after grazing.

Initially the lower rate of N applied/ha was set at 23kgN/ha but this was changed to the higher rate of 42 kgN/ha and the higher rate was changed from 42kgN/ha to 84kgN/ha for the duration of the trial. This was done due to the time-consuming nature of correctly calibrating sprayers and spreading equipment.

The treatments were applied using the following procedure:

- Granular applied using the cone seed with a spreader plate installed in lieu of tines;
- Liquid treatments applied using liquid systems equipment and applied via a boom spray with streaming nozzles;

- Experimental treatments (FPA) applied using a prototype applicator.

Results

Statistical analysis was done including the following; ANOVA, T-Test, LSD separation of means and linear regression using Genstat 11.

The statistical analysis and its results were not provided in the paper.

Table 10 below, presents the cumulative results from the 362-day trial for dry matter, nitrogen uptake and average protein percentage of dry matter, for the different nitrogen fertilisers and application methods. The results are for both the frequent (42kgN/Ha every rotation) and less frequent (84kgN/Ha every 2nd rotation) applications to pivot irrigated ryegrass pasture.

The cumulative dry matter results show that overall, the Experimental treatment applied more frequently at 42kgN/ha was significantly better than all treatments except the same Experimental treatment (FPA type) or Green Urea applied less frequently at the higher 84kgN/ha rate. The Experimental (FPA) application provided the highest DM kg/ha harvested at 10,376kgDM/ha for the 42kgN/ha rate and 10,290kgDM/ha for the 82kgN/ha rate. Ultimately the results provided no evidence to support using either a lower rate more frequently or a higher rate less frequently when looking at pasture production alone (See Table 10 below). However, there would most likely be negative environmental impacts at application rates of 82kgN/ha (author).

The cumulative nitrogen uptake results indicate that at both the 42kgN/ha and the 84kgN/ha rates of N applied using the Experimental (FPA) resulted in the highest N uptake at 386.5kgN/Ha and 389.6kgN/Ha.

All treatments gave similar estimated average protein concentrations and were significantly greater than the Control.

Table 10:

Cumulative results from 362 days of trial period for Dry Matter, Nitrogen Uptake and Average protein percentage of Dry Matter for the differentnitrogen fertilisers and application methids for both frequent (42kgN/ha every rotation) and less frequent (84kgN/ha every 2nd rotation) applications to pivot irrigated ryegrass pasture.

	Dry Matter (kg/ha)		Nitrogen Uptake (kg/ha)		Ave. % Protein (362 days)	
Treatment	**42 kgN/ha**	**84 kgN/ha**	**42 kgN/ha**	**84 kgN/ha**	**42 kgN/ha**	**84 kgN/ha**
Experimental treatment (FPA type)	10376	10290	386.5	389.6	22.39	22.12
Green Urea 14	9646	9946	333.2	348.6	21.67	21.76
Urea	9389	9214	336.7	323.2	22.39	21.03
Easy N	9007		287.8		20.19	
Easy N + Urease Inhibitor	7885		242.0		19.99	
Urea sol'n N + Urease Inhibitor	7376		227.3		19.62	
Control	3696		102.2		17.81	
cv%	6.5%		9.0%		3.2%	
lsd	641.6		31.1		0.7873	

This is cumulative data collected from the fisrt two harvests which had lower rates of nitrogen applied of 23 instead of 46kgN/ha and 46 instead of 84kgN/ha, as well as the following eight harvests which had the listed amounts of nitrogen applied.

Conclusion

- The frequency of nitrogen application did not change the outcome. This was with regards to dry matter response, N uptake and protein content. This meant that the higher rate of nitrogen applied less frequently was not being lost from the system, and was utilised by the growing pasture in a similar manner to the nitrogen applied more frequently at a lower rate.

- The Experiment treatment (FPA) appeared to be very efficient at dry matter production and nitrogen uptake. The reasons are unclear as to why this might be, and further assessment was recommended. One possibility is that the urea could be absorbed directly by the plant leaf tissue, as well as being taken up by the roots, enabling larger plant capture of applied nitrogen versus just root uptake.

- An outstanding result in cumulative dry matter production and N uptake was produced in the Experimental treatment (FPA), although this treatment proved difficult to apply consistently.

4.5. M. Zaman, M.L. Nguyen, M.M. Barbour, M.H. Turnbull, Influence of Fine Particle Suspension of Urea + NBTPT on N and water use efficiency in grassland using N15, в13 C and в18O techniques. Ballance Agri-Nutrients Limited.

According to the United Nations population estimates, over 77 million more people each year are being added to the current world population (6.98 billion) and will reach 9 billion by 2050. A 50% increase in agricultural productivity will therefore be required by 2050 to feed the world's growing population meaning more pressure on available land and water resources. Therefore, both the efficiency of applied nitrogen (N) fertilisers, especially urea, and water use efficiency in irrigated agriculture, need to be improved above their current levels of 50% and 40% respectively (www.fertiliser.org/ifa/statistics.asp) (2011).

Among the many management factors, such as developing improved crop varieties, and better insect pest control, improving N and water use efficiency, is critical to enhance agricultural productivity and to promote sustainability.

Among the chemical N fertilisers, urea, the most preferred form of N (over 66% of the total world N consumption), is usually applied in granular form. However granular urea application under less optimum conditions (extreme moisture and temperature) has been shown to have lower nitrogen use efficiency (NUE) in many cropping and pastoral systems compared to other N fertilisers. Among the various available options to improve NUE of urea, treating urea with urease inhibitor (UI) such as NBTPT (or Agrotain®), has received the most attention.

The objectives of the study were to:

- Assess the effects of urea with urease inhibitor NBTPT on NUE and water use efficiency (WUE by ryegrass;
- Assess the effect of irrigation on NUE;

- Assess the effect of NBTPT on N uptake by ryegrass and to investigate the relationship between N uptake and dry matter (DM) using N.

Controlled environment experiments were carried out to assess the effect of Agrotain treated urea applied in granular or fine particle suspension (FPS) forms to ryegrass on NUE and WUE. In the FPS treatment, N labelled as urea (10%) was carefully applied to ryegrass leaves in suspension form at equivalent rate of 25kgN/ha using a syringe.

There were 6 treatments as follows:

- Control (no N)
- Control + (spray of water on plant leaves to replicate FPA)
- Urea (granular)
- Urea + (Spray/FPA)
- Urea + Agrotain (granular application)
- Urea + Agrotain + (Spray/FPA application)

Results

- Urea applied to leaves significantly increased growth of the sward. Urea with Agrotain slightly, but non-significantly, increased pasture growth as well. Applying spray water on to the leaves increased growth in all cases. The increase in growth was strongly related to an increase in photosynthetic rate, probably due to higher N availability for Rubisco[2]. The higher photosynthetic rate in response to applied urea also resulted in higher leaf intrinsic water use efficiency.

TABLE 11:

Treatment effects on DM, Photosynthetic rate (*A*), and leaf intrinsic water use efficiency (WUEI).

Treatment	DM (g)	*A* (µ m^{-2} s^{-1})	'UE (mmol mol
Urea (Granular)	2.1 ± 0.1a	8.2±0.2a	4.4±0.1a
Urea + (FPA)	2.2 ± 0.4ab	9.4±0.6bc	4.7±0.1ab
Urea+Agrotain (granular application)	2.1±0.2a	8.6±0.3ab	4.5±0.1a
Urea+Agrotain+(FPA application)	2.6±0.1b	9.8±0.4bc	4.9±0.1b
Control	0.9±0.0c	5.4±0.3d	3.5±0.1c
Control+(spray of water on plant leaves)	1.3±d	5.0±0.2d	3.4±0.1c

Data are means ± standard errors (n=3); Data within a column followed by the same letter are not significantly different (P<0.05).

Conclusion

- As expected, urea applied to the leaves increased photosynthesis rates, WUE (Water Use Efficiency), and sward growth. Adding Agrotain with urea in FPS form resulted in slightly, but not significantly, higher photosynthetic rate and WUEi. Adding urea in FPA form increased WUE by 26%, and spraying water on a plant's

[2] Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) catalyses the conversion of atmospheric CO_2 into organic compounds during photosynthesis. (www.nature.com/articles/nplants201565)

leaves one day after urea application increased WUE by a further 12%. The mechanism by which Agrotain is expected to increase WUE is by reducing the loss of N from the soil, increasing the plant available soil N over a longer period as ryegrass leaves treated with the Agrotain was found to have higher N content and more ^{15}N.

4.6. B.F. Quin, J.D. Blennerhassett and M. Zaman. "The use of Urease Inhibitor-Based products to reduce nitrogen losses from pasture. 2005. www.researchgate.net Conference Proceedings.

The most important factor in controlling the efficiency of response of fertiliser N is the opportunity for utilisation for growth by plants before loss occurs. Granular urea, by its concentration, is providing small pockets of extremely concentrated N that in some conditions will limit the opportunity for access by all the roots of any one plant. This factor is likely to be most significant on less permeable soils, as migration of N from the zone of the granule is slower.

The use of urea in suspension or fine particle application form improves nitrogen uptake opportunity, as is a likely explanation for the much superior response with FPA products in the Taranaki Trial (Trial Summary below). Note that in both granular and FPA form, treatment of urea with Agrotain has resulted in a further improvement over normal urea FPA. This is not unexpected, given the benefits of using NBPT to treat animal wastes in the United States (Varel et al 1999).

In FPA form, the benefit of easier access by plant roots could be offset by increased volatilisation due to rapid hydrolysis of urea, unless an inhibitor is used. In wet, windy conditions which limit the physical and/or accurate application of granular fertiliser N, the application of SustainN (urea with Agrotain) has considerable potential.

This Taranaki Trial included the following treatments:

- Control
- Urea @30kgN/ha
- FPA Urea @30kgN/ha
- SustaiN @30kgN/ha
- FPA SustaiN Urea @30kgN/ha

The Trial Summary for the Taranaki FPA Trial below, indicates the kilograms Dry Matter pasture response in the Taranaki Trial in 2004 – 2005. An additional 18 and 32 kg DM/kg N response was measured for the FPA urea @ 30kgN/ha and FPA Sustain urea @ 30kgN/ha.

Trial Summary

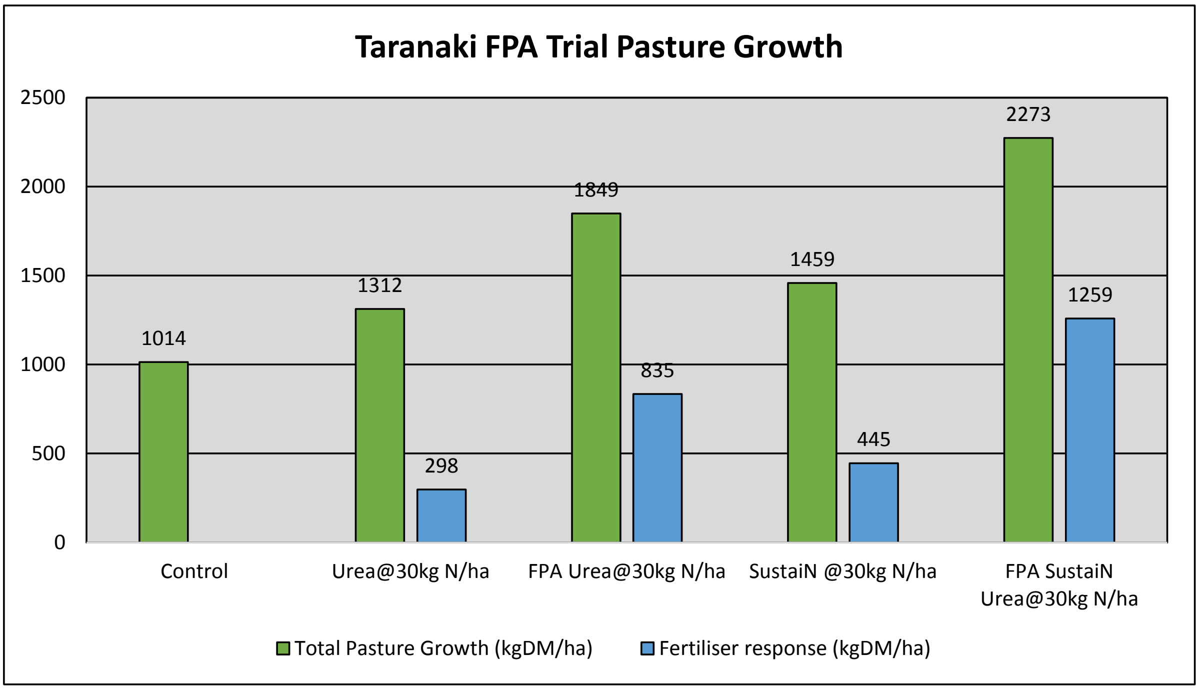
Taranaki FPA

Applications: Taranaki 2005

30kg applied

Cut 1: 22/12/2005 - 34 days growth

	Total Pasture Growth (kgDM/ha)	Fertiliser response (kgDM/ha)	N Response Efficiency (kg DM/kg N Applied)	Extra kg DM/kg N over Urea
Control	1014			
Urea@30kg N/ha	1312	298	10	
FPA Urea@30kg N/ha	1849	835	28	18
SustaiN @30kg N/ha	1459	445	15	5
FPA SustaiN Urea@30kg N/ha	2273	1259	42	32



Conclusion

The Taranaki Trial Summary above, shows that when applying urea by the fine particle application method, with or without Urease Inhibitor, it outperforms granular fertilisers applied under normal broadcast application.

5. PAPERS NOT CONSIDERED FOR REVIEW

- **Karlovsky et al. (1978)** was rejected as a resource for review as it considered applying solid phosphatic fertiliser (granular) and liquid phosphatic fertiliser, being a foliar spray. Fine particle fertiliser was not part of this study.

- **Carlier et al. (1990)** was not considered as it compared solid and liquid N fertilisers using different chemical forms of N. As this was not a comparison of solid fertiliser with FPF it was rejected for this review.

- **Korte et al. (1996)** conducted 3 trials in the Hawkes Bay examining the efficacy of **FPA** applied DAP (**DAP Slurry**). **DAP Cost** was a **solid** fertiliser applied at a similar cost as the **DAP Slurry** but applied at different rates (the aim was to indicate how much extra nutrient can be applied in normal granular form for the same cost as FPA). In the table below, the DAP Slurry, was applied at a significantly lower rate (nutrient kg/ha) than that of the DAP Cost in two of the three trial sites, i.e., Poukawa 1 and 2, especially as related to N and P applications. However, DAP Slurry N and P was applied at the same rate as DAP Solid in Poukawa 1 and 2.

  Table 12 below provides the rates of nutrients applied in kg/ha. The conclusion of the Trial was that there was no significant difference between the three treatments. However, what was not highlighted was that DAP Slurry achieved very similar levels of herbage production (kgDM/ha) as DAP Solid and DAP Cost, even at the significantly lower application rates compared to DAP Cost, especially when compared to Poukawa 1 and 2 trial plots. It is not made clear in the paper as to the reason for the higher application rates of N and P in the three treatments.

Table 12:

DAP trial Hawkes Bay - Rates of nutrient application (kg/ha) in Treatments 3, 4, and 5.

Treatment	Waipawa			Poukawa 1			Poukawa 2		
	N	P	S	N	P	S	N	P	S
DAP Slurry	2	2	6	3	3	6	5	5	4
DAP Solid	3	3	0.3	3	3	0.3	5	5	0.5
DAP Cost	6.5	7	0.7	20	22	2	22	24	2

Note: DAP Cost: DAP applied as a solid, at a similar applied cost per ha to treament 3

Table 13:

Herbage production (kg DM/ha) combined over three experiments

Treatments	Early cuts	Late cuts	Total
Control	4220	9880	13980
Trace elements	4200	9590	13660
DAP Slurry (FPA)	4350	10200	14410
DAP Solid (granular)	4520	10030	14430
DAP Cost	4740	9980	14570
LSD ($P \leq 0.05$)	260	780	830
F test significance	***	ns	ns
Coefficient of variation	8%	10%	7%

Table 13 above shows the DM results of the three treatments. What is significant when considering the Total kgDM/ha per treatment, is that DAP Slurry (FPA), even when the N and P were applied at the very low rates as recorded in this Trial, produced only 1% less dry matter herbage production

that the DAP Cost (which produced the highest kgDM/ha), the latter having a significantly higher nutrient input compared to DAP Slurry, with DAP Cost at 48.5kgN/ha and 43kgP/ha applied producing 14570kgDM/ha. As opposed to this, DAP Slurry (FPA) applied only 10kgN/ha and 10kgP/ha producing 14410kgDM/ha. So for 38.5kgN/ha and 33kgP/ha less than DAP Cost over the three experiments, DAP Slurry (FPA) produced only 1% less dry matter/ha than the DAP Cost, over the three experiment. This is not highlighted in the paper.

The authors go on to say in their discussion that no significant ($P \leq 0.05$) increase in herbage production over the unfertilised control treatment was measured in any of the three experiments where DAP Slurry (FPA) was applied. They say that DAP slurry treatment contained only 2-5kg/ha of N and P, insufficient to produce a measurable increase in herbage production. With considerably increased replication, a significant difference in herbage production between slurry and control treatments could have been detected (Johnstone & Sinclair 1991).

This paper was not considered for the review as the application rates of nutrients were considered to be too low. On face value, the rates of application for both the DAP Slurry (FPA) and DAP Solid were very low, resulting in poor response rates.

- **K. Wynn. (2007) FITT Final Report 07FT191. Nitrogen Product Comparison Trial**. This paper was not reviewed due to issues with the implementation of the experiments. It was firstly undertaken on small plots that made it extremely difficult to accurately use the FPA method while applying FPA by helicopter. The designed rates of application for the trial of urea versus Sustain was 30kgN/ha and 60kgN/ha in two forms, i.e., granular and FPA.

  Secondly, on the second FPA application in October 2007, the FPA rate applied at 70kgN/ha and 103kgN/ha, in error, far exceeded the experimental design. This resulted in significant pasture damage. The FPA plots were therefore not monitored after this second application rendering any conclusion from the response to the FPA applications, irrelevant. Finally, the N response rates could have also been affected by the variability of the Agrotain in the product applied.

- **H.C. Suter et al (2013).** Although this paper comprehensively covered the experiments looking at the influence of enhanced efficiency of fertilisation techniques on nitrous oxide emissions and productivity response from urea in a temperate Australian ryegrass pasture, when it came to the response from suspension applied urea, gibberellic acid was included in the suspension application in addition to the urease inhibitor applied to the urea. For the purposes of this Review, this composition would automatically render any dry matter response data from the pasture irrelevant as the response would be significantly affected by the gibberellic acid content as well as the urease inhibitor.

6. REVIEWER'S CONCLUDING REMARKS AND OBSERVATIONS

- The trials reviewed above have shown benefits being derived from applying fertiliser using the fine particle application method. It is important to note that there were a range of outcomes and levels of success using FPA technology. Several of the trials were affected by applications made during sub-optimal conditions, such as too low soil moisture levels, high winds and high soil temperatures. This points to the importance of ensuring applications of fertiliser, especially nitrogen, are made when environmental conditions are close to or at optimum levels, (Zaman and Blennerhassett, 2009).

- It is apparent from the literature that the FPA technology provides a wider range of benefits than simply more pasture dry matter grown, although this is a key benefit of the technology. There are environmental benefits that were observed and measured as in Dawar et al (2011). These benefits include reduced nitrate leaching which results from the finer particles being more easily taken up through cuticular uptake pathways. This early uptake would also reduce the loss of nitrogen through volatilisation.

- There was also evidence of fine particle applications improving soil N. The Winton Trial found that the FPA treatment showed higher soil N levels appearing to confirm the theory that this system appears to increase biological activity, leading to increased mineralisation and or N fixation

- The Winton Trial also noted an appreciable shift in the pasture sward composition with a denser ryegrass component arising, on the plots where nitrogen has been applied using the FPA method. This assessment was undertaken using a visual assessment by two people. It was an apparent shift in favour of an increasing ryegrass content with a slight drop in the content of clover and low fertility grasses in relative terms. On the plots where superphosphate had been applied they noticed an increase in the clover content as well as an increase in the ryegrass content.

- There were environmental benefits noted in the papers reviewed. Two main benefits were a reduction in nitrate leaching as well as the reduction in volatilisation of N. The research showed a reduction in N leaching as well as N volatilisation when just the FPA method was used in the application of urea without the inclusion of urease inhibitor NBPT. The trials show a statistically significant benefit in applying urea by the FPA method (without NBPT) compared to applying urea in the granular form (without NBPT).

- A summary of the response rates to the FPA trials comparing Sustain FPA with granular urea are tabled in Appendix 1.

7. RECOMMENDATIONS FOR FURTHER DEVELOPMENT OF THE BODY OF INFORMATION ON FINE PARTICLE APPLICATIONS AND ITS ROLE IN IMPROVING FARMING PRACTICE IN NEW ZEALAND

- One of the benefits of fine particle applications that has often been raised by farmers and others in the industry, is the noticeable increase in ryegrass pasture sward density that apparently stems from the prolific tillering by the individual plants. These tillers provide both dense and high-quality pastures. This could lead to the development of visual aids and systems for farmers to assess their pasture sward density relatively easily.

- There is a need to further investigate and confirm the biological pathways behind the benefits of FPA as opposed to granular fertiliser applications. The literature discussed within this Review indicates that there are key areas that require a better understanding to support the use and adoption of this technology by farmers. These refer to the biological pathways for uptake of nitrogen through the leaf of the plant, the mechanisms that the pasture plants employ to uptake nitrogen and the environmental and other benefits that arise from these uptake mechanisms.

- Fine Particle Application experiments require a more comprehensive understanding of the role of the grinding and spreading of the fertiliser. This is a very technical area of FPA and a good understanding of the challenges and issues surrounding this aspect of FPA would likely open further opportunities for improvement of the technology creating further environmental and economic benefits to the pastoral industry.

Recommendations

- A project be undertaken to study of recognized methods of accurately measuring tillering of ryegrass pastures and thereby the density of pastures resulting from fine particle applications;

- A further literature review be considered that will survey the body of research available with regards to the plant leaf uptake mechanisms and dynamics of nitrogen and other nutrients;

- A review of fertiliser grinding and spreading technology be undertaken to identify the benefits of different fertiliser grinds methods and spreading and distribution patterns, to possibly identify areas for further technological development and advancement of existing methods.

8. SUMMARY OF CONCLUSIONS REGARDING THE BENEFITS OF FINE PARTICLE APPLICATION

No.	Presenters	Benefits identified (yes/no)	Benefit FPA vs Granular	Notes
1	**AgConsult. Winton Trials**	Yes	FPA DAP produced >10% more pasture, i.e., 3 times the response; Visual assessment saw a change to the pasture sward in favour of ryegrass	See Tables 1, 3 & 5. Pages 6-9
2	**M. Zaman and JD Blennerhassett, Summit-Quinphos. 2009.**	Yes	Significantly more pasture DM. FPA is a good management tool for enhancing N response and greater potential for improved economic returns if applied under the right conditions.	See Trial Summary Tables for Ashburton, Lincoln and Mid-Canterbury Pages 9-14
3	**K. Dawar, M. Zaman, J.S. Rowarth, J. Blennerhassett, M.H. Turnbull. 2010**	Yes	More N recovery in the shoots. Mitigates against N losses, improving NUE.	Tables 8 & 9 Pages 14-18
4	**M. Mahoney; Agronomy Field Trial Report, Incitec Pivot, February 2010.**	Yes	Outstanding result in cumulative DM production and N uptake.	Table 10 Pages 18-21
5	**M. Zaman, M.L. Nguyen, M.M. Barbour, M.H. Turnbull, 2010**	Yes	Applying to leaves increased photosynthetic rate, WUE and sward growth.	Table 11 Pages 21-23
6	**B.F. Quin, J.D. Blennerhassett and M. Zaman. 2005**	Yes	FPA improves nitrogen uptake opportunity, and is a likely explanation for the much superior response with FPA products in the Taranaki Trial	Taranaki FPA Trial Pages 23-26

9. Appendix 1: Summary of extra dry matter grown over the trials listed in the papers reviewed.

SustaiN FPA Trial Summary

SQ Trials

	Rate (kg N/ha)	Urea Granular	SustaiN FPA	Extra kg DM/kg N using SustaiN FPA over granular urea
Taranaki FPA	30	10	42	32
Ashburton FPA	30	6.4	32	26
Mid Canterbury FPA				
25 N	25	15	22	8
50 N	50	17	21	4
Lincoln FPA				
No irrigation	30	28	36	7
Irrigation	30	29	46	18
Canterbury University	25	10	23	13
Average		16.5	31.7	15.4

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