Research Summary – Altering the rate of N supply to crops – field evaluations
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Summary:

- **Nine field experiments were undertaken to compare a range of N placement and product delivery strategies for wheat grown in the Mallee, Wimmera and Western District of Victoria.**

- **The experimental results were compromised by dry seasons and any responses reported here are relatively low due to those conditions.**

- **The marginal nitrogen removal (MNEff) in grain was used as an arbiter of the comparative efficiency of different placement and product delivery strategies.**

- **On all except one site, Deep Banding of urea at sowing was no less efficient than any of the other at-sowing strategies used.**

- **For the topdressing options, the use of a urease inhibitor or zeolite on top-dressed urea was never less than normal urea applications and, in two cases each, these treatments significantly improved MNEff.**

- **At Inverleigh in 2006 and 2007, the use of UAN top-dressed resulted in lower MNEff, probably due to the degree of crop damage.**

- **While topdressing urea at GS30 was not as effective in the Western District, the addition of a urease inhibitor resulted in marginal nitrogen use efficiencies similar to deep banding**

- **Despite these differences in efficiencies, potential savings in nitrogen use were generally small in the Western District (~10 kg N/ha) and the Mallee (~5kg N/ha).**

- **The decision concerning adopting different strategies should consider potential N savings, any additional capital and operating costs, changes to sowing efficiency and the extra cost of amendments or changed fertilizers.**

Introduction

Nitrogen (N) loss through leaching, volatilization, de-nitrification and other loss pathways is problematic for two reasons. Firstly there is less N available during times when N stress could restrict plant growth, and secondly losses can contribute to groundwater contamination, greenhouse gas accumulation and surface water contamination. There are several strategies that can be used to alter the rate at which N becomes available to crops so that plant uptake matches nutrient supply. These strategies include using urease inhibitors, nitrification inhibitors, various coatings or fertilizer amendments and placement and timing strategies. MAP is a dominant fertilizer mainly used by growers as a P source, but it supplies little N. The main product used by growers is urea either at or near sowing and/or top-dressed and the strategies evaluated here essentially revolve around increasing the efficiency of N uptake from urea.

The term enhanced efficiency fertilizers refers to strategies used to improve the uptake and utilization of supplied nutrients – in this case nitrogen – by crop plants. A recent review by Chen et al. (2008) indicated that management practices alone would not prevent all losses and that the use of enhanced efficiency fertilisers, such as controlled release products, and urease and nitrification inhibitors could result in a marked improvement in efficiency

This research, part of the GRDC Nutrient Management Initiative aims to compare a range of products with various agronomic practices when used on wheat crops in southeastern Australia. The focus was particularly on the stategies that could be used to enhance the efficiency of urea application both at sowing and in-crop.

Fertilizer Amendments

- **Urease inhibitors** reduce the rate at which urea is hydrolysed to form unstable ammonium carbonate. The main product used to amend urea fertilizers is nBTPT (N-(n-butyl)-thiophosphoric triamide) which is marketed at Agrotain®. The loss of ammonia via volatilization is highest when soils are either naturally alkaline or where they become alkaline in the immediate proximity to the fertilizer. Losses with untreated urea can be in the range of 5-20% of the total N applied although this may be up to 50% (Ryden 1986, Watson et al. 1990, Harrison and Webb 2001). Urea has shown losses of between 4.7 and 26% in the Wimmera / Mallee when measured using passive sampling methods under field conditions (Turner et al, 2009). Losses are highest on surface applications, with dry and warm soils, so this supplement is most likely to be effective at improving N use efficiency when top-dressed. Because of this variability, the effect of adding urease inhibitors will also be quite variable. When used as an at-sowing supplement, there is some evidence that urease inhibitor treated urea can reduce the phytotoxic effects of ammonium around the seed (Wang et al. 1995, Mahli et al. 2003). However, there is also some suggestion that nBTPT can result in some phytotoxic effect most probably because it leads to the direct uptake of urea by the plants (Krogmeier et al. 1989, Bremner 1995).

- **Nitrification inhibitors** operate to inhibit the conversion of ammonium to nitrate in the soil and have been shown to have beneficial effects by reducing nitrate leaching and nitrous oxide emissions (Stelly 1980, McTaggart et al. 1994, Velthof et al. 1997, Williamson et al. 1998, Merino et al. 2002). The most common inhibitors are Nitrapryn or N-Serve (2-chloro-6 (trichoromethyl) pyridine), dicycandiamide (DCD – Alzon, Didin, Ensan) and DMPP (3,4 dimethylpyrazole-phosphate - Entec®). Provided ammonia volatilisation can be minimized it is reasonable to expect that these inhibitors can improve N efficiency under particular circumstances. The activity is dependant on soil temperatures, moisture content, pH and organic matter content. Edmeades (2004) concluded that the impact of nitrification inhibitors is likely most on where nitrate leaching is probable, on friable soils under high rainfall. Improved crop yields under these circumstances then depends on soil N status, where the conservation of this extra N will have an impact if soil N is low. That author also concluded that the impact of nitrification inhibitors would be low on heavy clays with poor drainage. Conversely, authors such as Rochester et al (1994) concluded that nitrification inhibitors (tridiazole) were able to increase cotton yields on heavy clay soils by limiting biological denitrification. Therefore, the role of DMPP amended urea deserved added consideration for grain production systems in southeastern Australia.

- **Urea-Ammonium Nitrate (UAN**) liquid fertlizer. Although not strictly an amended fertilizer, UAN is a mixture of ammonium nitrate and urea dissolved in water and contains 42.5% w/v N. As a fluid (or liquid) fertilizer, the application requires different equipment, either pumps and tanks attached to seeding equipment for at-sowing applications, or boom sprays with coarse streaming nozzles. The product can be applied at sowing banded in a similar way to solid fertilizers, or applied post-sowing on developing crops. Timing for post-sowing applications is similar for other N sources. The N in UAN is exposed to similar loss processes as solid urea, although the pH of UAN solution is significantly less than that experienced in close proximity to a hydrolysing urea granule and so the use of enhancers such as nitrification inhibitors or urease inhibitors would have similar responses to their effect on urea. UAN is available commercially in Australia and the manufacturers caution that high rates (>20 l/ha) of this product can cause damage to the winter cereals when applied with flat fan nozzles, and late applications at rates as low as 10 l/ha can burn the flag leaf.

- **Stable U®** is a relatively new product developed in the US and it is a urea granule that is formed up around a calcium cyanamide core.

- **Urea + Organic Complex** is urea that has a surface coating of organic carbon and other biological agents applied and there is at least one commercial product. The manufacturers advise that this coating contains a range of organic acids and other organic compound. It is proposed that these compounds stimulate microbial activity and also help to reduce ammonium losses.

- **Polymer coated urea (PCU)** treated to restrict the rate of urea hydrolysis by reducing the rate at which water comes in contact with the urea. Although not evaluated here, some urea is sulphur coated, which reduced the rate of N release.

- **Zeolite –** is an expanded clay mineral that has a high cation exchange capacity. The theory is that this additive to urea acts as a buffer to capture ammonia should nitrification be restricted.

Fertilizer Presentation

Presentation of urea can also alter the supply to crops. The use of split applications can assist tailoring supply to crop demand, as well as having the additional benefits of reducing up-front fertilizer bills and as it is put on later, the seasonal conditions are better known. Banding, incorporation or surface applications are all strategies that can be used to alter the presentation of the fertilizer. Banding tends to slow the rate of N release down, while surface application can incur quite high losses from ammonia volatilization. The following strategies were employed and compared, and include at sowing options or options for in-crop application.

- **Deep Banding (DB)** where granulated urea is place in a band approximately 2.5 cm below the seed at seeding. This is now the industry standard for the use of urea at sowing, at seed and fertilizer are not in direct contact.

- **Mid-Row Banding (MRB)** where granular urea is placed in a band between each second seeding row. This strategy has been used to slow the rate of nitrate release from the urea and so reduce the rate of leaching. This strategy also preserves N for root access somewhat later in the season than N applied with or near the seed. This strategy has been shown to be successful on soils where subsoil limitations operate to restrict root growth by reducing early growth and preserving N for later uptake.

- **Incorporated by Sowing (IBS)** where the urea is top-dressed onto the soil and then incorporated by the sowing equipment. Ideally this should be as close to sowing as possible to avoid losses. This would not be an option for growers using zero tillage.

- **PreSpread Urea (PrS)** is similar to the IBS option but would be some time prior to sowing and could be either surface applied or drilled (pre-drilled). The pre-drilled option for urea was popular with growers when seasons were a little more predictable and urea was a little cheaper.

- **Split Applications (DS, TS)** are often used to spread the risk of an at-sowing option. A proportion, half for Double Split (DS) or a third for Triple Split (TS) of the fertilizer is applied at sowing and the balance applied later in the season. It is usual to time these applications to crop demand and the second dressing is applied spread through the crop at the start of stem elongation (Zadoks stage 31). If a third application is used, this is applied usually at early booting when the flag leaf is extending (Zadoks stage 41).

- **Top Dressing (TD)** is where the product is applied only to the growing crop. This defers the application to a time when seasonal conditions are better known and the condition of the crop can be more accurately assessed. Topdressing is the extension of splitting by deferring all application until stem elongation (usually). Part of the success of late or deferred applications depends on the ability of the crop to carry through until the supplement is applied. Generally, as application timing becomes later relative to crop stage, nitrogen will tend to partition more to protein and less to yield. This is particularly the case when nitrogen is applied after growth stage (GS) 33. In the case of liquids, TD refers to application using flat fan nozzles.

This report compiles the results of three years of field evaluations of a range of timings, formulation and presentations of N to wheat crops in the Wimmera, Mallee and Western District of Victoria.

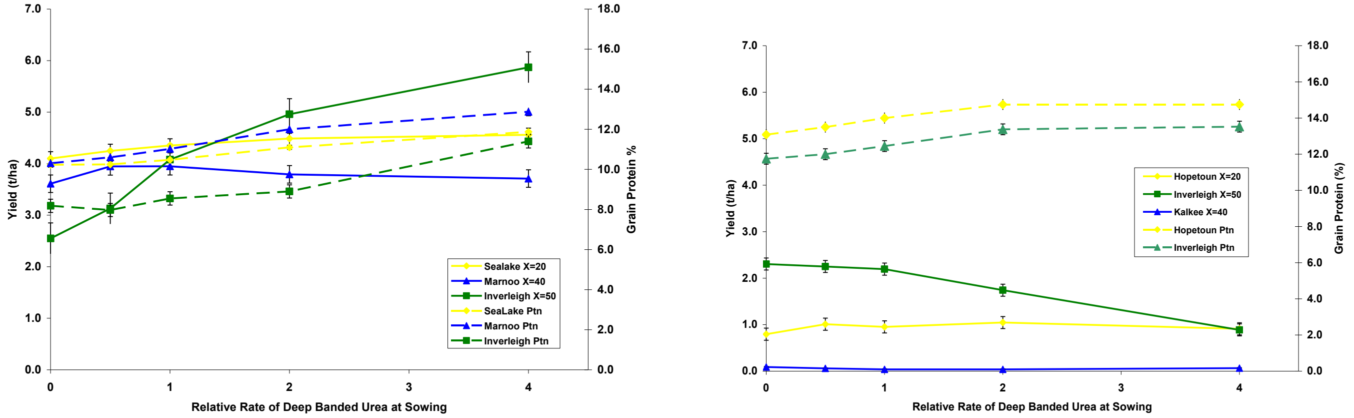
Outline of Experiments

In 2005, 2006 and 2007 field experiments were conducted at a range of locations across Victoria. Table 1 gives a summary of the locations and starting conditions for these experiments:

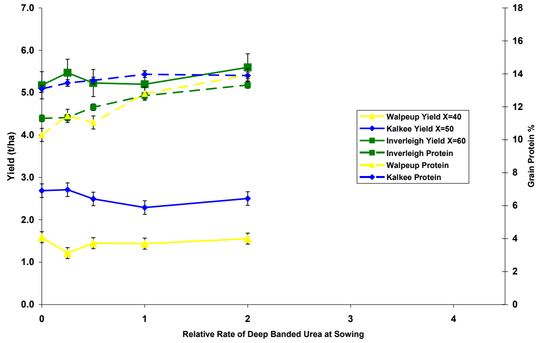
Table 1, summary of site locations, soil types and seasonal conditions for the N experiments

Region	Year	Location	Soil Type	Seasonal Rainfall (Apr-Oct)	Growing Season Decile	Site Mineral N (to 60 cm)	"Normal" N rate	Site Mean Yield (t/ha)
Mallee	**2005**	SeaLake	Calcarosol	234	7	124	20	4.28
	2006	Hopetoun	Calcarosol	96	1	44	20	0.91
	2007	Walpeup	Calcarosol	189	6	62	40	1.48
Wimmera	**2005**	Marnoo	Vertosol	288	4	208	40	3.99
	2006	Kalkee	Vertosol	161	1	63	40	0.06
	2007	Kalkee	Vertosol	250	2	119	50	2.73
Western District	**2005**	Inverleigh	Chromosol	350	5	175	50	3.45
	2006	Inverleigh	Chromosol	233	1	105	40	2.17
	2007	Inverleigh	Chromosol	393	7	87	60	5.23

The experiments at Inverleigh were conducted in collaboration with Southern Farming Systems and the site at Walpeup was on the Mallee Research Station. All other experiments were conducted on farmer’s paddocks. Rather than use standard rates across these environments, a test rate was used (see Table 1) and this was selected in response to expected stored water, seasonal forecast and paddock mineral N status at sowing. Half, double and quadruple standard rates were compared to develop response curves for each site. In 2007, a quarter rate was used and the highest rate deleted. Deep banding of urea at sowing was the standard against which other products, enhancements and delivery strategies were assessed.



A. 2005 B. 2006



C. 2007

Figure 1 Yield and Protein responses over three seasons (2005, 2006, 2007) at each of three sites. No data are presented for protein at Kalkee in 2006 as these data were not collected due to the drought.

The experiments were conducted under difficult seasonal conditions, especially in the Wimmera and Mallee, where decile 1-2 conditions during the growing season were experienced in 3 site/years. As is often the case, soil mineral N's at sowing in the year following these droughts were relatively high and as a result, significant positive grain yield responses ($p<0.05$) to N were seen at 5 of these site/years (Inverleigh 2005, Marnoo 2005, Sealake 2005, Hopetoun 2006 and Inverleigh 2007). The responses to 2X the normal rate deep banded at sowing for each of these sites were generally small, at 9% (0.39 t/ha Sealake), 35% (0.25 t/ha Hopetoun 2006) and 5% (0.18 t/ha Kalkee 2007), although the response (95%) was high at Inverleigh in 2005. Two sites (Kalkee 2006, and Inverleigh 2006) yield significantly declined with added N while there was no response to banded N at Walpeup in 2007. These response curves for grain yield and grain protein are shown in figure 1.

Even though yield increases were recorded about half the sites, grain protein content increased on all 8 sites where proteins were taken, N increased grain protein by an average of 1.0% for the 2X rate.

Over the three years, a range of experimental treatments were compared to the responses above. Those treatments are listed in Table 2, and 12 of these treatments were common in all sites in all years. The post-sowing applications at Inverleigh were not done at GS30 but at GS40.

Table 2, Nitrogen treatments and relative rates for 2005, 2006, 2007 experiments.

Nitrogen Treatment	Rates	**2005**	**2006**	**2007**
Control	0	Yes	Yes	Yes
Urea Deep Banded	X/2, X, 2X	Yes	Yes	Yes
Urea Incorporated by Sowing X	X	Yes	Yes	Yes
Urea Mid Row Banded X	X	Yes	Yes	Yes
Urea + Nitrification Inhibitor Deep Banded X	X	Yes	Yes	Yes
Urea Ammonium Nitrate Deep Banded X	X	Yes	Yes	Yes
Urea 50% Deep Banded, 50% at GS30	X	Yes	Yes	Yes
Urea Top-dressed at GS30	X	Yes	Yes	Yes
Urea Ammonium Nitrate Top-dressed GS30	X	Yes	Yes	Yes
Urea + Urease Inhibitor Top-dressed	X	Yes	Yes	Yes
Urea Deep Banded	4X	Yes	Yes	
Urea + Urease Inhibitor + Zeolite Top-dressed	X	Yes	Yes	
Urea + Zeolite Top-dressed	X	Yes	Yes	
Urea PreSpread	X	Yes	Yes	
Urea + Nitrification Inhibitor Deep Banded	2X	Yes		Yes
Urea 33% Deep Banded, 33% GS30, 33% Z41	X	Yes		Yes
Urea Ammoniun Nitrate 50% Deep Banded, 50% at GS30	X	Yes		
Urea + Nitrification Inhibitor Deep Banded	X/2	Yes		
Urea Poly Coated Deep Banded	X		Yes	
Urea Poly Coated Top-dressed	X		Yes	
Urea (StableU) Deep Banded	X	Yes		
Urea + Organic Complex Deep Banded	X		Yes	Yes
Urea + Organic Complex + Zeolite Deep Banded	X		Yes	
Urea + Urease Inhibitor Top-dressed	X		Yes	
Urea + Zeolite Deep Banded	X		Yes	
Urea + Organic Complex Deep Banded	2X			Yes
Urea Ammonium Nitrate + Nitrification Inhibitor Deep Banded	X, 2X			Yes
Urea Ammonium Nitrate + Urease Inhibitor	X, 2X			Yes
Urea Ammonium Nitrate Deep Banded	2X			Yes
Urea Ammonium Nitrate TD	2X			Yes

A range of growth and development data was collected (Shoot number DC30, Biomass DC30, biomass DC65, biomass DC90, head numbers and grain weights) this report will concentrate on the impact on final grain yield, grain protein and the efficiency with which the strategy evaluated delivered N.

Yield Responses to N Form Delivery and Timing Strategies

The overall results of the various treatments are presented in Appendix Table 1 for the main treatments tested, which is where at least two years of data were available. These tables have been redrawn at Table 3 to compare the effects across sites for the various at-sowing strategies, and as Table 4 to compare the various post-sowing strategies. The yield data from the Kalkee experiment has been excluded from this discussion because of the very low site yield (0.04 t/ha).

Table 3 Comparison of a range of at-sowing N strategies on grain yield for eight site/years tested. Means significantly more than the Urea Deep Banded as shown in green, while those with yields less are shown in pink.

	2005	**2006**	**2007**	**2005**	**2007**	**2005**	**2006**	**2007**
At Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Deep banded	**4.35**	**0.95**	**1.44**	**3.95**	**2.35**	**4.08**	**2.20**	**5.20**
UAN Deep banded	**4.24**	**0.89**	**1.46**	**4.06**	**2.64**	**3.62**	**1.92**	**5.33**
Urea + Nitrification Inhibitor Deep banded	4.40	1.03	1.49	3.88	2.83	3.83	2.16	5.68
Urea + Organic Complex Deep Banded	*	0.99	1.58	*	2.84	*	2.10	5.31
Urea Mid row banded	4.09	0.70	1.40	4.10	2.98	4.03	2.54	5.46
Urea Pre drilled	3.93	0.80	1.43	4.09	2.57	3.40	2.53	5.05
Urea Pre spread	4.36	0.86	*	3.97	*	3.48	2.23	*
LSD (p=0.05)	*0.27*	*0.22*	*0.23*	*0.30*	*0.28*	*0.54*	*0.23*	*0.40*

Table 3 shows that when compared to deep banding at sowing, the addition of a nitrification inhibitor gave a significant yield increase on 2 sites (Kalkee 2007 +20%, Inverleigh 2007 +9%), and that Urea + Organic Complex and UAN gave positive responses on one and two sites respectively, although the magnitude of these responses is generally small. The sites where the nitrification inhibitor was most effective both had relatively high rainfall around sowing with a wet seedbed. Other than that, there were no particularly consistent trends across regions or within seasons for these responses.

Of the post-sowing treatments compared (Table 4), some yield depressions were noted with UAN on three sites, and a significant positive response on one site. The reduced yield was a consequence of burning of the foliage of the crop damage following application and this was worst in 2007 at Inverleigh where yields were halved. Of interest, in 2007 where a urease inhibitor was added to UAN, the reduction was effect was less at this site (UAN + Urease Inhibitor yield = 3.61 t/ha compared to UAN alone 2.66 t/ha), and this “crop safening” effect was probably a result of the slower rate of N release with urease inhibitor. The inclusion of a urease inhibitor at either 3 l or 5 l did not show any differences in yield response in either 2005 or 2007 (data not shown) at any of the sites tested. The poor response at Inverleigh in 2005 was a result of the very late application of the top-dressing treatments.

Table 4 Comparison of a range of post-sowing N strategies on grain yield for eight site/years tested. Means significantly more than the Urea Top-dressed at GS30 as shown in green, while those with yields less are shown in pink.

	2005	**2006**	**2007**	**2005**	**2007**	**2005**	**2006**	**2007**
Post Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Top-dressed @GS30	***4.44***	***0.93***	***1.61***	***4.27***	***2.92***	***2.32***	***2.25***	***5.24***
Urea + Zeolite Top-dressed @GS30	**4.25**	**0.93**	*	**4.07**	*	**3.43**	**2.33**	*
UAN Top-dressed @ GS30	4.16	0.96	1.43	4.02	2.72	2.35	2.25	2.66
Urea + Urease Inhibitor Top-dressed @GS30	4.43	0.82	1.46	4.17	2.68	2.58	2.53	5.79
LSD (p=0.05)	*0.27*	*0.22*	*0.23*	*0.30*	*0.28*	*0.54*	*0.23*	*0.40*

Table 5 Comparison of a range of various timings for N strategies on grain yield for eight site/years tested. Means significantly more than the Urea Deep Banded at sowing as shown in green, while those with yields less are shown in pink.

	2005	**2006**	**2007**	**2005**	**2007**	**2005**	**2006**	**2007**
Post Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Deep banded	***4.35***	***0.95***	***1.44***	***3.95***	***2.35***	***4.08***	***2.20***	***5.20***
Urea Deep banded+ 50% @GS30	4.11	0.98	1.40	3.98	2.83	2.94	2.54	5.69
Urea Deep banded+ 33% @GS30 + 33% @Z41	4.29	*	1.39	4.17	2.77	2.86	*	5.59
Urea Top-dressed @GS30	4.44	0.93	1.61	4.27	2.92	2.32	2.25	5.24
LSD (p=0.05)	*0.27*	*0.22*	*0.23*	*0.30*	*0.28*	*0.54*	*0.23*	*0.40*

Table 5 shows a comparison of treatments where N is deferred either in part or full to GS30. The delayed application of all the N until GS30 produced significantly higher yields at three sites and did not reduce yields at any site when compared to an at-sowing application. Splitting 50:50 the applications did give benefits in three sites and no yield reduction at any site. The negative effects on yield at Inverleigh in 2005 can be attributed to the late application. These results would support the strategy of delaying part or the entire N until later in the season, even on relatively high yielding sites. The caution here is that on those sites the soil N supply was likely to be adequate to carry the crop through to GS30 with little N stress.

Grain Protein Responses to N Form Delivery and Timing Strategies

In general, grain protein responses were more common across this series of experiments than grain yield responses (Appendix Table 2). When comparing the at-sowing options (Table 6) slowing the rate of N release from urea by using nitrification inhibitors was successful on 3 sites. On the other hand, UAN at sowing also provided protein increases over urea deep banded. It is uncertain what mechanism operates under these conditions to improve the protein levels. The only negative impact on grain protein content among the treatments was for the mid-row banded treatment, which suggests that the N applied in this was, in this season, was only of limited availability, and this also applied to all presentations of urea as sowing that were separated further than the deep banding distance from the seed.

Table 6 Comparison of a range of at-sowing N strategies on grain protein content for eight site/years tested. Means significantly more than the Urea Deep Banded as shown in green, while those with protein contents less are shown in pink.

	2005	2006	2007	2005	2007	2005	2006	2007
At Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Deep banded	***10.5***	***14.0***	***11.1***	***11.0***	***13.6***	***8.6***	***12.5***	***12.0***
UAN Deep banded	11.2	13.8	12.4	10.9	13.9	8.4	12.1	12.5
Urea + Nitrification Inhibitor Deep banded	10.8	14.3	12.6	11.2	13.8	8.2	12.9	12.3
Urea + Organic Complex Deep Banded	*	14.0	13.1	*	13.7	*	12.7	12.4
Urea Mid row banded	10.5	13.5	11.2	10.8	13.8	8.7	11.2	12.8
Urea Pre drilled	10.5	14.0	12.3	11.0	13.5	8.2	12.6	12.4
Urea Pre spread	10.7	13.8	*	11.1	*	8.3	12.2	*
LSD (p=0.05)	*0.2*	*0.6*	*0.7*	*0.4*	*0.4*	*0.6*	*0.5*	*0.2*

The post sowing options compared (Table 7) were quite variable from site to site. UAN produced higher protein contents on two of three years at Inverleigh compared to urea, but at the other sites these two products were similar. At Inverleigh in 2005, the wettest year, the addition of the urease inhibitor provided a significant protein effect suggesting a slowing in nutrient release rates until later in the crop development pattern.

Table 7 Comparison of a range of post-sowing N strategies on grain protein content for eight site/years tested. Means significantly more than the Urea Top-dressed at GS30 as shown in green, while those with protein contents less are shown in pink.

	2005	**2006**	**2007**	**2005**	**2007**	**2005**	**2006**	**2007**
Post Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Top-dressed @GS30	***11.2***	***13.0***	***11.6***	***11.3***	***13.3***	***8.5***	***12.1***	***12.1***
Urea + Zeolite Top-dressed @GS30	11.1	13.8	*	11.5	*	9.9	11.7	*
UAN Top-dressed @ GS30	10.7	13.5	11.4	11.3	12.9	11.0	12.3	13.4
Urea + Urease Inhibitor Top-dressed @GS30	11.0	13.0	11.0	11.4	13.5	11.0	11.6	12.5
LSD (p=0.05)	*0.2*	*0.6*	*0.7*	*0.4*	*0.4*	*0.6*	*0.5*	*0.2*

Table 8 Comparison of a range of various timings for N strategies on grain protein content for eight site/years tested. Means significantly more than the Urea Deep Banded at sowing as shown in green, while those with yields less are shown in pink.

	2005	**2006**	**2007**	**2005**	**2007**	**2005**	**2006**	**2007**
Post Sowing	**Sealake**	**Hopetoun**	**Walpeup**	**Marnoo**	**Kalkee**	**Inverleigh**	**Inverleigh**	**Inverleigh**
Urea Deep banded	*10.5*	*14.0*	*11.1*	*11.0*	*13.6*	*8.6*	*12.5*	*12.0*
Urea Deep banded+ 50% @GS30	10.8	12.8	12.5	11.2	13.4	8.2	12.3	12.8
Urea Deep banded+ 33% @GS30 + 33% @Z41	11.1	*	12.1	11.3	13.7	8.5	*	12.2
Urea Top-dressed @GS30	11.2	13.0	11.6	11.3	13.3	8.5	12.1	12.1
LSD (p=0.05)	*0.2*	*0.6*	*0.7*	*0.4*	*0.4*	*0.6*	*0.5*	*0.2*

It would normally have been expected that the later applications of N would have shown a larger protein increase than the at-sowing application but this was only the case on two sites (Sealake 2005, Inverleigh 2007). The reverse occurred at the Hopetoun site (2006) where the late N decreased grain protein.

Marginal Nitrogen Use Efficiency

A major aspect of this work was to compare the efficiency with which each of the strategies and products tested. The Nitrogen efficiency (MNEff) can be defined as the marginal increase in N removed in the grain (product of yield * protein content * 0.5714) per kg of N applied as fertilizer. The conversion of protein to N (0.5714) is the factor considered for cereal grain proteins. This was calculated on a plot by plot basis for the treatments tested using formula 1 and expressed as a percentage.

$$\text{Marginal N Efficiency\%} = 100 * (\text{NRemTreatment} - \text{NRemControl}) / \text{N applied} \qquad \text{Eqn 1}$$

These values indicate how much of the applied N ends up in the grain. No account of straw N was included nor was soil N remaining after maturity considered.

Where *NRemTreatment* and *NRemControl* are the N contents of the grain for each treatment and the mean of the unfertilized controls in the experiments and these data are summarised in Appendix Table 3. There were no significant differences in MNEff at either of the Wimmera experiments, while at the Mallee and Western District sites, there were no consistent effects noted.

Across all sites, the mean N recovery in grain was 20%, which is similar to the international value suggested by Tillman et al. (2002). The mean site efficiency varied from a high of 36% at Sealake in 2005 and 33% at Marnoo in the same year. On all except one site, Deep Banding of urea at sowing was no less efficient than any of the other at-sowing strategies used. The exception was at Inverleigh in 2006 where predrilled N was the most efficient option, although the overall yield response to N was negative at this site.

For the topdressing options, the use of urease inhibitor or zeolite to top-dressed urea was never less than normal urea applications and, in two cases each, these treatments significantly improved MNEff. At Inverleigh in 2006 and 2007, the use of UAN top-dressed resulted in lower MNEff, probably due to the degree of crop damage seen with this treatment, although there were no adverse effects at six other sites tested where UAN was as effective at top-dressed urea.

It would seem though that of the at-sowing options, there are no reliably more efficient techniques that Deep Banding urea. There were no large differences with different timings (split or late applications) with urea, and if applied as top-dressed urea the use of a urease inhibitor would seem to provide an improved MNEff. The choice of strategies within this general group then becomes one that relates to risk and cost. Where there are no direct and reliable benefits, the efficiency enhancers selected or the application strategy used would have to be done at the same cost as Deep Banded Urea at sowing. If there are reliable benefits either as improved yield or reduced fertilizer costs, these costs should be greater than or equal to the additional costs incurred.

Table 9, Marginal increase in nitrogen recovery (MNEff%) in grain for selected treatments across 8 experiments. Relative Efficiency (RelEFF) is the mean marginal N recovery for each agroecological zone relative to deep banding urea at sowing. Extra N required is the amount of N that would be required to give an expected response similar to deep banding at sowing. LSD (p=0.05) = 21 for interaction values in the table body.

	Marginal increase in Nitrogen recovered in grain %				**Extra kg N required**
WESTERN DISTRICT (N rate = 50 kg N/ha)	**Inver05**	**Inver06**	**Inver07**	**RelEFF**	
Urea Deep Banded	48	1	22	1.0	**0**
Urea Pre Spread	27	21	12	0.9	**6**
Urea Mid Row Banded	48	8	34	1.3	**-11**
Urea 50% Deep : 50% Top-dressed GS30	10	18	42	1.0	**-1**
UAN Deep Banded	32	-16	25	0.6	**39**
Urea + Nitrification Inhibitor Deep Banded	36	3	33	1.0	**-1**
Urea Top-dressed GS30	-6	2	15	0.2	**50***
Urea + Urease Inhibitor Top-dressed GS30	25	11	40	1.1	**-4**
UAN Top-dressed GS30	16	4	**	0.4	**50***
WIMMERA (N rate =40 kg N/ha)	**Marn05**	**Kalk06**	**Kalk07**	**RelEFF**	**Extra kg N required**
Urea Deep Banded	27	*NO DATA*	-7	1.0	**0**
Urea Pre Spread	30		2	1.6	**-15**
Urea Mid Row Banded	30		22	2.6	**-24**
Urea 50% Deep : 50% Top-dressed GS30	32		11	2.2	**-21**
UAN Deep Banded	31		5	1.7	**-17**
Urea + Nitrification Inhibitor Deep Banded	27		11	1.9	**-19**
Urea Top-dressed GS30	47		17	3.2	**-27**
Urea + Urease Inhibitor Top-dressed GS30	45		6	2.5	**-24**
UAN Top-dressed GS30	35		6	2.0	**-20**
MALLEE (N rate = 20 kg N/ha)	**SeaL05**	**Hope06**	**Walp07**	**RelEFF**	**Extra kg N required**
Urea Deep Banded	33	26	11	1.0	**0**
Urea Pre Spread	41	8	7	0.8	**6**
Urea Mid Row Banded	10	-8	-1	0.0	*****
Urea 50% Deep : 50% Top-dressed GS30	23	21	7	0.7	**7**
UAN Deep Banded	51	18	9	1.1	**-1**
Urea + Nitrification Inhibitor Deep Banded	50	38	12	1.4	**-6**
Urea Top-dressed GS30	71	16	11	1.4	**-5**
Urea + Urease Inhibitor Top-dressed GS30	59	4	-1	0.9	**3**
UAN Top-dressed GS30	23	21	1	0.6	**11**

* Value fixed at the whole N rate applied

** This data point excluded due to treatment crop damage.

In an attempt to unify these data, the data set with common treatments were analysed with site/year and treatment as the main effects. These data are summarised in Table 9 which has, for each site/year the mean MNEff. Across all options considered, there were no clear and consistent practices that gave the most efficient uptake of nitrogen at all sites in all years. In a combined analysis of variance for the common treatments across the eight site years, the P value for this source of variation was 0.096, which provides only a low level of confidence that the differences were real across all sites and years. There was a significant interaction though (P=0.001) between site/year and treatment.

The relative efficiency of each treatment within each agroclimatic zone is also shown, with these treatments compared to deep banding of straight urea at seeding. A relative efficiency of 0.9 (for example) indicates that this treatment had – on average for that zone, an MNEff 90% of deep banding. From that, it could be deduced that to get the same N response, 10% more N would be needed, although there is a caution here that not only are these responses very variable from year to year but the response itself is not likely to be linear. Generally, MNEff is higher for lower N rates and declines with increasing rates. Despite those two significant features of response functions, a general view of the comparative value of each treatment can be made.

The final column in Table 9 shows the added N required (positive value) or N that could be saved (negative value) relative to deep banding. This N is relative to the actual N rate used for each agroecological zone and so the amounts potentially saved are larger where higher rates were used in the Western District zone, and much lower than in the Mallee.

From Table 9, the different strategies saved very little N in the Mallee but in the Wimmera, there were savings of between 30 to 50% of the applied N. This may be an artefact of the poor MNEff of Deep Banding at the Kalkee site in 2007. At the Western District sites, the top-dressed treatments (both UAN and urea) showed a low efficiency and so had little benefit relatively to deep banding at sowing. However, if the urease inhibitor was included, there was an improved efficiency over deep banding as well as little crop damage, plus the investment in N was deferred until later in the season.

It should be noted that these efficiencies are only for a single crop year and take no account of annual N carryover into the next crop.

Economic Summary of the N Strategies

The achieve an improved economic return from the use of different N strategies, the additional costs involved in deploying the strategy would need to be less than the either the extra grain yield/protein returned by using the same rate of N, or by the reduction in fertilizer used to give the same yield. The data analysed across all sites in these experiments can be used as case studies in the returns from various strategies.

Considerations in making the decision about a particular approach would involve:

1. Additional capital costs for transport, storage and application of products. For all the solid products, application could be done either at sowing using a seeder with deep banding and three tanks (grain, P source, N source). Additional costs incurred would be for adapting the seeder to mid row banding or to apply fluids (UAN). For the UAN option, storage and transport costs would also be somewhat higher due to the need for tanks, nurse tanks, pumps, etc. It is extremely difficult to put a value on this on an average basis, but and earlier analysis by Birchip Cropping Group suggested that there would be an additional $20,000 capital investment to adapt equipment to deal with fluid fertilizers. In CSP320, which investigated mid-row banding, it was estimated that existing air-seeders could be adapted for about $10,000, which included moving to wider rows. These values could be depreciated over 5 years (20%) and spread over 500 ha, giving a value of $8/ha for fluids and $4/ha for mid-row banding.

2. Additional operating costs would be incurred if the application is not just at sowing. Split or presowing applications will require an extra pass over the paddock. Presowing working and fertilizer application would be at about the same cost as sowing (~$10/ha). The application of fertilizers in-crop by topdressing would be similar (~$10/ha).

3. Effect on application efficiency is another factor to consider. Where fertilizer application is moved away from seeding, there are benefits in the efficiency of sowing as fewer seeder fills will be needed and so less stops to seeding will occur. Post-sowing, UAN application could be applied with crop protection chemicals which would be a significant improvement in efficiency even over post-sowing topdressing of solids.

4. Additional product costs will be incurred where enhancers (urease inhibitors, nitrification inhibitors, zeolite, humic acid) are used. This effectively increases the price of the fertilizer. The costs for these enhancers varies considerably from season to season, as does the cost of both urea and UAN.

These considerations are summarised in Table 10 but the actual financial benefit associated with employing any particular strategy is much more complex than this table suggests. It is extremely difficult to put a value on this on an average basis mainly because of the scale at which different cropping properties operate and the difficulties in including capital costs into comparisons that with enterprise scale and expertise of the growers.

Therefore, a full economic analysis should be done on a case-by-case basis with due consideration given to points 1 to 4 above and summarised in Table 10, balanced against the potential savings in N suggested by the field experiments summarised in Table 9.

Table 10, Considerations for various strategies for the application of N to field crops as compared in these experiments.

Treatment/Strategy	Equipment	Added Operating Cost	Sowing Efficiency	Extra Product Cost
Urea Deep banded	Seeder with deep banding	nil	0	Nil
Urea Pre spread	Seeder with deep banding	Extra operation pre-sowing	+++	Nil
Urea Mid row banded	Seeder adapted to mid-row banding	nil	0	Nil
Urea + Organic Complex	Seeder with deep banding	nil	0	Supplement
Urea + Nitrification Inhibitor Deep banded	Seeder with deep banding	nil	0	Supplement
UAN Deep banded	Seeder with fluid applicator	nil	0	UAN rather than urea
Urea 50% Deep banded + 50% @GS30	Seeder with deep banding, plus ground or air spreading	One topdressing	+	Nil
Urea 33% Deep banded + 33% @GS30 + 33% @Z41	Seeder with deep banding, plus ground or air spreading	Two topdressings	++	Nil
Urea Top-dressed @GS30	Ground or air spreader	One top dressing	+++	Nil
Urea + Urease Inhibitor Top-dressed @GS30	Ground or air spreader	One top dressing	+++	Supplement
Urea + Zeolite Top-dressed @GS30	Ground or air spreader	One top dressing	+++	Supplement
UAN Top-dressed @ GS30	Ground spraying	Done with crop protection application	++++	UAN rather than urea

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