



4R Approach to Nutrient Best Management Practice

NITROGEN APPLICATION on Wheat in Southeastern Australia

Summary – The Elements of N Best Management

- Base N rates on results from soils analyses
- Select products and techniques that will deliver the best efficiency
- Develop N management plans in response to seasonal conditions

Nitrogen and Crop Production



Nitrogen and P are usually the two most limiting nutrients for grain production in southeastern Australia, although attention should also be paid to K, S, Zn, and various trace elements to ensure balanced crop nutrition.

Other than when supplied by fertilisers, N is largely supplied by mineralisation from organic sources in the soil. Mineralisation is most rapid with warm and moist soils, especially if cultivated. Legumes make significant contributions to this pool although the net N contribution of pulses such as peas and lupins can also be important. On average, good pulse crops or pastures will fix enough N from the atmosphere for one or two non-legume crops, depending on the demand from the non-legume. With a decline in the area of pasture-legumes and the swing to more intensive cropping systems, the use of fertiliser N sources has become more common and

management of this input is a large part of growing successful crops.

Nitrogen is removed from the soil in agricultural products and there can be other losses from both the plant and soil so that around half of the N supplied can be recovered in grain.

Volatilization of N sources to the gas ammonia occurs on all soils irrespective of pH and is highest when N is surface applied and there is no rain to wash the N into the soil. Leaching of N beyond the root zone occurs under high rainfall and especially on light textures soils. When large amounts of carbon are added to soil, some N can be immobilized back into organic sources, including crop residues and soil organic matter. Under waterlogged conditions, nitrate can be converted to nitrous oxide (a potent greenhouse gas) and as N₂ which can be lost back to the atmosphere. Peak nitrous oxide losses occur at around 70% water-filled pore space, and taper off in favour of N₂ losses in saturated soils. The relative magnitude of these processes depends on the soil and climatic conditions, but N management should aim to at least balance input and output over time.

Our research indicates that there are no universal best bets for the 4Rs for N management, with the best source being affected by the timing and placement of the fertiliser N source. The strategy selected for supplying N will vary from year to year and across—and even within—paddocks and soil types.

Collated by Dr. Rob Norton, Director, IPNI Australia/New Zealand Program, on behalf of the project collaborators and supporters.

International Plant Nutrition Institute website: <http://anz.ipni.net>

Project Collaborators:

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Note:

Use of the monetary symbol \$ refers to Australian dollars.

Abbreviations:

N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc.



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The Global 4R Nutrient Stewardship Framework

Fertiliser best management practices (BMPs) can be aptly described as the application of the right source (or product) at the right rate, right time, and right place. Under the Global 4R

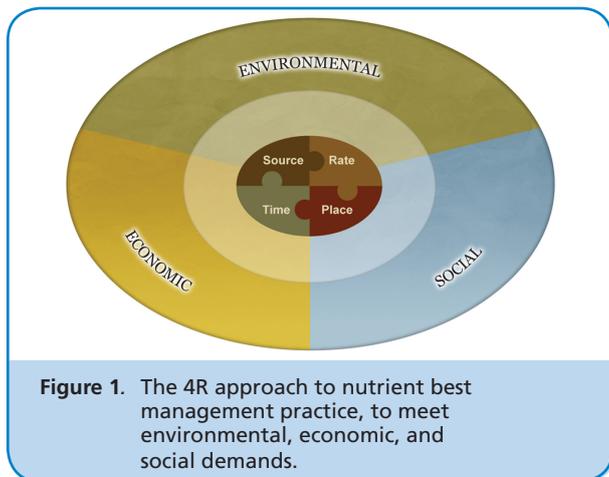


Figure 1. The 4R approach to nutrient best management practice, to meet environmental, economic, and social demands.

Nutrient Stewardship Framework, the four “rights” (4Rs) comprehensively convey how fertiliser applications can be managed to achieve economic, social, and environmental goals. The framework ensures that fertiliser BMPs are developed with consideration of the appropriate focus on all three areas of sustainable development (see **Figure 1**).

The Right Source of N

The selection of the right product depends on when the N is to be applied and also the soil and environmental conditions around the timing of application. Because N is mobile in the soil, for an at-sowing application, selecting sources that are initially slow to release N can be of value to prevent leaching and volatilization, and so better match the time of nutrient supply to the time of nutrient demand in the crop.

There are several common N products available to growers and these can be compared on the basis of cost per unit N delivered to the field and the efficiency with which the source provides the nutrient to the crop. At present, anhydrous ammonia is not commercially available in South Australia and Victoria.

Urea (46% N) is still the dominant N source for cereals

in southeastern Australia. It is generally the cheapest source of N at present, and can be applied at sowing or top-dressed during crop growth. As an at-sowing application, even moderate rates of urea are likely to cause damage to germinating seedlings and so it should be banded to the side and/or below the seed row if rates of more than about 20 kg N are planned. Surface-applied urea ... applied before sowing or at sowing, and then incorporated ... is generally of low efficiency.

Some growers have dissolved urea and applied it as a liquid, but this does little to improve efficiency. Urea is prone to losses through ammonia volatilization, particularly if surface-applied and if rain does not occur within a few days after application. Monoammonium phosphate (MAP, 10% N, 22% P) and diammonium phosphate (DAP, 18% N, 20% P) are significant P sources at sowing. However, at normal P rates, they do not usually supply adequate N for the whole crop. There has been considerable interest in the use of fluid N sources, especially urea ammonium nitrate (UAN, 32% N w/w). Use rates for fluid N sources should be less than 20 L/ha unless “dribble bars” or similar equipment is used. Ammonium sulphate (21% N) can also be of use, particularly where S deficiency is suspected and on alkaline soils.



Urease treated urea (left) and normal urea (right). Photo courtesy of Incitec Pivot.

A major problem with urea is that it can lose N due to ammonia volatilization and/or denitrification after application. Losses of ammonia can also occur when ammonium sulphate is applied to soils with high levels of free lime. Ammonia losses occur on both acid and alkaline soils and tend to be high unless rainfall occurs soon after topdressing. In this case, “urease” inhibitors (e.g. nBTPT) can be of value. This is an enhancement added to urea which





reduces the rate at which ammonia is released for some time after application.

Using a nitrification inhibitor (e.g. DMPP) slows the conversion of ammonium to nitrate and can reduce losses due to leaching and denitrification, so that some N is preserved for the crop rather than lost to the environment. This can be of particular value for applications to wet soils.

Organic N sources, such as piggery bedding litter, can supply N to crops. But because of the low nutrient density (usually less than 1% fresh weight) the use would be restricted to areas close to the sources of these materials. These materials can be surface-applied, but unless incorporated, a significant proportion of the N could be lost as ammonia. Organic materials can also take some time to mineralize the N.

Our research showed some small differences among a wide range of N sources when applied at the same time and with other nutrients balanced. However, the efficiency differences led to potential savings in N use that were generally around 10%. This saving would need to meet the added cost of the different sources, including added transport, storage, and application costs for specialized products.

The Right Rate of N

Of all issues for N, selecting the correct rate is the most important. Balancing N with water is critical as too much can reduce grain size while too little constrains yields. Nitrogen is expensive and its use should be directed to paddocks where the investment can have the most impact. These are likely to be paddocks with a low frequency of legumes and that have shown consistently low grain protein contents. Take care on paddocks that have subsoil constraints, and where leaching or water-logging is likely to occur. In those situations, use a starter N rate and top up as the crop grows.

To determine the right rate, a good assessment needs to be made of the current and future N status. A deep soil

N test (to rooting depth, usually 60 cm) taken as close to sowing as possible will give an assessment of the at-sowing status. Samples should be taken across the paddock or area of the paddock to be managed if zoning is to be used. Depth, timing, and handling of soil samples should be done according to the guidelines provided by the soil testing service used.

Mineralisation during the growing season depends largely on having adequate soil moisture and warm soils to encourage microbial degradation of organic materials. Soil organic carbon levels (usually top 10 cm) give an indication of the potential for mineralization, although the form of the organic matter can vary so that N supply can differ even with the same organic matter level. Some consultants use an in-crop estimate based on one sixth of the organic C level (%) multiplied by the seasonal rainfall in mm to give mineral N in kg N/ha.

The best rate of N will be one that matches the crop demand, even with low crop prices and moderate fertiliser prices. A 2:1 price ratio of grain to urea (for example) still gives a good return to fertiliser investments, and this investment can be progressively rolled out as the season develops. A paddock with 40 to 50 kg N/ha in the top 50 cm is able to sustain the crop until stem elongation starts,





Table 1. Balance sheet approach to estimating crop N application rate:

Supply Estimate	Demand Estimate	Balance to be met:
Soil mineral N at sowing = 50 kg N/ha 1% OC and 240 mm rainfall = 40 kg N/ha <i>N supply = 90 kg N/ha</i>	Yield Potential – 3 t/ha Based on soil water & seasonal rainfall estimates. N demand of 45 kg N/t of grain with 23 kg N/t of grain removed. <i>N demand = 135 kg N/ha</i>	 N required to support a 3 t/ha wheat crop = 45 kg N to be applied.

150 to 180 kg N/ha. But if the yield potential is higher – say 5 t/ha – the N demand will be 250 to 300 kg N/ha.

This yield uncertainty then creates a big uncertainty in the N demand.

To deal with the uncertainty of yield potential, growers can supply N as the season rolls out and the yield

thus providing time to make further investments or not as the season unfolds.

There are good N fertiliser decision support tools that use crop models driven largely by stored and seasonal water supply to predict yield. From this yield potential, full season N demand for the crop can be estimated. The difference between demand and the supply can be filled with topped up fertiliser. An example of a balance approach based on potential yield is shown in **Table 1**.

So, the right N rate is largely a function of the water-limited yield potential and the nutrient demand that this yield requires, less the supply from stored and mineralized N pools during the crop phase.

Because grain yield potential and N removal is driven by water supply, uncertainties in rainfall make for uncertainties in N demand. A wheat crop will remove around 23 kg N per tonne of grain, although this varies with grain protein content. With N use efficiency of around 40% to 50%, N demand will be between 50 and 60 kg N per tonne of grain. If the expected yield is 3 t/ha, then N demand will be around

potential develops. Provide adequate N at seeding to get the crop through to a time when the first topdressing can be undertaken, which is often at the end of tillering. At that time, if rainfall forecasts and seasonal predictions are favorable and/or there is adequate soil moisture, then assess the yield potential and match N demand to the revised yield.

A second major uncertainty is the amount of in-season mineralisation that can be expected. Mineralisation is driven by water, warm temperatures, and the availability of good quality organic materials. Some advisors estimate in-season mineralisation as the product of seasonal rainfall (in mm) and one sixth of the soil organic carbon (SOC) content. This approximation assumes that water will be available evenly over the growing season and the SOC/organic matter is all able to be mineralised. In some soils, SOC test levels can be raised due to presence of finely divided charcoal, which was derived from the long-term burning of old native grasslands. Techniques to refine the amount of labile or reactive organic matter are presently being developed, which will assist with improving the estimates of in-crop mineralisation.





"Dribble bars" used to apply UAN in-crop

The Right Time for N

There is some evidence that having some N near the P source can improve root access to both nutrients, so having some N at sowing can be of value. There is probably adequate N in MAP to provide this synergy, but unless soil stores and mineralization can meet the entire N demand, added N will be required as indicated by the yield potential. Provided there is around 40 to 50 kg N/ha at sowing in the profile, this will carry the crop through until stem elongation begins. But the period of peak demand occurs as the stem and head grow. Top-dressed N should be considered to meet that demand. In our experiments, we have seen no disadvantage to withholding a full N rate until this period of high demand. In fact, restricting the crop supply could provide some benefits if there is a dry finish to the season. Top-dressing is largely a risk management tool that allows growers to roll out added N as the season unfolds.

In recent research, deep banding the urea at sowing was as efficient as any of the other at-sowing delivery strategies such as UAN banded, urea mid-row banded or urea incorporated by sowing. Pre-applying urea was less effective in some cases than the other strategies, as well as requiring an additional pass over the paddock.

Ideally, urea would be top-dressed just prior to a rainfall event, but where this is not practical due to few fronts and large areas, using urease inhibitors can help preserve some N and increase the efficiency of N application or decrease the amount applied. Under wetter conditions, the use of nitrification inhibitors or other controlled release sources to preserve N for later crop uptake should be considered.

There is interest in UAN applied in-crop along with crop protection chemicals, subject to label restriction. However, care should be taken with using UAN, as the label rates indicate that crop foliar damage can occur with high rates and using flat fan nozzles. Dribble bars or hollow cone nozzles with the swirl plate removed are better options to avoid foliar burn. Higher rates of UAN can be safely applied with flat fan nozzles under cooler conditions, but consult with an agronomist for advice specific to particular situations.

Plant analyses for N can be a useful guide to the need for additional N, although the interpretative values for whole plant N or leaf N or sap nitrate are closely related to crop stage. Interpretation of tissue tests requires a view of the season as it unfolds as well the conditions leading up to sampling. As with soil sampling, plant sampling requires careful selection of samples across the area.

Post-sowing N application can occur up until the start of grain filling, but generally the earlier applications give more yield benefit while later applications can increase grain protein. Despite that general effect, it is not often worth applying N late in crop growth unless a grain quality grade change (and so large price change) is expected.



Wheat plant at mid- to late-tillering, showing the main stem and two tillers, with a third tiller emerging. This plant has three shoots.

It is important to monitor the crop during early growth in particular. Using in-field test strips are a good way to see if there is a response. Leaving a nil N strip by turning off the fertilizer delivery at seeding may be useful, as can adding extra N early in the crop growth over a strip in the paddock. These strips will help to see if there are responses likely in the paddock.

Wheat responds to N supply by adding or losing tillers (or shoots), so that counting shoot density has been proposed as a crop monitoring tool. Optimum shoot numbers per square meter will be around the annual rainfall for the region. In a 300 mm rainfall zone, 300 shoots per square meter is optimal, while in a 500 mm rainfall zone, 500 shoots per square meter would be the target. If densities are lower than these targets at mid- to late-tillering, then additional N could show a response.



The Right Place for N

Nitrogen in its nitrate form is quite mobile and will move with water through the soil, so generally where there is water moving, mineral N will move with it. The main issue with N placement is avoiding root damage by placing the fertiliser away from the growing root tips. Urea produces ammonia while other N fertilisers can have a significant salt effect, so that when placed even at moderate rates near to seed of susceptible crops, seedling damage can occur. While wheat is relatively tolerant, other crops such as canola should not have more than about 10 kg N/ha in the seedrow. With high rates and wide rows, the problem becomes even more significant but now most seeding equipment is able to place N fertiliser away from the seed, either to the side or below and to the side. Fertiliser can also be placed between alternate rows – termed mid-row banding, which slows the rate of N release until later in the crop's life. This can improve fertiliser use efficiency, although some machinery modification is required.

Similarly, fluid N sources applied in-furrow will require added costs for storage and delivery systems compared to granular fertilisers.

Although there are few experiments to test the method, auto-steer and precision guidance systems could enable fluid or granular N sources to be drilled inter-row well after the crop is sown. This would protect the fertiliser from volatilization and so should increase N use efficiency.

Can you make money from N fertilisers?

To 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 either the extra grain yield/protein returned by using the same rate of N, or by the reduction in fertiliser used to give the same yield.

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 an earlier analysis by Birchip Cropping Group suggested that there could be up to an additional \$20,000 capital investment to adapt equipment to store, transfer, and apply with fluid fertilisers. In a GRDC and CSIRO research project investigating mid-row N banding in Mallee, 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. But every situation is different and growers need to make their own calculations for their circumstances.

2. Additional operating costs would be incurred if the application is not just at sowing. Split or pre-sowing applications will require an extra pass over the paddock. Pre-sowing working and fertiliser application would be at about the same cost as sowing (~\$10/ha). The application of fertilisers in-crop by topdressing would be similar (~\$10/ha).
3. The effect on application efficiency is another factor to consider. Where fertiliser 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 can 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 fertiliser. The value of these enhancers varies considerably from season to season, as does the cost of both urea and UAN.

These considerations are summarized in **Table 2**, 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. For growers with larger areas, these costs would be lower on a per hectare sown basis. Similarly, machinery operating costs, as suggested in point 2 above vary with 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 summarized in **Table 2**, balanced against the efficiency gains and N savings expected with enhanced efficiency products.

Table 2. Considerations for various strategies for the application of N to field crops.

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 + 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 top-dressing	+	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
UAN top-dressed @ GS30	Ground spraying	Done with crop protection application	++++	UAN rather than urea



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