# *Improving nutrient use efficiencies with foliar applied nutrients*

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### *Introduction*

Nitrogen [N] inputs and subsequent soil interactions are notoriously reactive with significant amounts of applied N being lost from the system via volatilisation, denitrification or leaching[1]. In fact, data from over 800 experiments has shown that on average, only 51% of the fertiliser-N applied to cereal crops was recovered by plants[2] [in some instances some of those efficiencies were as low as 20% utilisation]. Although phosphorus [P] is nowhere near as volatile as N, it is still highly reactive – with applied inputs readily adsorbing onto soil surfaces and locking up in organo-mineral and cation-anion complexes. More than 80% of P applied as fertiliser can become unavailable for plant uptake shortly after application[3] resulting in appallingly low P-fertiliser use efficiencies of 10-15%[4]. Among many strategies that can play a role toward improving nutrient use efficiencies [NUE], foliar application of plant available nutrients has emerged as one potential tool that can play an important role in integrated nutrient management.

### *Moving beyond a spray and pray approach*

Soil applied nutrients are of course the most common and often the most effective means to supply nutrients to plants; however, there is great potential for foliar fertilisation to compliment and augment a good soil health improvement strategy – particularly in relation to the role of foliars substituting the volatility and inefficiencies of soil applied nutrients. That said, responses to foliar sprays can also be variable and an understanding of the factors that influence the uptake, translocation and metabolism of leaf applied solutes can help overcome the 'spray and pray' dilemma. There are many important factors that optimise the response from a foliar spray and this is no doubt the scope of an entire article on itself where much more detail could be explored, but for now I have summarised a few key considerations in Table 1.

***Table 1: Considerations for a top Foliar Response***

| Category | Strategy | Notes |
|---|---|---|
| **Formulation** | *Adjuvants* | *Modify the activity of the input or the properties of the spray solution.* |
| | *Chelation* | *Always combine a carbon source to chelate or complex mineral nutrients – molasses, fulvic acid, kelp etc.* |
| | *Solubility* | *Inputs must be water soluble for optimum diffusion.* |
| | *Spray EC* | *1.5-3 mS/cm is optimum.* |
| | *Spray pH* | *Generally, around 6 is ideal however specific pH's for specific inputs exist.* |
| | *Wetter Stickers* | *Increases adhesion time and rainfastness.* |
| **Application** | *Adhesion* | *Longer adhesion yields more time for nutrient diffusion.* |
| | *Droplet size* | *Fine mist for maximum leaf coverage, match to wind conditions also.* |
| | *Pressure* | *Too little or too much spray pressure can miss the leaf target. Ensure both top and underside of leaves are covered.* |
| | *Runoff* | *Leaf should be covered in spray solution up to the point of runoff.* |
| **Crop** | *Crop Stage* | *Young leaves [3-6 leaf stage] are particularly responsive and applications during reproductive stages are especially good for yield enhancement.* |
| | *Leaf Area Index* | *More canopy is ideal for interception of the foliar spray.* |
| | *Leaf Surface* | *Waxy leaves are less penetrable, include a spray oil to prevent beading and increase surface spread [refer Figure 1].* |
| | *Plant Age* | *Maturing plants are less responsive.* |
| **Environment** | *Drought* | *Foliar sprays help overcome early drought stress however photosynthetic activity declines under more severe stress thereby limiting utilisation of foliar inputs.* |
| | *Humidity* | *Higher humidity prevents drying and precipitation of applied solutes.* |
| | *Light* | *Daylight stimulates the opening of stomata.* |
| | *Temperature* | *Stomata close in higher temperatures, limits absorption.* |
| | *Time of Day* | *Morning and afternoon are best.* |

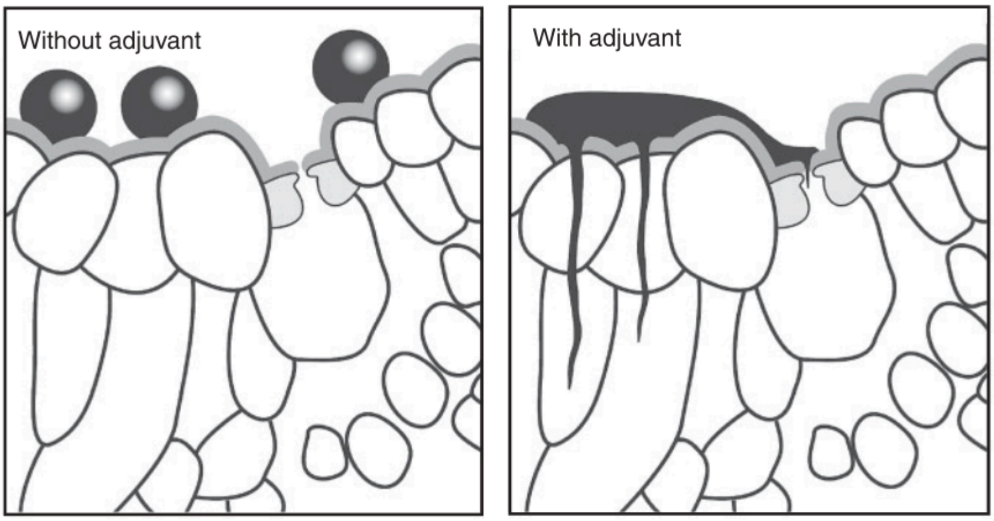


***Figure 1: Wetter/stickers, spray oils and adjuvants improve spreading and surface area coverage hence increase penetration of spray solutions [Source: [5]]***

Foliar applied nutrients can be absorbed by the plant through either the stomata or via micro pores in the cuticle layer. The waxy cuticle can certainly be a repellent to absorption, but solutes can still diffuse through and consequently, due to differences in cuticle thickness, different plant species can absorb foliar nutrients easier than others [ie waxy leaves absorb less easily]. Unlike in the roots, this diffusion through the cuticle is primarily a passive process meaning it is driven simply by a concentration gradient – that is, a high concentration of nutrients externally will diffuse into the internal leaf tissues if they are present at a lower concentration. Consequently, the spray solution strength and electrical conductivity are particularly important considerations – not too much, not too little. Some of the pros and cons of foliar applications are additionally summarised in Table 2.

***Table 2: Pros and Cons of Foliar Feeding***

| ***Pro*** | ***Con*** |
|---|---|
| *Increased nutrient use efficiency.* | *Benefits of foliars are not as long lasting as soil applied nutrients, follow up application often required.* |
| *Less nutrient losses via soil.* | *More units/ha can be applied via soil. Foliars have an upper limit.* |
| *Faster absorption and assimilation than soil applied inputs.* | *Possibility of burning.* |
| *Rapid correction of deficiency symptoms.* | *Variable responses.* |
| *Effective on plants with impaired roots [drought, salts etc].* | *Weather dependent – wind, rain, temp, humidity.* |
| *Micronutrient needs can be met with foliars and with more uniform application.* | *Macronutrient needs cannot be met solely with foliars.* |
| *Tactical top up of nutrition based on prevailing weather conditions.* | *Higher risk of upfront fertilisation if season is dry and low yield potential* |
| *Particularly effective for soil immobile nutrients.* | |
| *Can supply additional nutrition during high demand, peak growth periods.* | |

***Foliar N***

Although the emphasis on the ionic forms of nitrogen – ammonium [$NH_4^+$] and nitrate [$NO_3^-$] – as the primary sources of N for plant nutrition has dominated our thinking for N management, the reality is that plants can also and as easily absorb and utilise organic forms of nitrogen such as urea or amino acids through both their roots and shoots. In fact, plants have a specific absorption channel exclusively for the urea molecule[6] – evolutionarily speaking, they wouldn't contain the precise uptake mechanism for urea if they couldn't then make good use of it. Foliar applied urea in some instances has demonstrated as low as 5-10% volatilisation thereby hugely improving NUE as compared to soil applied urea although this efficiency gain is not always the case with foliars[7]. Urea is a particularly effective source of N to consider for foliar application, as it is highly and rapidly absorbed across the waxy cuticle – urea is the easiest form of artificial N for the leaves to absorb followed by ammonium, then nitrate. Additionally, having a lower salt index than ammonium nitrate or ammonium sulphate means urea is less likely to scorch foliage[8]. Because urea is so easily absorbed, it is often used as an adjuvant itself and combined with other inputs to aid in their absorption – this is particularly true with trace elements[9] and herbicides[10]. On top of this, the molecular structure of urea [known as an amide] means that once absorbed, it is efficiently converted into amino acids, then onto proteins. The problem with urea, lies with the fact that we primarily apply it not directly through the plant leaves, but via soil application. Once that urea is applied to the soil and hence exposed to the biotic and abiotic factors of the soil, it no longer remains in that amide form and ultimately, it is either: *[i]* volatilised off as ammonia gas [$NH_3$], *[ii]* hydrolysed into the ammonium [$NH_4^+$] form, and then *[iii]* converted into the nitrate [$NO_3^-$] form by nitrifying bacteria. As you can see then, soil applied urea often ends up entering the plant back in the ionic nitrate form which once absorbed by the plant, then utilises more energy to turn that $NO_3^-$ into proteins. Additionally, this process is dependent on the essential trace mineral molybdenum [Mo] which as part of the nitrate reductase enzyme catalyses this conversion. If Mo is deficient in the plant, nitrates will build up in leaf tissues as they are unable to be converted into amino acids and proteins.

So, what does all this mean for in field application? As always, there are many variables that influence the practical translation of principles and the complexity of this is exemplified in Table 1. A look into the literature on urea application yields a range of conditions, application rates and successes so it becomes not quite so clear cut. That said, the trend is certainly that late season N foliars are much more effective toward building protein and yield than earlier applications [although earlier applications can still be very useful if addressing an early N deficiency]. Much of the trial work highlights success with foliar urea at rates of up to 40 kg N/ha[11] [which equates to over 80 kg/ha of urea!]. Although rates this high appear feasible and beneficial in some instances, this seems rather high to me personally and considering the point of this article is to understand how to use foliar sprays to improve efficiencies and hence dial down on inputs, I'm more interested in how low we can go, not how high can we go? Consequently, there is also a body of literature highlighting great success with applying urea solutions of 3-7% particularly at the 4%[12] and 5%[13] concentrations [4 or 5 kg urea per 100 L of water for example]. I'm aware of some producers going as high as 20 kg urea per 100 L of water however again, although this is feasible, I think it is preferable to apply around the 4-10 kg/ha mark. Foliar applied urea has also been shown to have a positive impact even on legumes and a 2% solution has proven beneficial in chickpeas[14]. Regarding timings, it appears the preferred crop stage to apply urea on cereals is around anthesis and the 2 weeks that follow, on canola is mid to end of flowering and on pulses it is post flowering at pod set. Lastly, a spray solution pH of 6.5 is considered ideal for optimum absorption.

***A quick word on Nickel***

I'd hedge a bet there are many farmers around the world who are not aware of the essentiality of Nickel [Ni] which is the most recently classified element considered essential for plant growth. This is rather surprising considering its critical role in plant metabolism. Ni has but only one single function for plant growth currently known, which is part of an enzyme called urease. As you might guess from the name, urease is the enzyme that breaks apart the urea molecule liberating the N so that it can be converted ultimately into amino acids and proteins. This means that all the benefits that urea can potentially bring to plant growth, cannot be fully realised without this critical supporting trace mineral that catalyses urea conversion. Of all the research quoted above on urea as a foliar, none of these experiments included Ni and if by chance it was a limiting factor in any of those trials, then the protein and yield gains would have been held back [note that tiny amounts of Ni are required by plants and in many instances soil Ni supply may be more than adequate]. In instances where Ni may be limiting and urease activity is consequently low, urea can build up to toxic levels in leaf tissues and evidence has highlighted that urea related leaf burn and scorch was actually symptom of Ni deficiency, not necessarily the blame of the urea per se[15]. Interestingly, it has also been highlighted that a range of plant species when intentionally fed urea in the absence of Ni were in fact, nitrogen deficient[16]. I can't stress the importance of that finding enough – even under conditions of luxury supply of N [from urea] plants could not utilise that N and convert it into amino acids and hence, were functionally N deficient. The same can be said for the role of molybdenum in converting nitrates into amino acids [as just mentioned earlier] – without Mo, nitrates build up and cannot be converted into amino acids yielding a functionally N-deficient plant. Of course, a standard mineral tissue test measuring total N but excluding Ni or Mo will not detect either of these issues, because the plant contains plenty of N overall [but in the form of backlogged urea or nitrates for example], and not sufficient functional amino acids and proteins for optimum plant health. This somewhat stark example highlights perfectly the importance of taking a more holistic approach with nutrient management – all minerals are important and they should all be considered together, not in isolated silos. There has not been a great deal of research done on Ni as a foliar, however barley growing in a nickel deficient soil has proven responsive to 3 applications of a 0.2% nickel sulphate solution at 20, 40 and 60 days after sowing[17]. If 100 L/ha was the water rate, a 0.2% solution equates to 200 g/ha of nickel sulphate, however, keep in mind this study was a pot trial and intentionally used a very low Ni soil. Consequently, being mindful that Ni is also a heavy metal, I would consider trialling lower application rates of approximately 50 g/ha of nickel sulphate with a foliar urea application. Ni availability is greater in acidic soils and soils with a history of applications of organic amendments [compost, manures, biosolids] and hence additional applications may not be warranted in these scenarios. Nickel has also been shown to be essential for biological nitrogen fixation as part of another enzyme called hydrogenase, which helps to split $H_2$ [hydrogen gas] so that the $H^+$ can combine with atmospheric N to form $NH_3$ [ammonia] which is delivered to the plant. Although it is specifically the N-fixing bacteria who require this enzyme, and not the plants, clearly Ni plays an important indirect role for all N fixation.

***Foliar P***

Although foliar applications of P are far less common than N, they have great potential to fine tune management of this critical nutrient in high production systems. Soil P is typically applied all upfront at planting before we know what the prevailing weather conditions [particularly moisture] will bring. Will the season bring a high or low yield potential and how do we decide on P fertiliser rates prior to knowing that? It becomes a game of chance of course and this is the exact benefit of foliar applied P – a 'tactical top up' can be made mid-way through the season should moisture conditions dictate its value. This is not possible with a soil application of P [unlike with N] due to the very immobile nature of P in the soil and the high reactivity or lock up potential of P inputs and consequently, a soil applied top up will not become available in sufficient time for the current crop. Once again, there certainly are mixed results with foliar P in the literature however as with N, best response is typically seen in low P soils or where soil inputs have been reduced[5,18]. Typical input options include ammonium phosphate or potassium phosphate however sodium phosphate has been shown be highly effective albeit a less common input on the market. Research has shown that the presence of a cation [ie $NH_4^+$, $K^+$ or $Na^+$] aids the absorption of P when compared to straight orthophosphates[5]. Best yield response from foliar P has been observed when P is applied from canopy closure to anthesis in cereal crops, particularly prior to heading, while on pulses again at pod set appears ideal[5]. The literature indicates that an application rate of 1.5-4kg P/ha has yielded best results in terms of P uptake and yield. It has been demonstrated that a very acidic spray solution pH is ideal for P uptake – even as low as 2-3 which was found to be more than twice as effective for P absorption at a pH of 4-5[5]. I have no personal experience with applying foliar P at such a low spray pH and would encourage readers to trial a small area prior to field scale application.

***In Closing…***

Improving nutrient use efficiencies and supporting the cycling of soil mineral reserves remains an important challenge moving toward sustainable production systems. Foliar applied nutrients are one piece of the puzzle that can in the short term, compliment long term soil improvement strategies. There are many factors to consider when optimising the efficacy of foliar applied nutrients and producers should consider the formulation, application, crop characteristics and environmental conditions when spraying. Combining these application considerations with targeted nutrient inputs at key crop developmental stages has great potential to enhance the sustainability of crop production.

***Take Home Tips***

- Foliars are more effective in low nutrient status soils or when a % of soil applied nutrient is decreased and substituted with a foliar - use a systems approach when considering the integration of foliars – they are a tool in the tool box.
- Apply 4-10 kg/ha of urea on cereals at anthesis onwards, on canola at mid flowering onwards and a 2% urea solution on pulses at pod set.
- Apply foliar P prior to the onset of reproduction at 1.5-4 kg P/ha.
- Trace elements are particularly effective via foliar application. Include a 2% urea solution to enhance uptake of traces at any crop stage.
- Take a tissue test to determine exactly what nutrients you actually require – focus on addressing your limitations.
- Foliar applied nutrients can help alleviate a crop in the early-mid stages of drought stress.
- Spray formulation is important – consider pH, EC, wetter/stickers and carbon source.
- Early morning and late afternoon are the best times to spray.

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