(Possible) Nitrogen strategies, application timing and surface spreading in CQ (or, "things I know that I don't know")

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Take home message

- Managing fertiliser nitrogen (N) requires an understanding of seasonal yield potential related to soil water holding capacity and forecast rainfall. Note that inadequate levels of other soil nutrients such as phosphorous (P) and potassium (K) may reduce potential yields or water use efficiency, even with adequate soil nitrogen levels for the target yield.
- Zonal management lets you adjust for changes in yield potential across fields but understanding the cause of this variability is important. Use your knowledge of historic yields to separate the better, average and poorer production areas in a paddock and sample soils in each separately. ConstraintID is a starting option for this process but remember to measure enough detail in both the surface and subsoil layers to identify possible limits
- Applications of any nutrient should consider the basic principles: source, rate, time and place. Efficient crop N recovery is only possible when active roots and soil moisture are present in the soil layers containing the N. N moves slowly in clay soils, especially when they are wet, so we suggest early application of N fertiliser during the preceding fallow may achieve a better distribution of N with water down the profile
- Broadcasting urea offers a very fast application method, but it is not entirely without risk of loss – especially once soils are moist. There are potential trade-offs between speed of application and recovery for subsequent crops.

Introduction

Reaching water-limited yield potential is the goal of all dryland production systems. It is about extracting as much plant available water as efficiently as possible and converting that into harvested product. Challenges in reaching that water-limited potential include many managerial and environmental influences. Central Queensland soils provide producers and researchers with both challenges and opportunities. On the plus side, there are many high clay content soils with capacity to store large amounts of plant available water. The negative is commonly these same soils can have significant nutrient limitations as a consequence of low soil organic matter and their related soil N reserves coupled with low or declining reserves of immobile mineral nutrients like P and K.

Fertiliser inputs are therefore increasingly important and understanding how to get the best from these expensive inputs is critical for ensuring productive and profitable cropping. While the most expensive outlays in our fertiliser programs are typically for N, we cannot get value for our N investment unless we ensure other nutrients are also available in adequate quantity to support crop growth.

Holistic nutrient management practices

Nutrition research confirms the need to look at all essential plant available nutrients together, rather than as single limiting factors (i.e. just N, or P, or K). The Sprengel-Liebig water barrel model is a very effective visual metaphor for considering how nutrients can limit productivity (Ploeg, et al. 1999). In that simple analogy the lowest stave represents the limit to the capacity of the barrel, with any increased inputs wasted unless that height can be increased. While we have traditionally though of water as being that limit in our cropping systems, we are finding that as our crop soils age the most limiting constraint can increasingly be a low level of a particular nutrient. Unless that constraint is addressed, applications of other less-limiting nutrients may be wasted.

In CQ (as well as other areas of the northern grains belt), the barrel model is a bit simplistic because we have multiple nutrient that are at levels that may limit productivity and they interact with each other to constrain the yield of the crop. This requires more complex nutrient management decisions, such as those proposed in Liebscher's 'Law of the Optimum' (de Wit 1992), which states that a production factor which is in minimum supply contributes more to production, the closer other production factors are to their optimum. Long-story short, get all the pieces of the nutrition puzzle optimised and everything works much better. So, what do we need to consider, to solve this puzzle?

Plant nutrient uptake pathways

Before we can devise an effective fertiliser application strategy for any nutrient, we need to understand how that nutrient behaves in soil and is acquired by plant roots. Nutrients are generalised into two groups related to their behaviour in soils, and particularly their response to water movement through soil profiles: mobile and immobile.

Nitrogen is predominantly present in soils in organic forms that need to be converted to mineral forms (ammonium and nitrate) by microbial activity before plant uptake. Once in those mineral forms, particularly as nitrate, the N becomes 'mobile'. Mobile N can occur at quite high concentrations in soil water, which means as the plants take up water, they can accumulate N at the same time. As roots deplete the water (and N) close to them, water moves to the root from undepleted soil further away, bringing nitrate with it too. So, for the most efficient nitrogen recovery we want the available nitrate distributed with the available water.

During the fallow, as soil water profiles recharge, nitrate moves down the soil profile from the topsoil, where residues are decomposing or fertiliser is applied. However, in our clay soils this movement is a lot slower than it is in sands or loams. Rules of thumb suggest that movement of N is about ¼ the speed of the wetting front, although the rate changes with soil moisture. If you apply fertiliser N into a wet soil, the wetting front is minimal and vertical movement of N is extremely slow. In effect, the N is going to stay where you put it until the soil dries out enough to start to move as profiles are re-wet.

Phosphorus is the opposite of N in many ways. In our cropped soils in particular, most P is present in inorganic forms, but the solubility of different forms of P varies. The fraction that is readily available for plant uptake is either in the soil water at very low concentrations or held (sorbed) onto clay and organic matter particles. The sorption and desorption processes can occur rapidly, but the net effect is that at any time there is little P available in the soil water. This means P resupply from other parts of the soil profile is limited, and P is considered an immobile element in clay soils. Where you put it is where it stays, and for roots to access P they have to grow into undepleted soil (or close to a fertiliser band). Because of the strong affinity of clays and organic matter for P, roots have to be very close to a P source/high P concentration so that P can diffuse to the root without being sorbed to other particles. Effective P uptake therefore requires either low P concentrations across large soil volumes, with roots always able to grow into soil with available P (our soils before cropping, in many cases), or concentrated patches of high P availability (bands, slots) which stay moist and where roots can concentrate around in large numbers. Once you are relying on P fertilisers, placement is a critical success factor.

Potassium is an interesting blend of these contrasting characteristics. It is still held on clay and organic matter surfaces and occurs in relatively low concentrations in soil water. This means in our high clay soils it also is effectively immobile, although in lighter soils it moves a little further than P. What is challenging, though, is that roots don't congregate around a patch of high K like they do with P, and so it is harder to get rapid uptake of K from a band – unless you put some P with K, to act as an agent to ensure roots get interested and congregate in that area.

So, as you can see from this, each nutrients behaviour in soil will have an important impact on how we apply our nutrients in clay soils. We need to ensure that the application method used in each field is suitable for the nutrient being applied, and increasingly we are seeing that we may have to adopt different application strategies to achieve good crop recovery of N compared to P and K.

We now discuss some specifics related to ensuring effective N management.

Nitrogen management

Prior to assessing nitrogen demand, soils should be characterised for water holding capacity (how big is the bucket) and for soil water status (how full is it). These water supply parameters benchmark different soils for growth potential. There are a variety of tools and techniques to allow you to gather information about variability in soil profile, and we suggest a program of ground truthing to confirm soil profile depth, and the presence or absence of likely soil physical or chemical constraining properties to plant root growth. Soil testing in layers for available P and K is a very effective tool to establish fertility status for these essential elements. It is also important to capture pH, salinity and structural stability in deeper profile layers as this will help to understand likely limits to root exploration and ability to access the available water (i.e. they may limit the size of the bucket).

Estimating crop nitrogen demands

Once the soil's capacity to store plant available water has been estimated (measured), we are able to derive a demand potential against which we can consider plant nitrogen supply. Nitrogen budgeting is a robust method of estimating how much nitrogen is required for a given amount of available water.

The budgeting formula has several components to consider, particularly those relating to the recovery efficiency of applied fertiliser and those related to recovery of residual or mineralised nitrate. Historically these have been aggregated together and a generalisation of about 50% recovery is used to convert from soil N into grain N, with therefore 50% required to come from applied fertiliser. An important point to note about this assumption is that when it was derived, the proportion of N derived form the soil (i.e. release of N from organic matter by microbes, as well as residual mineral N left from previous years) was about the same as it was from fertiliser.

Since then, our soil organic matter has declined considerably, and this has meant that the N mineralised over a fallow is also declining. The result of this is that fertiliser N now has to make up a greater proportion of crop N supply. This has important implications, because the efficiency with which crops are able to acquire N from soil or from freshly applied fertiliser is quite different. Recent estimates from work with sorghum across Qld and NNSW suggest the figure for soil N is at least 70-80%, while that of fertiliser is more like 30% (Bell et al. 2016). The greater our reliance on fertiliser N, the more our recovery efficiency will resemble 30% rather than 50% or higher. Hence higher the potential rates of fertiliser N we will need to feed the crop where the application timing and placement are not adjusted.

The challenge this highlights is can we adapt our nitrogen fertiliser application practices to ensure that our fertiliser N behaves more like ‘soil N’ in terms of crop recovery.

Nitrogen loss pathways

There are two loss pathways we are primarily concerned about in arable systems in our clay soils: volatilisation and denitrification. Volatilisation is nitrogen lost from the soil surface back to the atmosphere as ammonia (NH_3). This typically occurs under conditions of high pH and high concentrations of ammonium (NH_4^+). Therefore, any fertiliser product that supplies N in the ammonium form, or that generates high NH_4^+ concentrations as it transforms in the soil, can be vulnerable to volatilisation losses. A product like urea can be particularly susceptible, as it generates high pH around the granule as the urea hydrolyses, and generates high concentrations of NH_4^+ during the process of converting to nitrate N. A key strategy for reducing the risk of volatilisation loss is ensuring the fertiliser is applied and covered by soil. Contact with soil particles holds the NH_4^+ ions on the clay particles, and coverage reduces direct exposure to the atmosphere – the loss pathway for the NH_3.

Research on the Liverpool Plains and NW slopes and plains of NSW (Schwenke et al. 2014) looked at urea volatilisation losses on bare fallows, and where N was top-dressed onto paddocks sown to wheat or growing pastures from applications in autumn and spring. Most of the sites had neutral to alkaline vertosols, and some also had $CaCO_3$ present above 10% of the soil mass. The application rates ranged from 60 to 100 kg N/ha. Results indicated mean volatilisation of ≈ 5% for top-dressed applications in wheat (3.1-7.6%), but 11% when broadcast onto bare soil during a fallow (5.4-19%). The pasture volatilisation results where highest (27%), partly due to no rain following spreading, but also highlight the risks of urea that is not covered in soil and which cannot interact with the clay particles in the soil (i.e. the granules are sitting on the thatch, or stubble). The trigger for higher losses is moisture availability, and in this case the greatest loss will result from a light shower that starts the urea dissolving but isn’t enough to wash it into the soil.

The other loss pathway, denitrification, occurs when N is in the nitrate N form. High concentrations of nitrate N can be generated in soil after fertiliser is applied but before crops can take that N up into crop biomass. Again, moist soil is the catalyst to start that transformation into nitrate, but it is often when soils get much wetter (and oxygen availability is reduced) that denitrification losses can occur rapidly. The key point to remember about this loss pathway is that it is the result of microbial activity, and so in soils where there is little organic matter or crop residues, denitrification losses are likely to be relatively small. Studies on summer sorghum crops have suggested that denitrification losses of 20-40% of applied fertiliser can occur when wet conditions occur after fertiliser applications (e.g. during the early stages of crop growth).

Options for nitrogen fertiliser applications in CQ?

Any nutrient input regime should tick off the basic principle: source, rate, time and place. For fertiliser nitrogen in Central Queensland farming systems, what are options for beneficially adjusting source, rate, time and place? In our opinion, there are a couple of things that are worthy of investigation:

Source: Both urea and anhydrous ammonia are effective products for supplying N to soils, as long as they are applied into soil to reduce the risk of volatilisation losses. Additionally, supplemental sources particularly as organic forms such as feedlot manure or compost can be included to act as slower release forms. With a different release pattern, they may provide different nitrate distributions in soil profiles. However, as these products are capable of releasing significant quantities of N, as well as containing organic matter to support microbial populations, they do come with a risk of gaseous losses if they are not incorporated into the soil. Wet weather and manures applied to the soil surface represent a significant denitrification risk in particular.

Rate: Fertiliser nitrogen inputs in CQ have historically often been low, most likely for a variety of reasons such as anxiety over recovery in the year of application, suppression of production potential through other nutrient (P & K) limitations, inability to plant a crop due to variability in rainfall pattern, etc. Some of these won't change, but the impact that subsurface P & K applications have had on lifting production has in some cases, been profound. As management of these other nutrient limitations gets better, nitrogen budgets will require re-examining to account for the higher yield potentials that are now on offer. Lower recovery efficiency of fertiliser nitrogen applied later in fallows (e.g. on wetter profiles with less movement and closer to planting) can also restrict crop access depending on seasonal growing conditions. You might think higher rates could be needed just because the efficiency of recovery by the plant is smaller – this is why we measure crop uptake. Did the plant access this year's fertiliser N, or is it instead relying on residual left from last year?

Timing and placement: These two are now more challenging discussions, and we are working from first principles, as experiments have not been conducted to validate options on timing or placement of fertiliser N.

What is the right time to start? There is no simple answer that will be applicable in all situations. In general, applying N earlier in the fallow period gives greater time for the wetting front to move the N deeper into the soil profile, and hopefully ensure that N and water are co-located to support growth.

What we want to achieve is application just prior to when the profile is wetting up, to support deeper movement into the profile. However, the N that moves through the profile is typically nitrate N, and we know nitrate N in soil is vulnerable to loss via denitrification if soils get very wet and oxygen is limited. Therefore, we think that risk could be minimised by applying towards the start of the fallow, when the soil is dry. That way, the water and dissolved N are generally moving into dry, oxygenated soil in deeper profile layers, minimising the risk. Once the top 1/3 of the profile is wet, the denitrification risks will increase rapidly and subsequent applications may not be as efficient, because water movement is slower and the chance of soils getting waterlogged in the layer with high nitrate N increases. Improved seasonal forecasts, particularly in environments with more skewed rainfall events (i.e., monsoonal type patterns), may provide more reliable opportunities to gain benefits from changes to application.

The biggest consideration with respect to placement is the differences (for and against) of surface spreading versus traditional subsurface banding. Our preference is still for subsurface applications, but the changes to loss risks with surface application in the CQ environment require further testing. It is worth remembering that deep placement of P and K represents an opportunity to top up deeper soil layers with N during the same operation, hopefully increasing the potential for deep movement. However, as that occurs infrequently, it will not represent a widespread opportunity.

A final point to consider here is the role of legumes. The N rich residues from legume crops behave much like an early (albeit surface applied) fertiliser N application, as the N is released rapidly as the legume residues 'melt away' once moisture starts to accumulate. Legume N therefore has the potential to move with water into deeper profile layers, and the resulting improved crop N availability may be part of the reason for yield responses in grain crops after a legume break. In a situation where soil N has been depleted and fertiliser applications in a fallow have not been possible, choosing a legume crop option may be one way of avoiding a potential N limitation in the next crop season.

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