Is it time to challenge current nitrogen strategies, tactics and rules of thumb?

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Key words

N pools, organic, efficiency, strategy, spread, drill

Take home message

- After a run of high-yielding years and wetter than normal soil conditions post-harvest for the coming season, we are likely to see soil mineral N reserves low, soil stored water at maximum capacity, crop residue levels higher than usual, recycling of nutrients from partially and unharvested crops, and minimal fertiliser nitrogen movement into the soil profile. These add up to a challenging situation in a cropping system that would typically expect greater than 50% of crop N to be sourced from mineralisation, some stored mineral N reserves distributed down the soil profile, and some movement of fertiliser N into the profile from the pre-sowing application
- In seasons and situations where there is a significant change in the balance of crop N sourced from organic, soil mineral and fertiliser N pools, caution is needed in determining seasonal N fertiliser requirements based on general rules of thumb, particularly as the crop N uptake efficiency is 50%
- Most current N management strategies are limiting the maintenance or growth of organic C and N reserves by not replacing the contribution from annual mineralisation in N budgets. A more strategic approach that concentrates on soil N management rather than crop N requirement may be more suitable to achieve both crop productivity and soil fertility goals
- With the seasonal conditions this year, the logistics of getting N applied will necessitate fertiliser N being applied in ways that would not usually be considered due to a higher risk of loss or lower efficiency. Even with the current high N fertiliser prices in highly N-responsive situations, insufficient N will likely cost more than losses and lower the efficiency of alternate application strategies.

Organic vs different fertiliser N sources

In managing crop N requirements for the last 30 years, there has been widespread reliance on simple N budgets that, in essence, treat all sources of N available to the crop, soil N depth distribution and fertiliser application strategies equally. But is accepting equality of N supply still the best approach , or is it computational expediency that, for the most part, has served its purpose and now it’s time for a closer look at a more informed approach??

At a gross functional level, plants acquire N from the soil dominantly via the mineral pool, which in turn is topped up by the plant residue (labile), the ‘old’ organic matter (humic), and fertiliser where the supply from other sources is adjudged to potentially limit yield and produce quality (Figure 1).

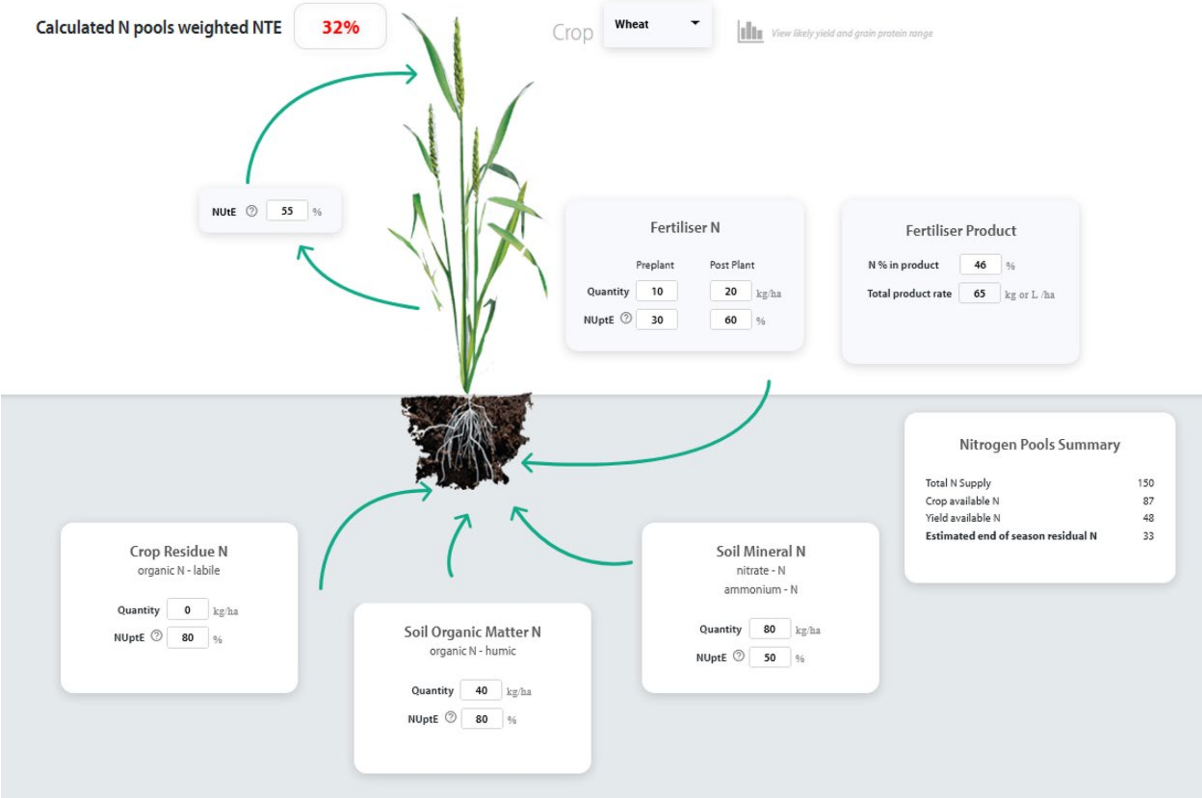

Figure 1. Representation of a soil N supply pool scenario with differing N quantity/N uptake efficiency contributions to plant N supply and potential grain yield and protein outcomes (image from Back Paddock Opterra N Pools Calculator).

The science says not all crop N supply pools are the same, differing in the quantity of N supplied and efficiency of crop uptake being impacted by characteristics of the N forms that make up the source pool (Table 1). Significant N supply pool balance changes affect crop N supply and may significantly affect seasonal fertiliser N requirement. This explains why many soils in their virgin state and after highly productive legume pasture ley can supply the entire crop N requirement based on the quantity and efficiency of supply and why similar amounts of N supplied as fertiliser are unable to reach the same yields and grain protein outcomes. It may also factor in the 'better than expected' N responses following canola and pulse crops for the quantity of N available. The relative uptake efficiency from the different soil N pools often explains the difference. While recent research suggests that the net soil N gain from pulse crops may be large (Brill et al. 2022; Kirkegaard et al. 2021), minimal and even negative (Sands et al. 2022), the faster rate of N turnover from these residues with lower C/N ratios and higher uptake efficiency can significantly influence yield and quality in the following crop (Kirkegaard et al. 2021).

Where the crop N supply quantity is heavily skewed toward the higher or lower uptake efficiency pools, there is a significant change from the widely adopted 'average' crop N efficiency (50 %, commonly represented as crop N demand equals 2 x removal) that the "standard" N budget may significantly over or underestimate the crop fertiliser N requirement.

Table 1. General range short-term crop uptake efficiency of N from 4 major supply pools by cereals.

Major soil N supply pool (and crude working definition)	**General crop uptake efficiency in cereals**	**Characteristics**
Humic OM – contribution from sources more than 3 seasons after incorporation to thousands of years old (Baldock 2019)	70 – 90%	• Largest organic N pool with a regular slow turnover rate of ~2% of total soil organic N annually • Losses via erosion; not subject to leaching, denitrification or volatilisation • Converted to crop-available mineral forms based on favourable soil temperature and moisture conditions • Highest efficiency where most of the contribution is released in-crop • If released during a fallow, it becomes part of the soil mineral N pool and is potentially vulnerable to multiple N loss pathways.
Labile OM – contributed from crop residues with less than 3 seasons of mineralisation (Peoples et al. 2017)	70 – 90%	• Variable size organic N pool based on quantity and quality (C/N ratio) of plant and animal residues returned • Losses dominantly via erosion; not subject to leaching, denitrification or volatilisation • Converted to crop-available mineral forms based on favourable soil temperature and moisture conditions • Net annual contribution depends on the outcome of net mineralisation/immobilisation processes • Legume residues provide up to 30% of total N in residual DM in the following season (Peoples et al. 2017). Some studies suggest that canola residues can perform similarly • Highest efficiency where most of the contribution is released in-crop • If released during a fallow, it becomes part of the soil mineral N pool and is potentially vulnerable to multiple N loss pathways.
Soil profile mineral N – nitrate and ammonium below 10 cm at sowing (Bell et al. 2010)	50 – 70%	• Variable size mineral N pool is based on a combination of residual mineral N from previous crops and N mineralised in the previous fallow • Losses dominantly via leaching and denitrification • Uptake efficiency is affected by N depth relative to rooting depth, soil water and constraints distribution • Quantity available below 60 cm may be limited by root density but is crucial in seasons where the soil profile above has dried.
High concentration, rapidly mineralisable fertiliser N (Daniel et al. 2018) – • applied in the fallow and at sowing • applied in crop	• 0 – 40 (70[1])% • 20 – 60%	• Highest annual uptake efficiency when applied into an active root system • Lowest annual efficiency when lost during fallow and if stranded in dry soil above the active rootzone for a significant period • If not lost during a fallow, it can become part of the residual soil N for the following crop at up to 2 x higher efficiency than the year of application • Losses dominantly via volatilisation, leaching and denitrification.

[1] Wimmera

For the future, rebuilding soil capacity to supply the majority (>70 %) of crop N requirements from higher-efficiency, low-risk soil sources must be considered a priority to help dampen the adverse effects of seasonal weather extremes and increased agricultural market volatilities (e.g., urea price and commodity price variance) by regenerating soil nutrient supply plasticity (soil contribution more when it is wet and less when it is dry).

Nitrogen – strategies for building the pool and reducing losses

Research suggests that implementing best cropping practices may have, at best, halted the decline in soil organic carbon and nitrogen stocks in continuous cropping systems; however, in most cases, they are still declining. Fundamentally this means that in the long term, the conversion of available rainfall to plant biomass is less effective than previous land uses they are being compared to. To emphasis this point it is worth understanding that estimates of total soil N decline in continuously cropped soils indicate that total soil N haves every 23 (+/- 12) years (Angus and Grace 2017).

The Yield Gap project has identified that across most areas of Australia, the lack of nitrogen is a primary factor in not reaching seasonal and long-term water-limited yield potential (average 40 %) (Hochman and Horan 2018) and, by inference, soil C and N return to the soil in plant residues during grain production.

This issue brings into sharp focus the basis for determining appropriate crop N supply strategies. Current strategies are primarily based on using organic matter mineralised N (contributed to fallow mineral N and mineralised in crop) to minimise the fertiliser N requirements. While this may be a sound short term financial strategy (i.e., targeting optimum economic yield annually), from a longer term view and soil nutrient resource perspective, it can only lead to further declines in organic C and N if the long-term aggregate rate of addition of N for a rotation is less than crop N removal + annual mineralisation and losses.

e.g., Annual average grain N removal of rotation = 71 kg N/ha

- 2 x wheat @ 4t/ha @ 11.5% protein = 160 kg N/ha
- 1 x canola @3 t/ha @ 23% protein = 110 kg N/ha
- 1 x barley@ 5t/ha @10.5% protein = 85 kg N/ha
- 1 x chickpea @ 2.5 % @ 24% protein + N fixation = 0 kg N/ha

Soil total N (0 – 10 cm) = 0.1 % (OC% ~1.2)

Annual humic mineralisable N = 2% of soil total N% = $0.1 \times 10{,}000 \times 1.3 \times 0.02 \approx 26$ kg N/ha

Minimum long-term annual N addition rate ~97 kg N/ha + seasonal N loss adjustment (15%?)

Some alternative approaches for consideration include:

- N strategy based on long-term crop + annual humic mineralisation replacement
- Replacement N based on long-term removal rates and strategic use of legume ley pasture (40 %) in mixed farming and pulse N
- N bank – N rate strategy based on long term crop available water
- N pools weighted budget + humic mineralisable N.

Use the greater of the above long-term minimum rate approaches and seasonal pools weighted N budget rate?

Spread urea or drill it in?

The answer to the question as to whether it is better to spread or drill urea can fall either way depending on factors such as physical soil conditions, soil chemistry, crop residue loads, beneficial or adverse effects of soil disturbance and application efficiency (including equipment and skilled labour) and cost. An individual situation should be evaluated on its merits considering the prevailing conditions. Table 2 highlights some pros and cons associated with each application method. The choice should also consider which method is most likely to promote the majority of mineral N in the 15 – 40 cm soil layer by crop establishment in summer dominant rainfall areas and other areas that rely significantly on stored soil water for crop production reliability.

Table 2. Pros and cons of spreading or drilling urea

	Pros	**Cons**
Spread	• Logistically, generally more efficient field coverage • Generally lower operator skill level required • Uses multi-purpose equipment • May avoid soil moisture loss associated with soil disturbance • Avoid potential plant establishment effects if urea is drilled at sowing. • Wider application window and conditions.	• Potentially high volatilisation losses, if not incorporated or not treated with a volatilisation inhibitor • Higher yield impacting immobilisation "losses" in high crop residues (5 kg/t compensation when residue volume >5 t/ha) • Calibration and spread pattern can be variable.
Drill	• Potential to delay mineralisation of urea/ammonia (slow release) from some application configurations. • Deeper application (>15 cm) may be less prone to stranding • Can be multi-tasked where soil disturbance is required for other purposes.	• If too shallow in wet alkaline soils, volatilisation losses can be higher than spread. • Potential for higher N_2O emissions during nitrification.

What does a systems approach look like?

We must develop practical long-term strategies and ensure strong alignment with short-term tactics when considering systematic restoration of the soil's nutrient-based production capability.

Some of the primary considerations for the long-term management of soils in the sub-tropical grains industry include:

- All nutrients have residual value when not taken up due to crop water deficit, positional unavailability or erosion
- Uptake efficiency of residual nutrients can be many times greater than freshly applied, if not lost during a fallow due to redistribution within the soil profile
- Reporting of single-year crop uptake efficiencies and profitability for nutrients is misleading where there is yield active residual value
- Plan to manage nutrients for a rotation first, then by crop
- Using nutrient removal is not an appropriate short or long-term application rate for all soils, nutrients and situations
- Monitoring soil nutrient and grain nutrient content trends and balance are essential for long-term management
- Soil phosphorus and potassium strategies need to include the 10 – 30 cm layer in sub-tropical Vertosols
- As seasonal and nutrient cost variability becomes more extreme, soil nutrient-based production plasticity becomes more important to help stabilise costs and income
- Nitrogen mineralised from organic matter annually may need to be added to, not deducted, from crop requirements to arrest further soil organic carbon and nitrogen decline.

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Date published

February 2023