

Nutrition

The effect of stubble on nitrogen tie-up and supply - the Mallee experience

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RESEARCH



- **Urea fertilizer N recovery by the wheat crop it is applied to is <50%, which needs to be considered in fertilizer recommendation programs.**

Background

Carbon availability along with soil moisture are the most limiting constraints of microbial functions in low organic matter Mallee soils. Previous research in the Mallee has shown that the management of biologically available C is the key to improving biological functions including those involved in N mineralisation and availability. Crop residues are one of the major sources of C for soil biota, therefore stubble retention can provide benefits through changes in soil physical, chemical and biological properties which influence carbon turnover, nutrient generation and subsequent availability of nutrients to crops (Gupta and Roget, 2008). Although stubble retention benefits are expected to be realised in all soil types, the magnitude and nature of change in biological functions can vary depending on type and timing of stubble management and is influenced by soil type and environmental factors (e.g. rainfall).

Most dryland farmers in the Mallee retain all, or most of their crop residues to protect the soil, retain soil moisture and maintain soil fertility in the long term. However, a proactive and flexible approach to stubble management that recognises and avoids situations in which stubble can reduce productivity or profitability makes sense, and has been promoted as part of the GRDC Stubble Initiative (Gupta *et al.* 2016; Swan *et al.* 2017). One such situation is where large amounts of retained stubble, especially high C:N ratio cereal stubble, “ties-up” soil N leading to N deficiency in the growing crop that may reduce yield. The timing, extent and consequences of N tie-up are all driven by variable weather events (rainfall and temperature) as well as soil and stubble type, so quite different outcomes may occur from season to season and in different paddocks (Gupta, 2016). In this article we review in simple terms the process of N tie-up (immobilisation) and mineralisation, to understand the factors driving it.

Key messages

- **Cereal stubble should be thought of as a source of C for microbes, not as a source of N for crops. In the Mallee under no-till systems, only 1-2% of the N requirement of wheat crops is derived from the previous wheat stubble.**
- **N tie-up in cropping soils is only a temporary constraint as the immobilised N will be released through microbial turnover, generally later in the crop season in spring.**
- **N tie-up by cereal residue is not just a problem following incorporation – it also occurs in surface-retained and standing-stubble systems.**
- **Management of tie-up is reasonably straightforward - supply more N (5 kg N for each t/ha of cereal residue) and supply it early to avoid impacts of N tie-up on crop yield and protein.**

We then provide the results from a 3-year field experiment at Karoonda and other examples from experiments in the southern NSW (both long-term and short-term) that serve to illustrate the process, and the ways in which the negative consequences can be avoided while maintaining the benefits of stubble.

N cycling processes and controlling factors

Nitrogen mineralised from the soil organic matter and crop residues makes a substantial contribution (~50%) to crop N uptake (Angus and Grace, 2017; Gupta, 2016). The rate and timing of N mineralisation regulates plant available mineral N levels in soils and the release of mineral N in soil is regulated by the processes associated with microbial turnover (Figure 1). Microbial activities are also responsible for the conversion of fertilizer N into plant available forms.

The process of N tie-up and release (N-immobilisation and supply)

Farmers are always growing two crops – the above-ground crop (wheat, canola, lupins etc.) is obvious, but the below-ground crop (the microbial biomass, MB) are always growing as well; and

like the above-ground crop they need water, warm temperatures and nutrients to grow (there's as much total nutrient in the microbes/ha as in the mature crop, and two thirds are in the top 10 cm of soil!). There are two main differences between these two "crops" – firstly the microbes can't get energy (carbon) from the sun like the above-ground plants, so they rely on crop residues as the source of energy (carbon). Secondly they don't live as long as crops – they can grow, die and decompose again ("turnover") much more quickly than the plants – maybe 2-3 cycles in one growing season of the plant. The microbes are thus immobilising and then mineralising N as the energy sources available to them come and go. In a growing season it is typical for the live microbial biomass to double by consuming carbon in residues and root exudates – but they need mineral nutrients as well. Over the longer-term the dead microbe bodies (containing C, N, P, S) become the stable organic matter (humus) that slowly releases fertility to the soil. In the long-term, crop stubble provides a primary C-source to maintain that long-term fertility, but in the short-term the low N content in the cereal stubble means

microbes initially need to use the existing soil mineral N (including fertiliser N) to grow, and compete with the plant for the soil N.

Microbial biomass in soil

Soil microbial biomass (MB) is a storehouse for nutrients, changes in the amount of MB due to management and seasonal variation can exert a significant impact on microbial immobilisation and net N mineralisation. In Australian agricultural soils, MB-C accounts for 1.5 to 3.0% of soil organic C and MB-N 2-5% of total N. The amount of MB varies with soil type and agro-ecological region (Table 1), and is influenced by crop rotation, tillage and stubble management practices that influence microbial populations and the quantity and quality of residues. For example, MB is generally higher after legume and canola crops compared to cereal crops. MB-C:N ratio generally varies between 6.5 and 9 and a wide MB-C:N ratio is shown to be associated with cereal crop residues and rhizosphere soils. Due to the short turnover time of MB in Australian soils, it may only act as a short-term reservoir for nutrients and as a biocatalyst for soil organic matter cycling and N release, in particular in-crop N mineralisation.

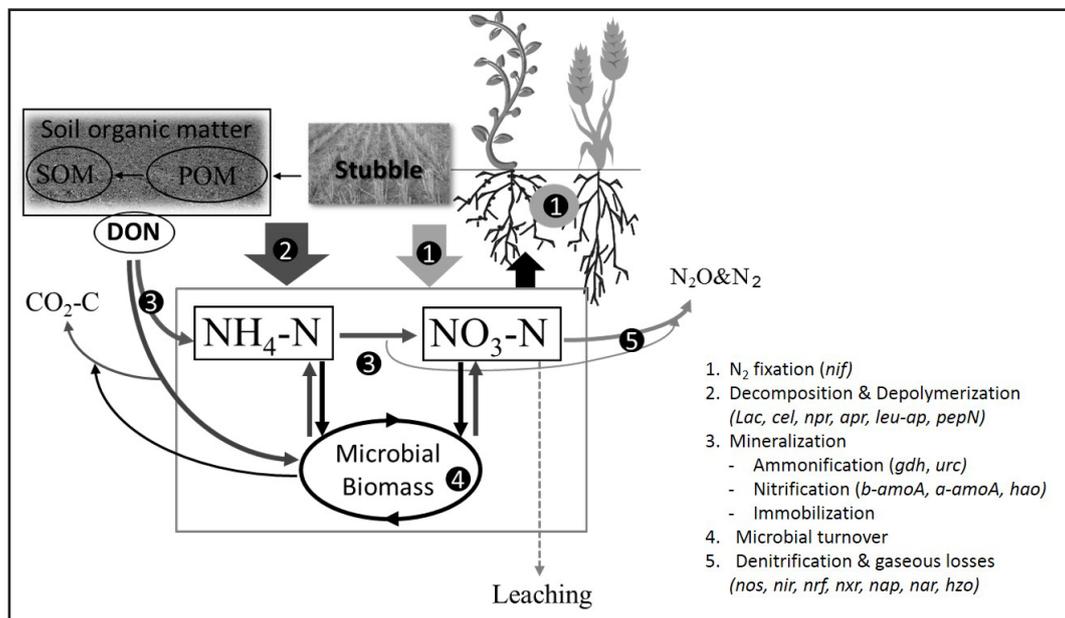


Figure 1. Biological processes involved in nitrogen cycling that influence plant available nitrogen levels in soil. SOM – soil organic matter, DON – dissolved organic nitrogen, POM – particulate organic matter (Gupta, 2016)

As microbial turnover and associated N mineralisation-immobilisation balance is influenced by seasonal conditions, estimation of N supply potential at the beginning of a crop season should include the amount of N in MB and the N that can be mineralised from SOM and crop residues (Gupta 2016, McBeath *et al.* 2015a). Additionally, management practices that increase the size of the MB pool and modulate its turnover could assist with the synchronisation of N mineralisation to crop demand. For example, higher N mineralisation after a legume crop is related to higher MB, whereas greater microbial turnover after canola also contributes to higher N mineralisation (Gupta, 2016).

In modern farming systems, where stubble is retained on the surface and often standing in no-till, controlled traffic systems, less is known about the potential for immobilisation. In GRDC-funded experiments as part of the Stubble Initiative (CSP187, CSP00174, MSF00003, BWD00024), we have been investigating the dynamics of N in stubble-retained systems.

Cereal stubble isn't a major source of N for crops - Tracing N from previous cereal crop stubble

Studies at three sites in southern Australia (Karoonda, Temora and Horsham) have tracked the fate of the N in wheat stubble to determine how valuable it is for successive wheat crops under Australian systems. Stubble labelled with ¹⁵N (a stable isotope that can be tracked in the soil) was used to track where the stubble N went.

At the Karoonda experimental site (at Lowaldie, north east of Karoonda, SA), the 2-year continuous wheat experiment was conducted on the dune (sand) with different stubble management treatments using the ¹⁵N wheat stubble grown at the site during 2014. The trials were generally sown at the end of May in each year using knife points with 50 kg/ha DAP and 24 kg/ha Urea placed below the seed (P10, N20). Results from the analysis of soils (sowing and harvest), crop residues and plant and grain samples (Figure 2) have indicated that, of the 12 kg/ha of N contained in 2.5 t/ha of retained wheat residue retained in 2014, only 0.75 kg/ha N (5%) was taken up by the first (following) wheat crop (representing 1.2 %

of crop requirement); and 0.4 kg/ha N (3.5%) was taken up by the second wheat crop (1% of crop requirement).

The majority of the N after two years remained in the soil organic matter pool (5.5 kg N/ha or 45%) and some remained as undecomposed stubble (20% or 2.4 kg N/ha). Thus we can account for around 73% of the original stubble N in crop (8.5%), soil (45%) and stubble (20%) with 26.5% unaccounted (lost below 50 cm and/or denitrified). Similarly, N in cereal stubble represented only 6% and 1.1% of crop requirements over two years at Temora (7.6% Year 1; 4.4% Year 2) and at Horsham (3% Year 1; 2.5% Year 2), respectively. In similar work carried out in the UK which persisted for 4 years, crop uptake was 6.6%, 3.5%, 2.2% and 2.2% over the 4 years (total of 14.5%), 55% remained in the soil to 70 cm, and 29% was lost from the system (Hart *et al.* 1993).

The successive crops took up 5% (0.75 kg N/ha) and 3.5% (0.4 kg N/ha) of the N derived from the original stubble representing only 1.2% and 1% of the crops requirements. Most of the stubble N remained in the soil (45%) or was lost (27%).

Table 1 Amount of microbial biomass carbon and N supply and immobilisation potentials in the surface 0-10 cm of agricultural soils from the different cropping regions of Australia (Gupta 2016)

Location	Soil type	MB-C	N immobilization potential ^{&}	N supply potential ^{&}
		(kg C/ha)	(kg N/ha)	
Waikerie/Karoonda, SA	Sand and sandy loam	150 - 300	15 - 25	10 - 35
Streaky Bay, SA	Calcarosol - sandy loam	210 - 400	15 - 30	20 - 50
Minnipa, SA	Calcarosol - loam	560 - 710	40 - 51	42 - 56
Appila, SA	Loam	450 - 585	32 - 42	35 - 45
Kerrabee, NSW	Loam	420 - 525	30 - 40	35 - 50
Millewa, NSW	Sandy loam	150 - 310	11 - 22	14 - 31
Condobolin, NSW	Sandy loam	240 - 585	17 - 42	20 - 45
Horsham, Vic	Sandy loam	140 - 230	12 - 24	10 - 16
Horsham, Vic	Clay	546 - 819	39 - 59	52 - 72
Wongan hills, WA	Loamy sand	250 - 350	18 - 25	25 - 40

[&] N immobilisation potential is estimated assuming an average 50% increase of MB during a growing season.

[&] N supply potential is calculated from N in MB plus N mineralization measured in a laboratory aerobic-incubation assay.

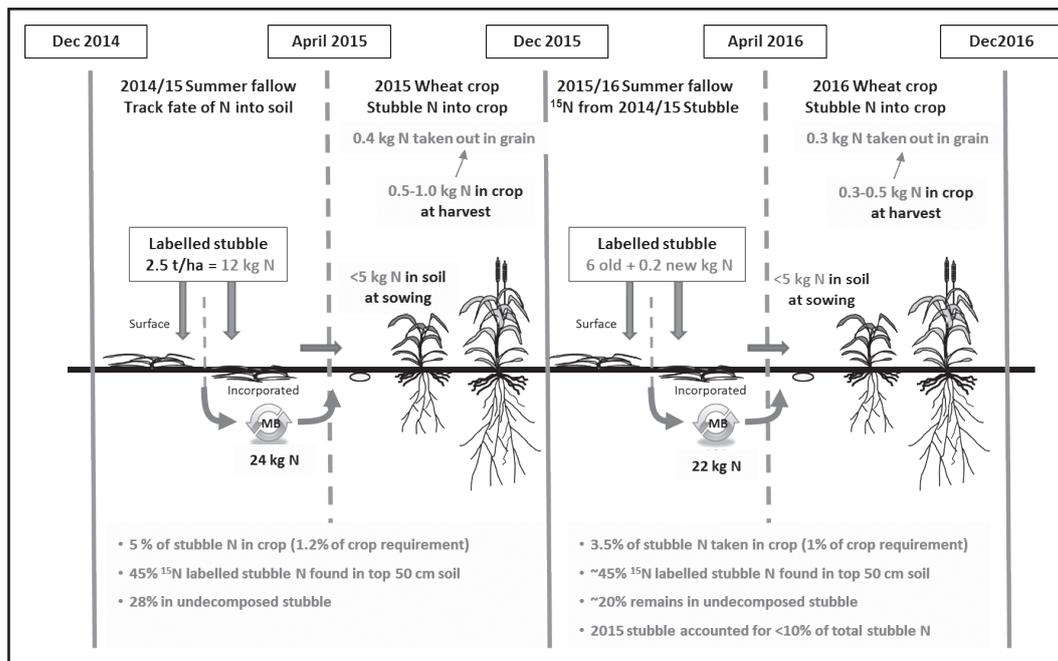


Figure 2 The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 2.5 t/ha of wheat stubble containing 12 kg/ha N

The main point from the above evidence is that the N in cereal stubble represented only a small percentage of crop requirements over two years and takes some time to be released through the microbial biomass and organic pool into available forms and losses can occur during the process. Therefore, cereal stubble is not a major source of N, instead a source of C for biological activity. In the lower rainfall cropping regions, microbial turnover of C and N from residues is influenced by stubble retention practices and environmental conditions (rainfall; duration of wet and warm soil conditions). Results for soils at sowing indicated that stubble retention generally increased dissolved organic C (DOC) levels in the soil and Standing and Incorporated stubble treatments significantly increased MB C and MB N compared to *No-Stubble (cut low and removed)* and *Surface (cut low and retained)* stubble (Gupta *et al.* 2016).

Can stubble really reduce yield significantly in no-till systems - and is N-tie up a factor?

Five years of experiments across the Mallee environment (Karoonda, Loxton and Ouyen), have investigated the;

- i. effect of amount and timing of N fertiliser application according to soil type,
- ii. effect of sowing on previous season's crop row (on or near-row) vs. in between rows (inter-row) and
- iii. the response to application of fertiliser with the seed or at depth on crop performance, N supply capacity and N uptake. Surface soils collected at sowing and in-crop were analysed for MB, mineral N, N supply potential (NSP) levels (see McBeath *et al.* 2015-17 Mallee Compendium articles for full details).

Sandy soils with low organic matter have lower N supply potential, hence any imbalance between mineralisation to immobilisation plays an important role in early season N nutrition of a cereal crop. The immobilisation (tie-up) potential in the surface (0-10 cm) soils at Karoonda range between 15 to 30 kg N/ha which would mean a considerable amount of N from the upfront fertiliser application would be tied-up, but would be released later in the season through microbial turnover. In the sandy soils, MB acts as a buffer or temporary storage pool for nitrate N protecting it against leaching,

especially in the non-crop season and early crop season, conversely lower MB in the No-stubble treatment would result in greater loss of N in the soil profile. With the higher MB and activity levels, soils on the swale have greater N immobilisation potentials (25-40 kg N/ha) compared to soils on the dune (10-25 kg N/ha), especially in cereal stubble retention systems, but they also have higher NSP. While on-row soils have a higher N immobilisation potential (15-25 kg N/ha) compared to off-row soils (10-15 kg N/ha), benefits in terms of crop N uptake have been measured for on-row sown wheat.

Having N fertiliser placed with the seed and 8 cm below (50 kg DAP with seed and 35 kg Urea below) yielded better than all fertiliser 8 cm below the seed at Loxton but not Karoonda in 2017, despite the possibility of a fertiliser toxicity effect of 50 kg DAP/ha with the seed (McBeath *et al.* 2018). This result, combined with other measured responses to fertiliser placement (2016 and 2017) suggest that placement may be a tool to improve N supply in sands where there is immobilisation pressure.



Overall, the timing of N fertiliser has not had a big impact on yield and there was a notable absence of response to N inputs over the five years of experimentation on the swale soil (including a lack of difference between nil and plus N fertiliser, data not shown) (Table 3). However, there have been a few cases (3 of 10 sand site years) where all N at sowing on sands did generate more yield (in the order of 16-40% more yield). Immobilisation is likely to be proportionally more important on these sands and there are seasonal variables that enhance it's effects. However, the overall season type did not appear to drive the effectiveness of the in-season N application and in all cases the in-season N was applied with impending rainfall.

In the lower fertility Mallee soils, N tie-up and associated N deficiency could exacerbate effects of soilborne diseases (e.g. rhizoctonia disease), in turn reducing yields, hence fertilisation strategies should compensate for N tie-up effects, especially in cereal stubble retained systems. However, as stubble retention increases MB and overall N supply potential, long-term stubble management generally improves N supply potential and overall N availability.

Fertiliser N use recovery

Fertiliser N use efficiency is calculated as the amount of urea N applied which ends up in the wheat plant the year the fertiliser is applied. In the 2014 season it was 40% in the Mallee sand at Karoonda, 35% in the clay vertisol at Horsham and 45% in the red brown earth at Temora (Table 4). These results support previous observations from across different regions of Australia i.e. $44 \pm 14\%$ (Angus and Grace, 2017). The fertilizer recovery at Cummins varied depending upon the time of application (Table 4). Fertiliser use efficiency is affected by seasonal conditions and soil properties influencing the conversion of fertiliser N into plant available nitrate and losses of N as gases and N leaching. Immobilisation (tie-up and/or opposite of mineralisation) of N fertiliser in microbial biomass would also affect its immediate availability to plants depending upon the quantity and quality of stubble, tillage and time of application.

Residual fertiliser N use efficiency refers to the amount of N applied to a previous crop which becomes available to the following crop. The residual recovery values varied between sites likely due to the differences in rainfall. For example, at Horsham, in 2015 it was 10% and in 2016 it was 13%

(for example 10% of the total amount of N in the 2015 wheat crop was supplied through the residual fertilizer of the 2014 crop) which becomes available in the following year.

Post-sowing N tie-up by retained stubble

The evidence emerging from these studies suggests that even where cereal crop residues are retained on the soil surface (either standing or partially standing) and not incorporated, significant N immobilisation can be detected pre-sowing in some seasons. The extent to which differences emerge are related to seasonal conditions (wet, warm conditions) and to the time period between stubble treatment (burning or grazing) and soil sampling to allow differences to develop. However, even where soil N levels at sowing are similar between retained and burnt treatments (which may result from the fact that burning is done quite late) ongoing N immobilisation post-sowing by the microbes growing in-crop is likely to reduce the N available to crops in retained stubble as compared to those in burnt stubble, especially during the early crop growth period. At the Karoonda site, based on the amount of MB, a 3 t/ha stubble load could cause 19-24 kg N/ha of N tie-up depending upon the seasonal conditions.

Table 3 Wheat yield (t/ha) in response to time of fertilizer application and season (2010-2014) on different soil types in a dune-swale system in the Mallee region of SA (McBeath et al. 2015)

Fertilizer treatment	2010	2011	2012	2013	2014	Average
	Swale					
High N upfront ^{&}	4.3	3.4	3.2	1.3	3.0	3.04 (4.1%*)
High N split [§]	4.0	3.3	2.9	1.4	3.0	2.8
Mid-slope						
High N upfront	3.2	3.8	2.4	1.8	3.5	2.94 (7.3%)
High N split	3.1	3.6	1.7	1.8	3.5	2.74
Dune						
High N upfront	2.0	2.9	1.5	1.6	2.1	2.02 (9.8%)
High N split	2.0	2.5	1.3	1.6	1.8	1.84

Note: Within a season and soil, yield values in response to fertilizer strategies that are significantly different ($P < 0.05$) are shown in bold. *Values in brackets indicate percentage higher than 'High N split' application. [&]40 kg N/ha with 10 kg P/ha applied at sowing, [§]N inputs split (9 kg N/ha at sowing and 31 kg N/ha first node with 10 kg P/ha at sowing). The N inputs split treatment received the second application of N at an earlier stage in 2013 and 2014, applied at early tillering.

Table 4 Recovery of urea fertilizer nitrogen taken up by wheat crops

Location	Soil type	Year applied	1 st wheat	2 nd wheat	3 rd wheat
			% urea fertilizer N applied		
Karoonda, SA	Mallee Sand	2014	40	4	2
Horsham, VIC	Vertisol	2014	35	10	13
Temora, NSW	Red brown earth	2014	45	7	2
Cummins, SA	Cummins Clay	10 April 2015	26	-	-
Cummins, SA	Cummins Clay	14 May 2015	51	-	-

Conclusions

In stubble retained systems in the Mallee, cereal stubble contributes only a small percentage (1-2%) of the N requirement for a following cereal crop, hence it should mainly be considered as a source of C for soil microorganisms. Our studies have confirmed a risk of N-tie up by surface-retained and standing cereal residues which may occur in-season, in addition to during the summer fallow, and so may not be picked up in pre-sowing soil mineral N measurements. Yield penalties from retained residues especially to successive cereal crops could be reduced by reducing the stubble load or by applying more N (~5 kg N per t/ha of cereal residue) and applying it earlier to the following crop. However, it is important to note that stubble provides the much needed C source to soil microorganisms in Australian agricultural soils. Deep placement of the N improved N capture by crops irrespective of stubble management, but was especially effective in stubble-retained situations. Although, N tie-up is a temporary issue, it could be potentially costly as early N supply is important for plant nutrition and health. In summary, N tie-up is an easily managed issue for growers with suitable attention to the management of stubble and N fertiliser.

Acknowledgements

We would especially like to thank Loller family (Karoonda), Darryl Moore (Horsham), O'Connor family (Harden) for the long-term use of their land for these experiments. We acknowledge the expert technical assistance

provided by CSIRO staff (Mel Bullock, Tony Swan) and BCG staff (Claire Browne) and Farmlink Research (Paul Bruest, Tony Pratt, Colin Fritsch) who managed and measured the experiments. Funding was provided through GRDC Projects: CSP00174, CSP00186, MSF00003 and BWD00024.

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