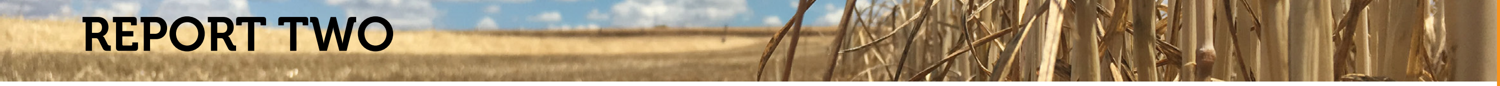

REPORT TWO

The effects of stubble on nitrogen tie-up and supply

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Take home messages

Cereal stubble should be thought of as a source of C for microbes, not as a source of N for crops. In no-till systems, only ~6% of the N requirement of crops derived from the stubble.

N tie-up by cereal residue is not just a problem following incorporation – it occurs in surface-retained and standing-stubble systems and can reduce wheat yields by 0.3 to 0.4 t/ha.

Management 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.

Deep-banding N can improve the N uptake, yield and protein of crops, especially those in stubble-retained systems.

Background

Most dryland farmers in Australia retain all, or most of their crop residues (wherever possible) to protect the soil, retain soil moisture and maintain soil fertility in the long term. However, a pro-active 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 (Swan *et al.,* 2017a). One such situation is where large amounts of retained stubble, especially high C:N ratio cereal stubble, "ties-up" soil nitrogen 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. In this paper we firstly review in simple terms the process of N tie-up or immobilisation as it is known, to understand the factors driving it. We then provide the results from a series of recent experiments in 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.

The process of "N-tie up" (immobilisation) – put simply

Farmers are always growing two crops – the above-ground crop (wheat, canola, lupins etc) is obvious, but the below-ground crop (the microbes) 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 2/3 are in the top 10cm 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.

A worst-case scenario

That simplified background helps to understand the process of immobilisation, when and why it happens, and how it might be avoided or minimised. Imagine a paddock on 5th April with 8t/ha of undecomposed standing wheat stubble from the previous crop after a dry summer. A 30mm storm wets the surface soil providing a sowing opportunity. Fearing the seeding equipment cannot handle the residue, but not wanting to lose the nutrients in the stubble by burning, the residue is mulched and incorporated into the soil. A canola crop is sown in mid-April with a small amount of N (to avoid seed burn) and further N application is delayed until bud visible due to the dry subsoil.

So in this case, the cereal stubble (high carbon and low nitrogen – usually ~90:1) is well mixed through a warm, moist soil giving the microbes maximum access to a big load of carbon (energy)

– but not enough nitrogen (microbe bodies need a ratio of about 7:1). The microbes will need all of the available N in the stubble and the mineral N in the soil, and may even break-down some existing organic N (humus) to get more N if they need it (so carbon is lost from the soil!). The microbes will grow rapidly, so when the crop is sown there will be little available mineral N - it's all "tied-up" by the microbes as they grow their population on the new energy supply. Some of the microbes are always dying as well but for a time more are growing than dying, so there is "net immobilisation". As the soil cools down after sowing, the "turnover" slows, and so is the time taken for more nitrogen to be released (mineralised) than consumed (immobilised) and net-mineralisation is delayed. Meanwhile - the relatively N-hungry canola crop is likely to become deficient in N as the rate of mineralisation in the winter is low. This temporary N-deficiency if not corrected or avoided, may or may not impact on yield depending on subsequent conditions.

Based on the simple principles above, it's relatively easy to think of ways to reduce the impact of immobilisation in this scenario:

1. The stubble load could be reduced by baling, grazing or burning (less C to tie up the N)
2. If the stubble was from a legume or canola rather than cereal (crop sequence planning) it would have lower C:N ratio and tie up less N.
3. The stubble could be incorporated earlier (more time to move from immobilisation to mineralisation before the crop is sown)
4. N could be added during incorporation (to satisfy the microbes and speed up the "turnover")
5. More N could be added with the canola crop at sowing (to provide a new source of N to the crop and microbes), and this could be deep-banded (to keep the N away from the higher microbe population in the surface soil to give the crop an advantage)
6. A different seeder could be used that can handle the higher residue without incorporation (less N-poor residue in the soil)
7. A legume could be sown rather than canola (the legume can supply its own N, can emerge through retained residue and often thrives in cereal residue).

In modern farming systems, where stubble is retained on the surface and often standing in no-till, control-traffic systems, less is known about

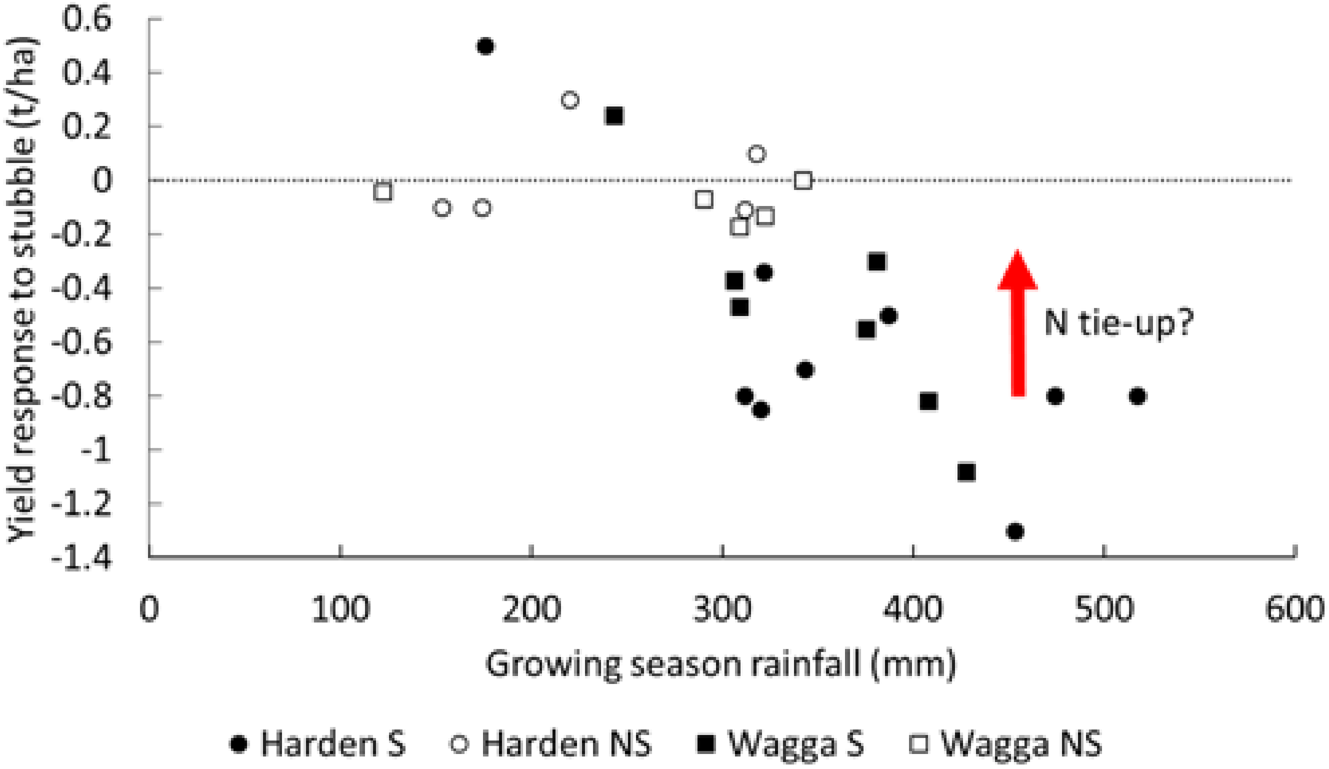

Figure 1: Effect of retained stubble on wheat yield is worse in wetter seasons at the Harden (circles) and Wagga (squares) long-term tillage sites. Open symbols where difference between retain and burnt were not significant (NS), solid where significant (S).

the potential for immobilisation. In GRDC-funded experiments as part of the Stubble Initiative (CSP187, CSP00174), we have been investigating the dynamics of N in stubble-retained systems. Here we provide examples from recent GRDC-funded experiments in southern NSW, and discuss the evidence for the impact of immobilisation and provide some practical tips to avoid the risks of N tie-up.

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

Harden long-term site

In a long-term study at Harden (28 years) the average wheat yield has been reduced by 0.3 t/ha in stubble retained vs stubble burnt treatments, but the negative impacts of stubble were greater in wetter seasons (Figure 1). Nitrogen tie-up may be implicated in wetter years, due to higher crop demand for N and increased losses due to leaching or denitrification. But we rarely found significant differences in the starting soil mineral N pre-sowing. For many years, we were not convinced N tie-up was an issue (though we had insufficient measurements to confirm it).

In 2017, we implemented two different experiments in sub-plots at Harden to investigate the potential role of nitrogen tie-up in the growth and yield penalties associated with stubble. A crop of wheat (cv. Scepter) was sown on 5 May following a sequence of lupin-canola-wheat in the previous years. In both the stubble-retained and stubble-burnt treatments we compared 50 or 100 kg N/ha broadcast as urea at sowing in one experiment, and compared the 100 kg N/ha surface applied with 100 kg/N deep-banded below the seed. The pre-sowing N to 1.6 m was 166 kg N/ha in retained and 191 kg N/ha in burnt, but was not significantly different. Plant population, growth and N content at GS 30 did not differ between treatments (data not shown) but by anthesis, the biomass and tiller density were significantly increased by the additional 50 kg/ha of surface-applied N in the stubble-retained treatment, while there was no response in the stubble burnt treatment. At harvest, both stubble retention and increased N improved grain yield, but the increase due to N was higher under stubble retention (0.6 t/ha) than stubble burnt presumably due to improved water availability. The increase in yield with higher N, and the low protein overall (and with low N) suggests N may have been limiting at the site, but the water-saving benefits of the stubble may have outweighed the earlier effects of immobilisation.

Table 1: Effect of additional surface applied and deep-placed N on wheat response in stubble burnt and retained treatments at Harden in 2017.

Treatment		Anthesis		Harvest (@12.5%)	
Stubble	N	Biomass (t/ha)	Tillers (/m^2)	Yield (t/ha)	Protein (%)
Retain	50	7.1	324	4.3	8.8
	100	8.4	401	4.9	9.6
Burn	50	8.8	352	4.2	9.3
	100	8.7	372	4.5	10.5
LSD ($P<0.05$)	Stubble	0.9	ns	0.2	ns
	N	0.5	33	0.1	0.2
	Stubble x N	0.8	38	0.2	ns

Deep-banding the N fertiliser had no impact on crop biomass or N% at GS 30, but increased both the biomass and N content of the tissue at anthesis more in the retained-stubble than in burnt stubble (Table 2). Retaining stubble decreased biomass overall but not tissue N. N uptake (kg/ha) at anthesis was significantly increased by deep-banding in both stubble treatments, however the increase was substantially higher in the stubble-retain treatment than in the burn treatment (38 kg N/

Table 2: Effect of surface-applied and deep-banded N on wheat response in stubble-burnt and stubble-retained treatments at Harden in 2017.

Treatment		Anthesis			Harvest (@12.5%)	
Stubble	100 N	Biomass (t/ha)	Tissue N (%)	N Uptake (kg N/ha)	Yield (t/ha)	Protein (%)
Retain	Surface	8.1	1.1	91	4.5	9.3
	Deep	9.1	1.4	129	5.1	10.2
Burn	Surface	8.9	1.2	104	4.5	10.3
	Deep	9.5	1.3	119	5.0	10.8
LSD ($P<0.05$)	*Stubble*	0.6	ns	ns	ns	0.8
	N	0.2	0.1	8	0.2	0.4
	Stubble x N	0.6	0.2	12	ns	ns

*Table 3: Effect of stubble burning on grain yields at Temora in Phase 1 and 2. Crops in italics are canola, and bold are the 2nd wheat crops. * shows where significantly different (P<0.05)*

Phase	Treatment	2009	2010	2011	2012	2013	2014	2015	2016	2017
Phase 1	Retain	1.7	*4.2*	4.6	4.4	*0.7*	3.8	4.1	*3.2*	3.7
	Burn	1.7	*4.0*	4.6	5.0*	*1.0*	3.8	4.6*	*3.2*	3.2
Phase 2	Retain	-	6.3	*3.4*	4.5	2.0	*2.0*	5.5	5.2	*2.1*
	Burn	-	6.2	*3.5*	4.8	3.4*	*2.0*	5.3	5.7*	*2.4*

ha *cf* 15 kg N/ha). The overall impact of deep-banding on yield persisted at harvest, but there was no effect, nor interaction with stubble retention, presumably due to other interactions with water availability. However the fact that deep-banding N has had a bigger impact in the stubble retained treatment provides evidence of an N-related growth limitation related to retained stubble. It's appearance at anthesis, and not earlier, presumably reflects the high starting soil N levels which were adequate to support early growth but the cold dry winter generated N deficiencies as the crop entered the rapid stem elongation phase. The increased protein content related to both burning and deep-banding and its independence from yield, suggest on-going N deficiencies generated by those treatments.

Temora site

At Temora, a 9-year experiment managed using no-till, controlled traffic, inter-row sowing (spear-point/press-wheels on 305mm spacing) in a canola-wheat-wheat system investigated the effects of stubble burning and stubble grazing on soil water, nitrogen and crop growth. In the stubble retain treatment, stubble was left standing through summer, and fallow weeds were strictly controlled. In the stubble grazed treatment weaner ewes were allowed to crash graze the stubble immediately after harvest for a period of 7-10 days and weeds were controlled thereafter. Stubble was burnt in mid-late March and the crop sown each year in mid-late April. Nitrogen was managed using annual pre-sowing soil tests whereby 5 kg/ha N was applied at sowing and N was top-dressed at Z30 to attain 70% of maximum yield potential according to Yield Prophet® (see Swan *et al.*, 2017 for full details).

Burning

In un-grazed treatments, retaining stubble, rather than burning had no impact on the yield of canola or the first wheat crop over the 9 years, but consistently reduced the yield of the second wheat crop by an average on 0.5 t/ha (Table 3). This yield penalty was associated with an overall significant reduction in pre-sowing soil mineral-N of 13 kg/ha, while there was no significant difference in pre-sowing N for the first wheat crop (Table 4).

Table 4: Mean effect of stubble burning or grazing across years and phases on soil mineral N (kg N/ha) to 1.6m depth prior to sowing either 1st or 2nd wheat crops at Temora. LSD for interaction of treatment and rotational position where P<0.05.

Rotation position	**Stubble treatment**		**Grazing treatment**	
	Retain	**Burn**	**No graze**	**Graze**
1st wheat	117	110	107	120
2nd wheat	102	115	92	125
LSD (P<0.05)	13		13	

Grazing

Grazing stubbles never reduced the yield of any crop at the site, but increased the yield of the second wheat crop by 1.2 t/ha in 2013 (Phase 1) and by 1.0 t/ha in 2015 (Phase 2) Table 5. This was unrelated to pre-sowing soil N in 2013 (both had ~85 kg N/ha at sowing) where we suspect increased frost effects in the ungrazed stubble – while in 2015, the yield benefit was related to pre-sowing N with an extra 61 kg/ha N at sowing in the grazed plots. Overall, grazing increased the

*Table 5: Effect of grazing stubble on grain yields at Temora in Phase 1 and 2. Crops in italics are canola, and bold are the 2nd wheat crops. * shows where significantly different (P<0.05)*

Phase	**Treatment**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Phase 1	**No graze**	1.7	*4.2*	4.6	**4.4**	*0.7*	3.8	**4.1**	*3.2*	3.7
	Graze	1.7	*4.3*	4.5	**4.8**	*0.9*	3.7	**5.3***	*3.3*	3.3
Phase 2	**No graze**	-	6.3	*3.4*	4.5	**2.0**	*2.0*	5.5	**5.2**	*2.2*
	Graze	-	6.2	*3.3*	4.8	**3.0***	*2.2*	5.6	**5.6***	*2.3*

pre-sowing N by 13 kg/ha in the first wheat crop and by 33 kg/ha in the second wheat crop (Table 4).

Deep N placement

In an adjacent experiment at Temora in the wet year of 2016, deep N placement improved the growth, N uptake and yield of an N-deficient wheat crop but this occurred in both the stubble retained and the stubble removed treatments and there was no interaction suggesting N availability was not reduced under stubble retention (Table 6). However we believe the level of N loss due to waterlogging in the wet winter and the significant overall N deficiency may have masked these effects which were more obvious at Harden in 2017.

*Table 6. Effect of deep banding vs surface applied N (122 kg N/ha as urea) at seeding, at Temora NSW in 2016 (starting soil N, 58 kg/ha). The crop captured more N early in the season which increased biomass and yield in a very wet season. (Data mean of 3 stubble treatments). *indicates significant differences (P<0.01). (Data source: Kirkegaard et. al., CSIRO Stubble Initiative 2016 CSP00186)*

Treatments	**Z30**			**Anthesis**			**Grain Yield (t/ha)**
	Biomass (t/ha)	**N%**	**N-uptake (kg/ha)**	**Biomass (t/ha)**	**N%**	**N-uptake (kg/ha)**	
Surface	1.4	3.8	51	7.8	1.3	103	4.0
Deep	1.4	4.4*	60	9.2*	1.5*	136*	5.2*

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. This was demonstrated in 2017 at Harden where the additional 50 kg N/ha applied at sowing completely removed the early growth reduction observed in the stubble-retained treatment, although due to the overall water limitation at the site, this did not translate into yield.

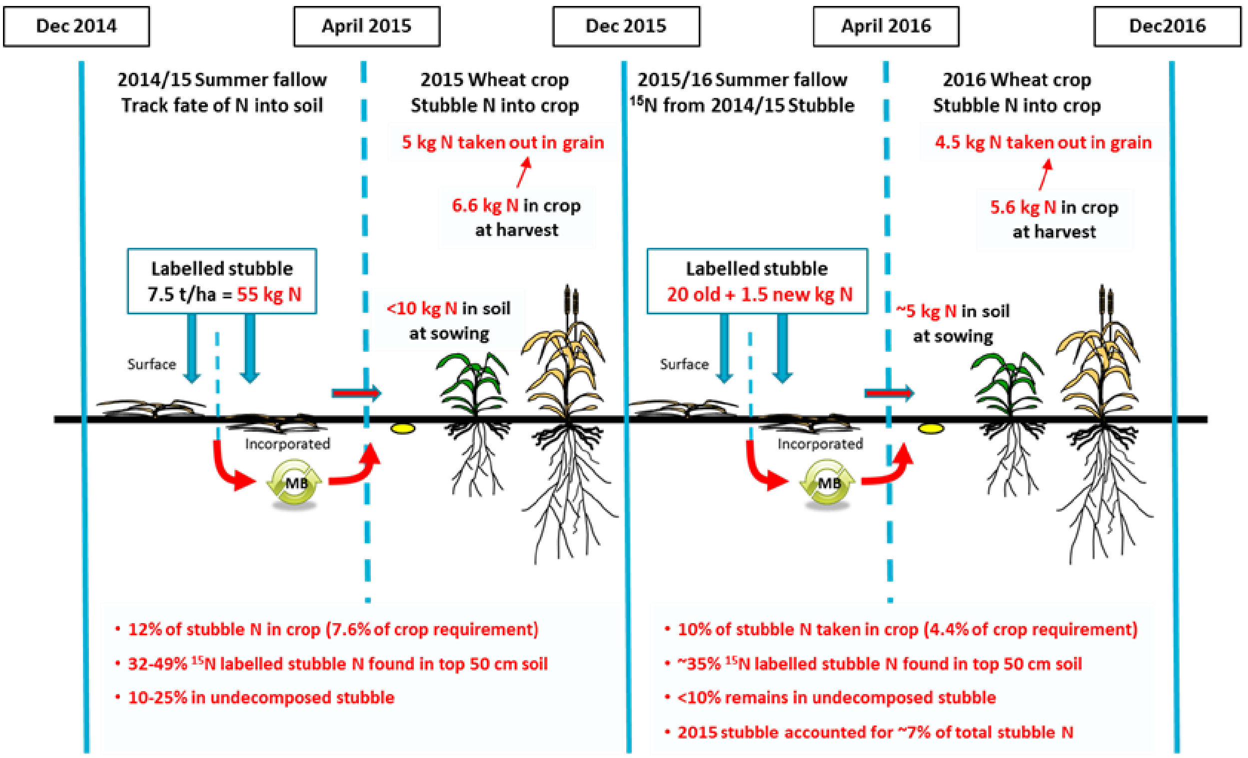

Figure 2. The fate of the N contained in retained wheat stubble over two years in successive wheat crops following the addition of 7.5 t/has of wheat stubble containing 55 kg/ha N. The successive crops took up 12% (6.6 kg N/ha) and 10% (5.6 kg N/ha) of the N derived from the original stubble representing only 7.6% and 4.4% of the crops requirements. Most of the stubble N remained in the soil (35%) or was lost (33%).

Cereal stubble isn't a good source of N for crops

Studies at 3 sites in southern Australia (Temora, Horsham and Karoonda) have tracked the fate of the N in stubble to determine how valuable it is for succeeding wheat crops under Australian systems. Stubble labelled with ^{15}N (a stable isotope that can be tracked in the soil) was used to track where the stubble N went. At Temora (Figure 2), of the 55 kg/ha of N contained in 7.5 t/ha of retained wheat residue retained in 2014, only 6.6 kg/ha N (12 %) was taken up by the first crop (representing 12 % of crop requirement); and 5.6 kg/ha N (10%) was taken up by the second wheat crop (4.4% of crop requirement). The majority of the N after two years remained in the soil organic matter pool (19.1 kg N/ha or 35%) and some remained as undecomposed stubble (10% or 5.5 kg N/ha). Thus we can account for around 67% of the original stubble N in crop (22%), soil (35%) and stubble (10%) with 33% unaccounted (lost below 50 cm, denitrified). 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 main point is that the N in cereal stubble represented only 6% of crop requirements over two years (7.6% Year 1; 4.4% Year 2) and takes some time to be released through the organic pool into available forms during which losses can occur.

Conclusion

Our studies have confirmed a risk of N-tie up by surface-retained and standing cereal residues which may occur in-season, rather than during the summer fallow, and so may not be picked up in pre-sowing soil mineral N measurements. Yield penalties for retained residues were significant, but confined to successive cereal crops, and could be reduced by reducing the stubble load or by applying more N (~5kg N per t/ha of cereal residue) and applying it earlier to the following crop. Deep placement of the N improved N capture by crops irrespective of stubble management, but was especially effective in stubble-retained situations. In summary, N tie-up is an easily managed issue for growers with suitable attention to the management of stubble and N fertiliser.

Useful resources

http://www.farmlink.com.au/project/maintaining-profitable-farming-systems-with-retained-stubble

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