Managing nitrogen nutrition under intensive cropping in low rainfall environments

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Abstract
In sandy soils of low fertility the need for increasing inputs of nitrogen (N) as the intensity of cereals increases is clear. Testing of N management strategies on dune, mid-slope and swale soils at Karoonda, South Australia over six different growing seasons ranging from decile three to ten rainfall, showed that yield was substantially improved by increasing N inputs (from 9 to 40 kg N/ha) on the sandy soils and that production was maintained at nil N input on the swale. However, analysis of net N balance supports the increasing concern that intensive, cereal-dominant cropping systems are drawing down on soil organic N reserves where N inputs are low. The inclusion of a legume based pasture break on this site had a measurable positive impact on both grain yield and N supply to subsequent crops. However, this increased N supply was over a limited timeframe. Therefore even with a legume based break, fertiliser derived N was required to maintain productivity. In low rainfall environments, deferring a significant proportion of the N input until later in the season when estimates of yield potential can be made with more certainty is an attractive concept for managing risk. However, testing of in-season N application over a range of seasons showed that some sandy soils that have been intensively cropped with cereals are so deficient in N that the benefit of eliminating early season N deficiency can outweigh potential efficiency gains from later in-season N application.

Key words
Soils, Fertiliser, Mallee, Nitrogen Supply Potential, Nitrogen Balance

Introduction

The intensification of cropping, particularly of cereals, in low-rainfall environments in Australia has been advocated as a management strategy that increases profit for growers. The low rainfall (< 350 mm annual rainfall) Mallee environment features dune swale systems with soil types that vary considerably in production potential within relatively small distances (Rab et al. 2009). The sandy topsoils associated with the dunes and mid-slopes are low fertility in terms of organic matter and nutrition, in particular nitrogen (N) and microbial activity. Microbial activity and N mineralisation to supply N to crops in these soils with low organic matter are largely dependent upon the quantity and quality of carbon inputs from crop residues and is often a yield limiting factor (Gupta *et al*. 2011). Cropping intensification can lead to a reduction in the frequency of legumes, which results in a decline in soil organic N reserves (Angus et al. 2006). The study presented here is one of very few involving multiple soil types in the Mallee land system and measuring net N balance over a long-term sequence. The aims of this study were to identify:

1. Optimal N input levels for each soil type considering long-term net N balance; and
2. Soil-specific strategies for increasing the yield and improving the N nutrition of cereals.

Method

Wheat crops were sown in May of 2010-2014 (following opening rains of at least 20mm) at Lowaldie (S 33°59.616, E 136° 19.915) 20 kms North East of Karoonda, SA. The agronomic treatments included volunteer pasture in 2010 followed by wheat managed with district practice fertiliser inputs (9kg N/ha and 10 kg P/ha applied as DAP at sowing) for the remainder of the experiment, and continuous wheat treatments with the use of nil fertiliser inputs, district practice fertiliser inputs, higher N inputs at sowing (40 kg N/ha with 10 kg P/ha) and higher N inputs split (9 kg N/ha at sowing and 31 kg N/ha first node with 10kg P/ha at sowing). The volunteer pasture had an approximate composition of 1.8-3.1 t/ha medic and 0.5-2.5 grass and broadleaf weeds and was spraytopped in spring but did not receive any other management intervention. The treatments were applied to 15 m long plots on four key Mallee soil types (swale, mid-slope, dune-crest and dune) and treatments were arranged in a randomised complete block design with four replicates. The difference between management strategies within a soil and season was analysed using ANOVA.

The soils were characterised for a range of properties given in Table 1. The swale had higher pH, organic carbon content, cation exchange capacity and mineral N content with lower water repellency than the other soil types and all soils had Colwell P status in the adequate range. All soils with a sandy topsoil layer (mid-slope, dune-crest and dune) had water repellency and low organic carbon. The dune-crest had the lowest plant available water capacity with no water extraction below 60cm depth (Table 1). The direct cause of this has not yet been determined.

Table 1. Key soil properties at the commencement of treatments in 2010.

Soil Property	Swale	Mid-slope	Dune-crest	Dune
Topsoil texture	Loam	Sand	Sand	Sand
[a]Soil pH (H_2O, 1:5), 0-10cm depth	7.4	6.6	6.3	6.3
[b]Colwell P (mg/kg), 0-10cm depth	39	30	28	25
[c]Organic Carbon (% w/w), 0-10cm depth	1.4	0.7	0.5	0.5
[d]Mineral N (kg/ha), 0-100cm depth	168	115	NA	57
N supply potential (kg N/ha/average growing season)	31.5	18.6	NA	12.0
[f]Plant Available Water Capacity (mm water/ 100cm depth)	116	110	31	120

Methodologies for assessment of soil properties are all available in Rayment and Lyons (2011);[a]4A1,[b]9B1, [c]6A1, [d]7C2b. [e]Analysed according to Burk and Dalgliesh (2008).

Soils from a subset of treatments were analysed using the N supply potential technique described in McBeath et al. (2015). Briefly, the technique is a measurement of microbial biomass N and N mineralised following a 21 day moist incubation where it is assumed that 50% of the microbial biomass N is available for plant uptake. The N balance for a given year was calculated as N balance (kg/ha) = N input (kg/ha)-N Yield (kg/ha) where, N Input= N fertiliser (kg/ha) + N supplied from legumes (kg/ha) + 10 kg/ha N from free living N fixation (Gutpa et al. 2006). N from legumes= 25% of N fixed in year prior (Ladd et al. 1986) assuming 20kg N/t dry matter is fixed (Peoples et al. 2009). N Yield= grain yield (kg/ha) x grain N content (protein/ 5.7). The net N balance is the cumulative outcome of yearly N audit for the five years of the experiment. The audit did not account for N losses through leaching, volatilisation or denitrification or differences in fertiliser use efficiency for different soils and seasons.

Results and Discussion

Yield

There was a notable absence of significant response to the N management strategies imposed over the five years of experimentation on the swale soil (Table 1). As discussed elsewhere, this supports the conclusion that reduced inputs on the swale soil type are feasible in this particular environment (Monjardino et al. 2013). Confidence in this strategy has grown in light of the lack of response to fertiliser input over five years with a range of season types from decile 3 to 10. However, the productive potential of this soil relative to the other soil types in the same paddock cannot be ignored and the effect of reduced inputs requires monitoring to ensure that production potential is not jeopardised. On the mid-slope soil, there was a difference between nil fertiliser and district practice (Table 2). Because the nil fertiliser did not receive any P inputs, it was not possible to determine with certainty whether the response was related to inputs of N or P, however soil P test results indicated that this soil should have been adequate for P at the commencement of the experiment (Table 1). On the dune-crest and dune soils, it was only with inputs of more N through fertiliser (at 40 kg N/ha) or a legume based pasture break that yields were significantly more than the nil fertiliser and district practice treatment. In 2013 and 2014, three and four years after the last pasture break, the effect of the pasture break on productivity was reduced to levels equivalent to district practice yields (Table 2). These results suggest that, in the absence of a major disease problem, N is a major driver of yield on these sandy soil types, and that repeated inputs at higher levels of fertiliser input are required to maintain productivity. The difference between supplying extra N in fertiliser at sowing compared with in-season was less consistent. Generally, the best yields were achieved with the extra fertiliser N applied at sowing, but in some instances there was no penalty for delaying to an in-season application (Table 2). The 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.

Nitrogen Supply Potential and Nitrogen Audit

Analysis of the two best yielding treatments showed that there was a greater potential supply of N in the year following a legume-based pasture break (2011) compared with increased inputs of N fertiliser at sowing (Figure 1). In the second year after the pasture break (2012), these differences were not significant (Figure

1). This suggests that the N related break benefit has a limited time span and is consistent with additional break crop experiments located at the same site (McBeath et al. 2015). Had the pasture treatment been more intensively managed (e.g. weed control and pasture sown for higher density) it is possible that more N related benefits would have been available for subsequent crops. Given 2010 was a decile 10 season it is possible that pasture production and resulting N fixation was well above normal levels but additional trials at this site measured comparable N derived break effects in later seasons (McBeath et al. 2015).

Table 2. Yield in response to season (2010-2014), soil type and management, including a volunteer pasture in 2010. Within a season and soil, the row is appended by a least significant difference (LSD) value. Yield in response to management strategies that differ by more than the LSD are significantly different (P < 0.05). The magnitude of the LSD for each soil and season illustrates the level of in-paddock variation that needs to be managed even within soil types.

Year	Nil Fertiliser	District Practice	High N Upfront	High N Split	Volunteer Pasture	LSD
			Swale			
2010	4.4	4.2	4.3	4.0		NS
2011	3.3	3.1	3.4	3.3	3.6	0.4
2012	2.8	2.7	3.2	2.9	2.8	NS
2013	1.4	1.4	1.3	1.4	1.5	NS
2014	2.7	2.8	3.0	3.0	2.8	NS
			Mid-slope			
2010	2.6	3.0	3.2	3.1		0.6
2011	2.7	3.1	3.8	3.6	4.5	0.4
2012	1.2	1.7	2.4	1.7	2.4	0.4
2013	1.0	1.3	1.8	1.8	1.6	0.3
2014	2.0	2.5	3.5	3.5	2.6	0.4
			Dune-crest			
2010	0.8	1.1	1.7	1.4		0.5
2011	0.8	1.0	2.1	1.4	2.9	0.4
2012	0.4	0.4	0.8	0.5	0.9	0.3
2013	0.3	0.4	0.8	0.7	0.6	0.2
2014	0.5	0.8	1.6	1.3	1.1	0.4
			Dune			
2010	1.4	1.4	2.0	2.0		0.6
2011	1.8	2.0	2.9	2.5	2.8	0.4
2012	0.9	0.8	1.5	1.3	1.2	0.4
2013	0.6	0.9	1.6	1.6	1.1	0.4
2014	0.8	1.1	2.1	1.8	1.2	0.4

X shaded cells denotes significantly greater than nil, X shaded cells denotes significantly greater than nil and district practice.

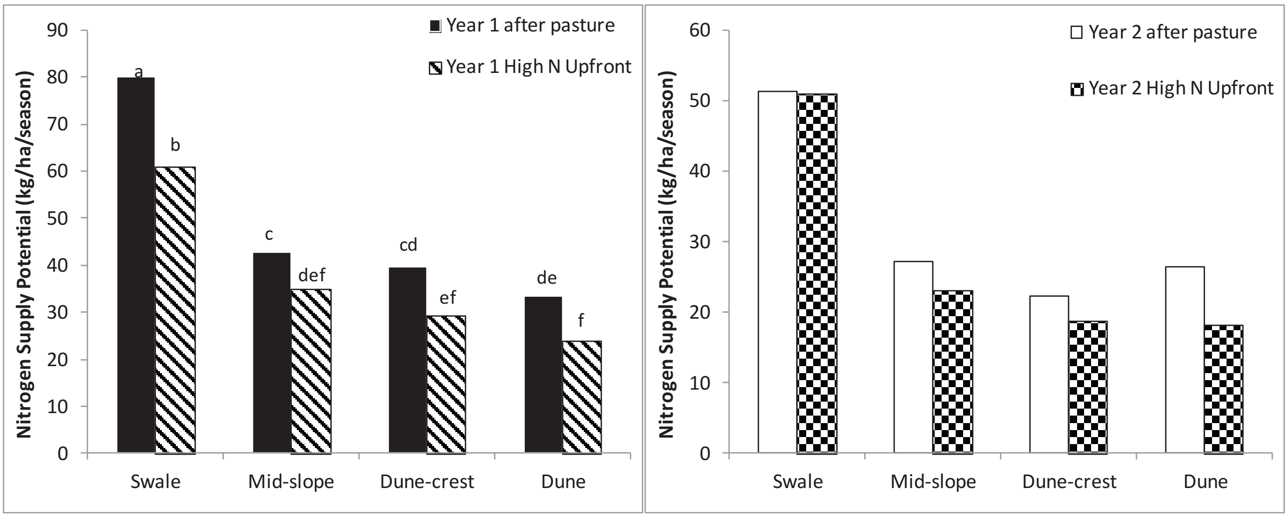

Figure 1. Nitrogen supply potential (kg N/ha/average growing season) in response to treatments with higher N inputs on key Mallee soil types. In Year 1 at P 0.05, LSD between treatments was 8.7 kg/ha/ growing season while in Year 2 P >0.05. A column appended by a different letter is significantly different from another.

An audit of N inputs and outputs highlighted that while productivity on the swale was maintained without additional inputs of N, the N balance was negative and soil organic N reserves were likely being depleted. An alternative view is that there could have been movement of N from the dune to the swale that has supplied N to maintain crop production on these soils, but this has not been confirmed by measurement. The low N input treatments (over the five year period) resulted in a negative balance for N on the mid-slopes with a neutral balance at 40 kg N/ha input. On the low yielding dune-crest, the N balance was positive for all levels of fertiliser N input and up to 117 kg N/ha. This is indicative of the presence of other constraints to production (e.g. soilborne diseases) on this soil type preventing utilisation of the N applied. On the dune, there was a positive N balance for high inputs of N at 54-60 kg N/ha over the five year period.

Table 3. The net N balance (kg N/ha) following five year implementation of treatments on key Mallee soil types. Within a soil (row) at P 0.05, LSD between treatments was 34 kg N/ha and a treatment annotated with a different letter is significantly different from another.

Soil	Nil Fertiliser	District Practice	High N Upfront	High N Split	Volunteer Pasture
Swale	-210 d	-156 c	-82 ab	-61 a	-102 b
Mid-slope	-102 b	-81 b	-5 a	10 a	-92 b
Dune-crest	-22 c	23 b	91 a	117 a	-24 b
Dune	-64 c	-15 b	54 a	60 a	-21 b

Conclusions

Cereals grown on sands showed continued responses to N inputs at levels higher (40 kg N/ha) than district practice (9 kg N/ha) while heavier soils on the swales maintained production with nil or low N input, but a net N audit suggests the possibility of a significant decline of soil N reserves at this level of inputs. Break effects derived from legume based pastures only lasted for up to two years. As a result maintaining N in the system using N inputs of fertiliser and/or legume based breaks is required on sandy soils in the Mallee to maintain production.

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