Can soil-specific inputs of N fertiliser be a risk-reducing strategy?

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Abstract

The dune-swale land system typical of the Mallee environment has strongly contrasting soil types with differing fertility. Variable rate fertiliser applications are increasingly being used to deal with this variation which typically exists within paddocks. However, nitrogen (N) deficiency remains a major determinant of the gap between actual and potential wheat yields in low fertility sandy soils. In this study we used N fertiliser trials across dune-swale soil types and two growing seasons in conjunction with biophysical simulation and economic analysis of returns using several measures of riskiness to develop N management guidelines that consider the range of possible outcomes caused by differing seasonal conditions. The level of risk that is acceptable to a land manager will vary and we have undertaken an analysis that incorporates levels of risk preference. Results from field trials on dune, mid-slope and swale soils at Karoonda, South Australia, show that yield and profit can be maximised by using lower N rates on swales in order to provide the opportunity to increase N inputs on the sandy soils. This is supported by the outcomes of crop simulation across 60 season types where returns for additional fertiliser N above the district practice level of 15 kg/ha were substantially greater on dune soils relative to swale soils. Including risk aversion suggests that preferred N rates will be well below yield and profit maximising rates. However, even risk-averse land managers were found to benefit from increases in the level of N fertiliser application on sandy soils. Soil-specific N rates can reduce the level of risk associated with using higher N inputs to increase average crop returns.

Key words
Mallee, economics, risk aversion, simulation, field experiments, @risk, APSIM

Introduction

Cropping in the low-rainfall Mallee region of south-eastern Australia is risky business, caused by high climatic and within-paddock soil variability. High spatial variation in soil types is an important determinant of yield variation within paddocks but, while use of variable rate technology on sub-paddock zones is increasing, it is not yet common practice (Robertson et al. 2011. The Mallee region is characterised by dune-swale systems. The crest of the dune is typically deep sand with low organic matter and N fertility. Moving down the slope, mid-slope soils of this system are characterised by low fertility sands overlaying a clay layer that results in these soils holding both more water and fertility than the deep sands. At the base of the slope, swale soils tend to have the highest levels of organic matter and fertility but often suffer poor production in low rainfall seasons due to the presence of subsoil constraints (Whitbread et al. 2008). Farmers in this region typically minimize the risk of not getting a return on N fertiliser in poor seasons by applying fixed low rates of N to their cereal crops across all soil types. However, N deficiency on the sandier dune soils is one of the main causes of a gap between actual and potential yields in wetter seasons in these environments (Sadras 2002), while poor crop performance on swales in drier seasons leads to high accumulation of N beyond levels required to produce average crops.

In this study we used a combination of field experimentation, crop simulation, economics and finance techniques to estimate the average and variation in net returns, taking both yield and price variation into account. We used a range of risk metrics that may be relevant to the land manager for making N management decisions including: standard deviation; probability of positive returns; downside risk; and return on fertiliser investment. By accounting for variable soil types, we then examined the potential for soil-specific management to allow for use of higher N rates to generate higher profits on some soils, without necessarily increasing exposure to risk.

Methods

Field Experiments
N fertiliser rate experiments were conducted on dune, mid-slope and swale soil types at the Mallee Sustainable Farming research site at Karoonda, South Australia. The experiments were conducted over two growing seasons. Each experiment comprised five rates of N, 0, 10, 20, 40 kg/ha and 80 kg/ha, replicated 3 times in a completely randomised block design. The 80 kg/ha N treatment comprised 40kg N/ha added at sowing followed by an in-season application of 40 kg N/ha at GS31. In the other treatments, N was banded below the seed at sowing. All N was applied as urea. Adequate S, P and micronutrients were applied to overcome potential deficiencies in these nutrients affecting results. In 2010, plots were sown with wheat (*Triticum aestivum* cv. Correll) on the 27th of May and harvested on the 6th of December in a Decile 10 growing season (342 mm). In 2011, plots were sown on the 25th of May with wheat (*Triticum aestivum* cv. Mace) and harvested on the 20th of November in a season with decile 10 annual rainfall (494 mm), but decile 3 growing season (193 mm) rainfall. Plots were sampled and analysed for pre-sowing soil N (using 1M KCl), and grain yield at harvest.

Economic Analysis
The Agricultural Production Systems Simulator (APSIM v.7.3; Keating et al. 2003) was used to model grain-yield responses to a range of N treatments over the 1950-2010 growing seasons for the three soil types at this site. Validation of the model with field trial data gave a relationship between actual and predicted yields with an R^2 of 0.84 and a RMSE of 0.3 t/ha. Daily climate data (1950-2010) came from the SILO historical climate database for the township of Karoonda. In the simulations, lower starting N levels of 18 kg N/ha for the dune, 36 kg N/ha for the mid-slope and 52 kg N/ha for the swale were used. These levels reflect values measured in the region following a long-term continuous cereal cropping history (an expanded version of this work will explore the economic outcome of a range of sowing soil N values for each soil type). The mid-maturity wheat cultivar, Yitpi, was planted every season, with sowing between 25th April and 14th July, following 10 mm of rainfall within a five-day period. The 'treatments' comprised N fertiliser applied as urea at sowing at 0, 7.5, 15, 30, 60, 90, 120 and 150 kg N/ha. Frequency distributions of wheat yields were generated for each of the N treatments and probability density functions were fitted to the frequency distributions to characterise variability in yield using @RISK™ software (Palisade, 2002). In addition, two farm-gate-price datasets were created for the years 1970-2010, one for Australian Standard White (ASW) wheat and the other for N fertiliser (urea) from a range of data sources including historical pool returns from the Australian Wheat Board, commodity statistics (ABARE 2010) and farm budget guides (Rural Solutions SA 2011).

We used a profit function to calculate economic net returns for each yield-price simulation of wheat:
$NR_{nz} = (Y_{nz} \text{ x } P_w)-(R_{nz} \text{ x} P_n)-C_o$

Where, NR_{nz} is the net return by total N rate n on management zone z (\$/ha), Y_{nz} is crop yield by total N rate n on management zone *z* (kg/ha), P_w *is* the price of ASW wheat (\$/kg), R_{nz} is the rate of N applied at sowing on management zone *z* (kg N/ha), P_n is the price of N (\$/kg N), and C_o (\$/ha) are the other cropping costs (seed, weed control, machinery etc) which were assumed to be the same in each simulated crop. To quantify variability in net returns for each scenario, we used @RISK to generate 1000 Monte Carlo simulations (Hardaker and Lien 2010) of net returns with random samples drawn from the modelled probability density functions for yield, as well as with random samples for prices based on the distributions of these prices over the defined period. Frequency distributions were then developed for the average of net returns under all scenarios. Five indicators were used to quantify the expected variability and/or magnitude of net returns from each scenario: mean of expected net return, standard deviation of net return, probability of break-even or positive mean net return (NR≥0), mean of the lowest 10% of mean net return (an indicator of downside risk) and return on N fertiliser investment (value of yield gain/cost of fertiliser N). A Stochastic Efficiency with Respect to a Function (SERF) analysis (Hardaker et al. 2004) was used to rank the preferred N fertiliser rates for each soil type, when accounting for different attitudes to risk, ranging from no aversion to risk where profit maximisation is the only objective through to extreme risk aversion where avoiding income variation is the primary objective. Based on a utility function that incorporates risk aversion, the point at which the decision-maker becomes indifferent between the value of the strategy and its risky outcome gives the certainty equivalent (\$/ha) for that N treatment.

Results and Discussion

Field Experiments
In 2010, soil N levels at sowing ranged from 55 kg N/ha in the dune, 100 kg N/ha in the mid-slope to 170 kg N/ha in the swale. There was a significant response to N on all three soil types in 2010 (Figure 1.A), with a response of 7 kg grain/ kg N on the swale, 16 kg grain/ kg N on the mid-slope and 26 kg grain/ kg N on the dune. The smaller response to N on the swale than the sandy dune and mid-slope soil types was expected due to the high sowing profile N values in the swale. In 2011 sowing soil N levels ranged from 77 kg N/ha in the dune to 83 kg N/ha in the mid-slope and 200 kg N/ha in the swale. There was a significant positive response to N on the dune and mid-slope (Figure 1B), with a response of 16 kg grain/ kg N on the dune and on the mid-slope. There was no response to N when added to the swale. The sandy soil types were responsive to N addition in both seasons but more so in the wetter season of 2010. The lower response to N addition in the swale suggests that in the situation of low blanket N inputs, investment in N application on these soil types could be reduced in favour of increased applications in sandy topsoils.

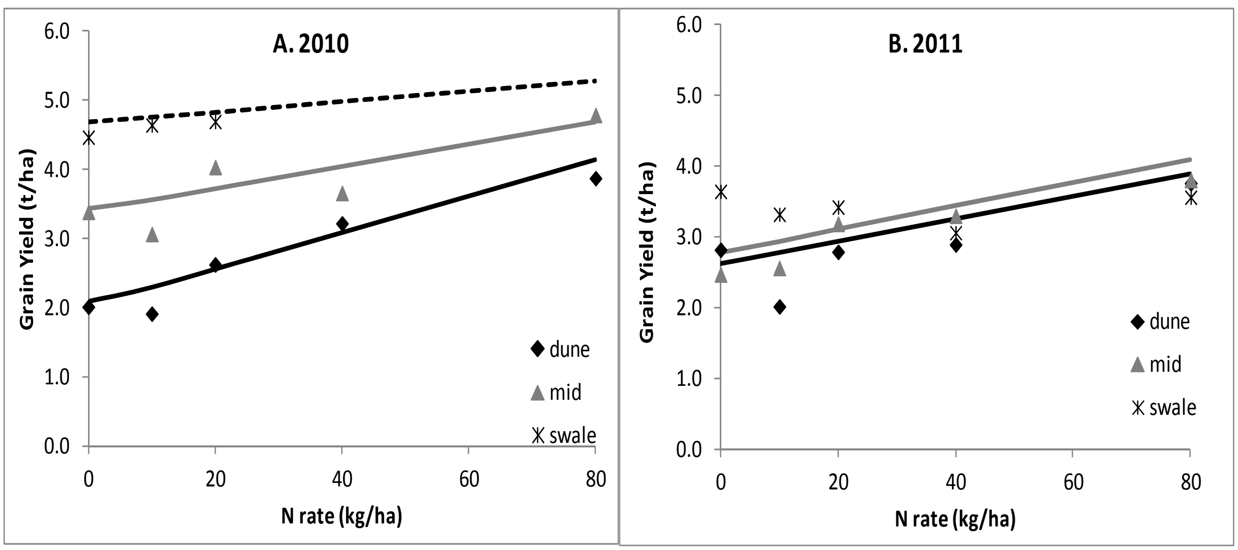

Figure 1. Average grain yield response to additions of N (kg/ha) on the dune, mid-slope and swale in A. 2010 and B. 2011 at the Karoonda trial site.

Economic Analysis
District practice at Karoonda is in the order of 10-20 kg N/ha applied at sowing. A comparison of district practice (assumed to be 15 kg/ha) with alternative N management strategies on the three soil types of dune, mid-slope and swale was done using soil N at sowing set at 18, 36 and 52 kg N/ha for the three soil types respectively. Results suggested that net returns may be improved through altering N input strategies. District practice had a negative mean net return (-$30/ha) in the dune, with a low net return of $7/ha in the mid-slope, and a relatively higher net return of $66 /ha in the swale (Table 1). The results of the economic risk analysis indicate that there is scope to use more N within the dune and the slope zones of a Mallee paddock while the least attractive management options (measured as a combination of profit and risk) result from under-fertilising with zero/low N inputs in the dune and mid-slopes. For example, one of the best net returns on the dune was in response to a sowing application of 60 kg N/ha, which, compared to the standard 15 kg N/ha, increased mean net return by $136/ha, break-even probabilities by 71%, and net return on fertiliser investment by $0.7 per $ of invested N fertiliser, but the potential cost associated with this change in management was an increase in the standard deviation by $85/ha and the mean of losses in the worst 10% of years increasing by $16/ha (Table 1). The best performing N rates are lower for the more fertile (higher soil N) mid-slope compared to the dune, with most of the economic-risk indicators near best-performing at 30 kg N/ha. For the swale, very few management strategies offered an economic-risk benefit relative to district practice (Table 1).

The N management strategies were ranked based on certainty equivalents for the range of risk attitudes from very risk averse through to risk neutral. At the level of risk aversion that resulted in the district practice N rate of 15 kg/ha being the preferred rate on the mid-slope zone instead of the more profitable higher rates, the preferred N rate on the dune soil was higher than the current district practice N rate and; the preferred N rate on the swale soil was lower than the current district practice. This indicates that at a level of risk aversion likely to be common in the farmer population, soil-specific application that can apply N rates above current common district practice on dune soils and reduce rates on swale soils is desirable from a profit- risk perspective.

Table 1. Indicators of magnitude and variation of net return for a selected subset of N management scenarios for each soil type (district practice in bold font).

Sowing fertiliser N (kg/ha)	Mean Return ($/ha)	Standard Deviation ($/ha)	Probability of Break-Even (% of years)	Mean return of bottom 10% of cases ($/ha)	Return on N ($ return/$N)
			Dune (sowing Soil N 18 kg/ha)		
15	**-30**	**24**	**11**	**-68**	**1.9**
30	22	49	69	-67	2.6
60	106	109	82	-84	2.7
90	183	171	83	-125	2.6
			Mid-slope (sowing Soil N 36 kg/ha)		
15	**7**	**57**	**57**	**-94**	**2.2**
30	55	92	72	-111	2.7
60	105	165	68	-143	2.1
90	128	253	65	-198	1.7
			Swale (sowing Soil N 52 kg/ha)		
7.5	55	133	67	-175	2.1
15	**66**	**154**	**68**	**-200**	**1.7**
30	74	188	66	-260	1.2
60	112	379	51	-174	1.2
90	156	865	43	-202	1.2

Conclusions

In summary, higher N rates in the sandy topsoils (relative to common district practice rates) do not necessarily increase downside risk. Risk-averse Mallee farmers with low starting N values seem likely to benefit from increasing their N rates on sandy soils to well above the 15 kg N/ha rate commonly applied at present, but this is not the case on heavier soil types. The use of soil-specific N fertiliser application can allow higher fertiliser rates to be applied only where required to increase production and profitability within the bounds of farmer risk preferences.

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