Are farmers in low-rainfall cropping regions under-fertilizing?

An Australian case-study

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Abstract

Cropping in low-rainfall regions can be risky business. Farms are often characterized by high climatic and spatial variability, while input prices, particularly nitrogen (N) fertilisers, are rising steadily relative to grain prices. Consequently, in anticipation of having a poor season, farmers minimize downside-risk, which is perceived as far more likely than upside gain in such risky environments, by applying fixed low rates of N to their cereal crops. However, farmers might benefit from using higher fertiliser rates and adjusting the rate of N fertiliser applied during the growing season, because if seasons are favourable the crop demands more nutrients. Using a combination of crop simulation, probability theory, profit function and finance techniques to quantify the trade-offs between magnitude and variability in net returns, we found that the use of higher N rates (relative to the region's average) can reduce risk in a highly variable dryland environment like the Mallee region in south-eastern Australia. Overall, typically risk-averse Mallee farmers with low starting N seem likely to benefit from increasing their N rates to up to 60 kg N ha^{-1} from the 15 kg N ha^{-1} currently applied, with less risk-averse farmers being likely do this by adopting a more tactical approach to N fertilisation.

1. Introduction

In the face of high climatic and spatial variability, low nutrient use efficiency, and intense market volatility, identifying the most profitable rate of nitrogen (N) fertiliser presents a challenge to dryland farmers. The situation is becoming even more pressing because fertiliser costs account for about 60% of all variable crop production costs in Australia (ABARE, 2010) and their costs have been growing faster than the prices obtained for grain prices (Kingwell and Pannell, 2005; Price, 2009; FAO, 2010).

Because N is such a significant investment, farmers seek to minimize the risk of a loss in poor seasons by applying standard low rates of N to their cereal crops. In doing so, their fertiliser management reflects recommendations for average seasons, and ignores the fact that N deficiency is one of the main causes of a gap between actual and potential yields, especially in the wetter seasons (Asseng et al., 2001; Sadras and Roget, 2004).

Part of the reason for the conservatism on the part of the farmer is the perception that excess N supply in dry seasons increases their exposure to risk, which is why N fertiliser is often considered to be a risk-increasing input in dryland agriculture (Russell, 1968; Just and Pope, 1979; Quiggin and Anderson, 1979; McDonald, 1989; Leathers and Quiggin, 1991; van Herwaarden et al., 1998; Sadras, 2002; Roosen and Hennessy, 2003; Broun, 2007; Lobell, 2007; Rajsic et al., 2009; Picazo-Tadeo and Wall, 2011). This issue is specific to risky dryland conditions, in contrast to other regions where the cost of over-applying N is clearly lower than the cost of under-fertilising (Rajsic and Weersink, 2008; Gandorfer et al., 2010).

In this context, it is timely to explore the significance of N management in dryland grain production under high risk and uncertainty, particularly since the variance in wheat revenue has more than doubled in every significant wheat-growing state in Australia over the last 15 years (Kingwell, 2011). So we ask the question: could those farmers in the low-rainfall Australian wheatbelt who adopt a low N input strategy in the attempt to minimize economic risk in fact be missing out on greater returns from more intense cropping in the more favourable seasons? In short, are dryland farmers under-fertilizing with N?

The issue of N management in agriculture has been widely studied in the context of managing risk, with one strategy of particular interest being the benefits of responding to seasonal

conditions with extra N applied tactically in-season (Nordblom et al., 1985; McDonald, 1989; Kingwell et al., 1993; Angus, 2001; Broun, 2007; Lobell, 2007; Moeller et al., 2009; Oliver and Robertson, 2009). Most studies have used only a single or few approaches in the risk analysis, and many have relied on limited data. In addition, only a few have accounted for seasonal or spatial variation as to trigger time- or site-specific management, or have included a full risk aversion analysis. In this study we aim, not only to overcome these limitations, but also to revisit the issue of N management in light of updated knowledge and information specific to the study region (a full risk assessment of N fertilisation strategies in the three most representative Mallee soil types is being considered for journal publication). In the process, we expect to address new concerns in the farming community that have arisen in recent times as a result of a shift in rainfall and market trends.

We use a range of tools, including crop growth modelling, Monte Carlo simulation, economic-risk measures and stochastic efficiency analysis, to evaluate the combined impact of yield and price risk on long-term performance of N fertiliser strategies, including those where rates are adjusted from year to year, according to the seasonal outlook, by applying extra N within the growing season. The results are then re-scaled according to the farmers' level of risk aversion. The main outcome for our case-study in the Mallee region in southern Australia is a response scale associated with adding N at the selected site, which is intended to help inform farmers in their fertiliser decisions. In particular, higher N input and tactical management are proposed to be beneficial for farmers trying to cope with an increasingly risky environment.

2. Methods

2.1. Study area

The focus of this study is Karoonda in the Mallee, a low-rainfall region that lies south and east of the Murray River, across part of South Australia, Victoria and into New South Wales (Figure 1). The Mallee region comprises 7 million hectares of land, of which three quarters are allocated to dryland agriculture (Sadras et al., 2003). Mallee agricultural fields typically include sandy dunes and plains that have soils with a strong texture contrast between the surface (sand through to loam) and the subsoil (heavy clay). The northern part of the Mallee is dominated by limestone plains with low easterly-trending sand dunes with mean annual

rainfall of 250 - 300 mm and mean annual evaporation of 2200 mm. The southern Mallee is dominated by sand plains with dunes and frequent outcrops of calcrete. Here, annual rainfall is around 300 - 350 mm and annual mean evaporation is 1975 mm (McLeod, 1989).
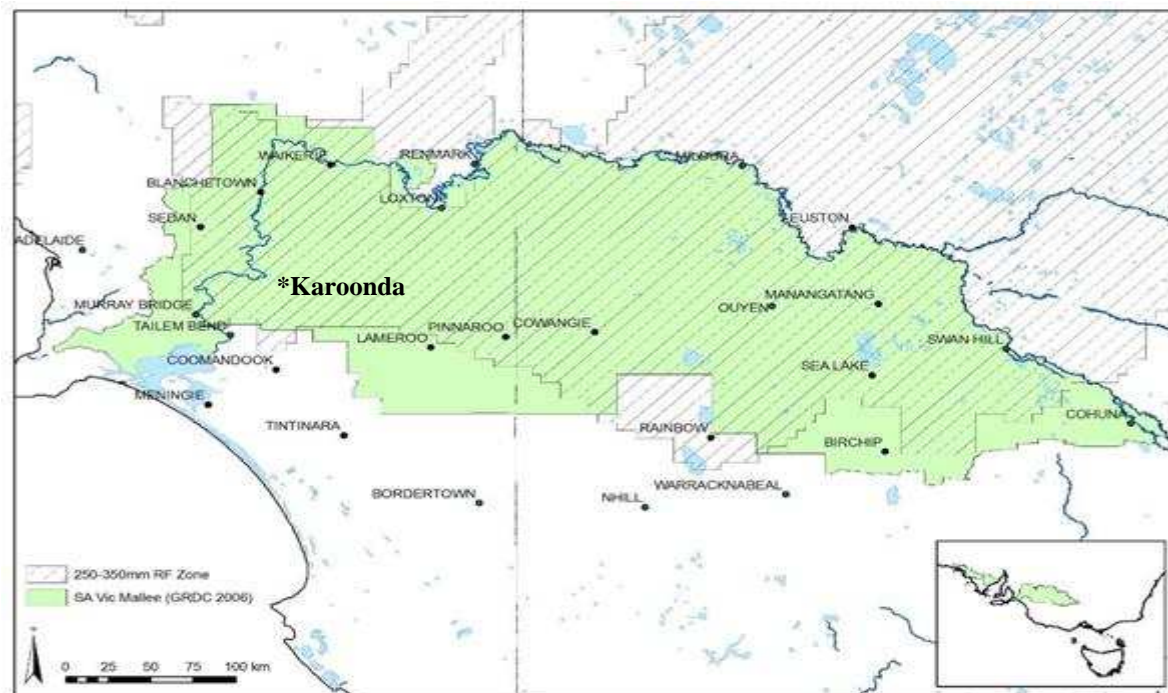
Figure 1. Map of the SA/Vic Mallee region (shaded area).

The region has a Mediterranean-type climate (Aschmann, 1973; Boyce et al., 1991) and soils with low plant-available water content, resulting in winter cereal crops that are often exposed to varying degrees of moisture stress, including terminal drought (Sadras, 2002). Farming in the Mallee is considered risky (Makeham and Malcolm, 1988), and this is the main reason why agricultural inputs, such as N fertiliser, have traditionally been kept at low levels (Sadras, 2002). Recent investigations suggest current rates in the region are in the order of 10-20 kg N ha^{-1} at sowing with some more intensive cropping farmers using up to extra 50 kg N ha^{-1} applied in-season (J. Braun, consultant 2011, pers. comm.). For comparisons in this analysis, we assume an upfront application of 15 kg N ha^{-1} as the current district practice.

2.2. Yield simulation and response curves

The Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003) was used to model water-limited yield potential and grain-yield N-response curves over the 1950-2010 growing seasons. The model was validated against wheat yield response to N application in 2009 and 2010 at the Karoonda site to ensure credibility of long-term simulations. The fit of actual yield versus predicted yield is approximately 0.8. To simulate yields, the APSIM wheat module was used in conjunction with the soil-water module (SOILWAT2), the soil-nitrogen module (SOIL N) and the surface-residue model (RESIDUE) (Probert et al., 1998, Oliver and Robertson, 2009). Daily climate data came from the township of Karoonda source in the SILO historical climate database. The wheat cultivar, Yitpi, was planted at 150 plants m^{-2} in every season, between 25th April and 14th July, following 10 mm of rainfall within a five-day period.

The model was parameterised for a representative soil type based on soil and crop measurements for the hill-top position within the field at a site near Karoonda in the Southern Mallee region of South Australia (Whitbread et al., 2008, 2009; Whitbread, 2010). This soil type is characterised by sandy soils with low subsoil constraints, low initial fertility status and good response to fertilizers, and corresponds roughly to 30% of the typical farm and region (Whitbread, 2010). Ten representative soil cores were taken for the soil type and the 'average' value of the analyses of these cores at depth intervals of 0-10, 10-20, 20-40, 40-60, 60-80 and 80-100 cm were used as the model input values (Jones and Whitbread, 2010). These bulked soil samples were analysed for organic carbon, salinity, boron, chloride, total nitrogen and crop lower and upper limit.

Annual yields were simulated for wheat on the Mallee soil over 60 years from 1950 to 2010. The simulation treatments comprised N fertiliser applied as urea at sowing (upfront) at rates of 0, 7.5, 15, 30, 60, 90, 120 and 150 kg N ha^{-1}, as well as a tactical (i.e. a split approach) that tested all sowing N rates in combination with 0, 7.5, 15, 30, 60, 90, 120 and 150 kg N ha^{-1} applied at Zadoks crop growth stage 31-40 (GS31-40) (Zadoks et al., 1974) when soil water, soil N and rainfall rules were met. Tactical or split application of N was triggered by the simultaneous occurrence of threshold values of soil water (greater than crop lower limit), soil

N (less than 100 kg N ha^{-1}), and rainfall (greater than 10 mm over 3 days) within GS31-40. Because crop yield potential is not known when the tactical N application treatment is triggered, there are some seasons where the crop yield potential is too low to warrant extra N addition but the GS31-40 conditions trigger N application, or GS31-40 conditions do not trigger N application but yield potential may be adequate to warrant extra N application. On average, in 21 seasons (35%) the tactical application of N was not triggered.

Simulated wheat crops were grown based on a starting mineral soil N of 18 kg N ha^{-1} (0-110cm) based on actual soil test values in the 2009-2011 growing seasons. Soil N and surface organic matter (1.5 t/ha) were reset on April 1 each year while soil water was reset each year on Dec 12 at crop lower limit to remove the effect of the previous crop and season on the following crop response to season and N treatment. A total of 64 scenarios were investigated for Karoonda.

2.3. Data sets

In addition to the 60-year time-series wheat-yield data sets generated in APSIM, two farm-gate-price datasets were created, one for Australian Standard White (ASW) wheat and the other for N fertiliser (urea, 46% N) from a range of data sources including historical pool returns (AWB 2010), commodity statistics (ABARE, 2010) and farm budget guides (Rural Solutions SA, 2009; 2010; 2011). The highly versatile ASW wheat with medium-to-low-protein white wheat grain is represented best in APSIM, even though protein, which partly determines the price received for wheat, is not considered. Real prices (in Australian dollars, AUD) were used to capture long-term deflation over the 40 years from 1970 to 2010 (adjusted to 1998, using the consumer price index).

Correlation between wheat and N prices over that period was calculated, along with the means and variances of each price series (Table 1). Wheat prices were found to be logistically distributed, whereas N prices best fitted a Beta General distribution, which is positively skewed and best captures the increasing price volatility observed in the late 2000s.

Table 1. Mean, variance and correlation coefficients of wheat and nitrogen prices.

	Wheat	Nitrogen
Mean price (AUD t⁻¹)	210	1030
Variance	0.16	0.22
Correlation coefficient	0.12	0.12

A coefficient of 0.12 reflects a relatively weak relationship between both prices because grain price depends primarily on the global grain supply and N price is affected by the cost of energy (Kingwell, 2000). Based on the correlated price distribution at Karoonda, 1000 random draws were generated using @RISK (Palisade Corporation, 2002). These price distributions were used in calculating economic net returns from growing wheat at a range of N fertiliser rates by two different methods, as shown later in Equation 2.

2.4. Crop yield variability

Given the stochastic nature of climate (Kingwell, 1994, 2011; Pannell et al., 2000; Quiggin and Anderson, 1979), climate-driven variability in crop yields, and thus variability in agricultural net returns over a given time frame can be quantified using probability theory (Hardaker et al., 2004b; Hardaker and Lien, 2010).

A suitable framework to characterize yield variability involved the generation of frequency distributions of wheat yields for each of the N treatments. Using the @RISK software, the yield frequency distributions were then fitted using a range of suitable probability density functions (PDF) including InvGauss, Weibull, Pearson5, normal, logistic, uniform and beta distributions. We chose the Anderson-Darling statistics test (Anderson and Darling, 1952) to measure the goodness of fit of each distribution. In comparisons of power, Stephens (1979) found A^2 to be one of the best empirical distribution function statistics for detecting most departures from normality, in other words, the one that best fits the distribution tail. We calculated the Anderson-Darling statistics, A^2, to measure the goodness of fit of each distribution using Equation 1.

$$A_n^2 = n \int\limits_{-\infty}^{+\infty} \left[F_n(x) - \hat{F}(x) \right]^2 \Psi(x) \hat{f}(x) dx$$

(1)

Where,

n total number of data points (crop yield)

$$\Psi^2 = \frac{1}{\hat{F}(x)\left[1 - \hat{F}(x)\right]}$$

$\hat{f}(x)$ hypothesized density function

$\hat{F}(x)$ hypothesized cumulative distribution function

$$F_n(x) = \frac{N_x}{n}$$

N_x number of X_i's less than x.

The probability density function with the best fit as measured by the Anderson-Darling statistic test was selected for use in Monte Carlo simulation of net economic returns.

2.5. Net returns function

Crop yield risk and price of inputs/outputs or market risk are among some of the major risks faced by farmers (Hardaker et al., 2004b; Kingwell, 2000, 2011), particularly in marginal regions such as the Mallee (Makeham and Malcolm, 1988). The effects of rainfall and soil variability, as well as of market volatility, on economic net returns from dryland agriculture in the study area are accounted for by quantification of variability in net revenue from sale of wheat grain produced per hectare less the fixed and variable costs incurred in its production.

Economic net returns for wheat were calculated via a profit function as shown in Equation 2, with the prices and costs (in AUD) obtained from a range of sources (ABARE, 2010; Rural Solutions SA, 2009, 2010, 2011).

$$NR_n = (Y_n \times P_w) - ((R_{n1} + (R_{n2} * f)) \times P_n) - (C_t \times f) - C_o$$

(2)

Where,

NR_n net returns by total N rate n (AUD ha^{-1})

Y_n crop yield by total N rate n (kg ha^{-1})

P_w price of ASW wheat grain (AUD kg^{-1})

R_{n1} rate of N applied at sowing (kg N ha^{-1})

R_{n2} rate of N applied in-season (kg N ha^{-1})

P_n price of N (i.e. price of urea/0.46) (AUD kg^{-1} N)

C_t operational cost of applying extra fertiliser in-season (AUD ha^{-1})

f frequency of seasons with tactical N application in-season

C_o other costs (AUD ha^{-1})

Other costs, assumed unchanged over time, include variable costs of growing wheat (e.g. seed purchase and treatment, herbicides, fuel and oil, and fertilisers other than N), fixed costs of production apportioned on an AUD ha^{-1} basis (e.g. repairs and maintenance, labour, insurance and levies), interest on variable costs (8%), and depreciation of machinery investment (10% of AUD 200 ha^{-1} in machinery investment).

Variability in net returns for each scenario was quantified by using @RISK to generate 1000 Monte Carlo simulations of net returns using Equation 2 with random samples for both the yield parameter Ynz, drawn from the modelled probability density functions for yields, and the price parameters P_w and P_n, based on the correlated distributions of these prices over the defined period. In the same way as for yield, we fitted probability density functions to frequency distributions of net returns under all scenarios, and selected the best using goodness of fit and Anderson-Darling test (see Equation 1).

2.6. Economic-risk measures

Farmers in the Mallee region are faced with the challenge of choosing from a range of N rates and timing of application with uncertain net returns in each season type. In a similar analysis comparing the benefits of four options for enterprise mix diversification, Kandulu et al. (2012) identified in the financial risk management literature four measures for assessing potential trade-offs between expected net returns and overall variability in net returns. Like them, we propose that variance or standard deviation used alone is an insufficient measure of

risk to inform an N application decision, so we used a combination of eight main indicators to quantify the expected magnitude and variability of yield and net returns from each scenario. These are:

1. Mean of expected net returns, i.e. the magnitude of net returns;
2. Mode of expected net returns, i.e. the most frequent net return value in the distribution;
3. Standard deviation of net returns, SD, i.e. a measure of variance or dispersion from the mean;
4. Coefficient of variation, CV, i.e. a measure of dispersion of a probability distribution ($SD/mean$);
5. Probability of break-even, $P(NR_{i,d} \geq 0)$, i.e. the probability of returning a profit;
6. Conditional value at risk of the lowest 10% of possible outcomes, $CVaR_{0.1}$, i.e. the mean of the lowest 10% net returns or, in other words, the risk of extreme financial loss associated with unfavourable events (Chavas and Holt, 1996);
7. Return on total fertiliser investment at risk (R_N), i.e. a measure of the investment in total N fertiliser made with the least certainty of return;
8. Return on tactical fertiliser investment at risk (R_{NT}), i.e. a measure of the value of extra tactical N fertiliser applied in-season.

Calculation of the return on total/tactical N fertiliser (R_N / R_{NT}) is shown in Equations 3 and 4:

$$R_N = \frac{NR_n - NR_{0n}}{C_n} \tag{3}$$

$$R_{NT} = \frac{NR_{n2} - NR_{0n2}}{C_{n2}} \tag{4}$$

Where,

NR_n / NR_{n2} net returns by total N rate n / tactical N rate $n2$ (AUD ha^{-1})

NR_{0n} / NR_{0n2} net returns by total zero N / tactical zero N (AUD ha^{-1})

C_n / C_{n2} cost total N / tactical N (AUD ha^{-1})

Calculating the probability of break-even and $CVaR_{0.1}$ allows for a more clear estimation of magnitude and risk of net returns, as well as probabilities of low-end net returns from alternative options (Uryasev and Rockafellar, 2001; Rockafellar and Uryasev, 2002).

2.7. Farmers' preferences

Farmers with different degrees of risk aversion are likely to have different preferences for N strategies (Hardaker et al., 2004b; Kingwell, 1994; Leathers and Quiggin, 1991; Pannell et al, 2000). Therefore, assessment of nutrient management strategies is likely to be modified when attitude to risk is considered. This is because, when risk matters, an individual's objective shifts from maximizing expected profit to maximizing expected utility, or overall satisfaction (Arrow, 1971; Lambert, 1990; Pratt, 1964).

Fertilization preferences under risk were revealed in this study through a Stochastic Efficiency with Respect to a Function (SERF) analysis (Hardaker et al., 2004a). SERF ranks a set of risky alternatives (N fertilization application rates and methods in this case) in terms of Certainty Equivalence (CE), or willingness to pay, for a specified range of risk attitudes. The risk attitude range is typically measured by a risk aversion coefficient, measuring either absolute or relative risk aversion (Hardaker et al., 2004a), based on the magnitude and spread of the distribution of net returns. In this study, a Constant Absolute Risk Aversion (CARA) coefficient, also known as Pratt's Measure of Risk Aversion (Arrow, 1971; Pratt, 1964) is used to represent the risk attitude of the farmer, based on a pooled variance-covariance matrix for the relevant type of farming (i.e. dryland cereal cropping) (Abdullahi et al., 2003; Hardaker et al., 2004a; Lien, 2002).

Constant aversion to risk implies a particular class of utility function, for example the negative exponential utility function (Anderson et al., 1977; Hardaker et al., 2004a, 2004b), which is particularly relevant for evaluating marginal risky investments that are small relative to the equity of the business, such as risks affecting only next year's income (Hardaker and Lien, 2007) (Equation 5):

$$U(W) = 1 - \in^{-cW} \tag{5}$$

Where,

W wealth or income expressed as a wealth equivalent

c constant absolute risk aversion (CARA) coefficient ($c \geq 0$)

In SERF analysis, simultaneous comparison of strategies by their utility determines the most efficient strategy for a farmer with a particular risk attitude. The CARA coefficient typically varies between 0.0 (risk neutral) and 0.0266 (very risk averse), based on the relative risk aversion scale of 0.0 to 4.0. Here, we use wider absolute risk aversion bounds, from 0.0 to 0.035, for a better illustration of the impact of ranking alternatives (Hardaker et al., 2004a).

3. Results

In this section, we present results on variability in both crop yield and economic net returns, assess the potential benefits of different N fertiliser management strategies, and consider how a set of preferred strategies might change according farmers' attitude to risk.

3.1. Yield variance analysis

A yield variance analysis is conducted here because yield variance was found to have a greater impact than price variance on variance in wheat revenue (Kingwell, 2011). Mean wheat yields ranged from 192 kg ha^{-1} with zero applications of N fertiliser to 2235 kg ha^{-1} with applications of 150 + 90 kg ha^{-1} of N (Tables 2). Overall, the lowest coefficient of variation of the mean yield was achieved with 15 kg ha^{-1} of N applied at sowing (CV of 0.23), indicating that farmers currently target lower yield variance (Tables 2).

Generally, application of higher N rates, both at sowing and in-season, contributed to higher yields. Gains in crop yield arising from extra N inputs are often, but not always, accompanied by greater yield variance (reflected in larger standard variation and coefficients of variation), which may translate to higher economic risks, as discussed later.

The proportion of seasons that achieve wheat yields below 0.25, 0.5, 1.0 and 2.0 t ha^{-1}, and greater than 5.0 t ha^{-1}, was also calculated (Tables 2). Very poor yields (Decile 1 and 2) were generated when no N was applied to the crop, while an upfront rate of at least 60 kg N ha^{-1} was required to achieve consistent yields between 1.0 and 2.0 t ha^{-1}. The yield variance analysis suggests that applying upfront N rates up to 90 kg N ha^{-1} could be beneficial in terms of increasing yields, while managing yield variance. Because a rate of 60 kg N ha^{-1} in-season was the point at which the highest yield variance occurred in most cases, only economic results for scenarios with rates up to 60 kg N ha^{-1} applied tactically will be presented.

Table 2. Measures of yield variability for selected N rate scenarios (upfront N on left and extra in-season[*] N on right in first column; current practice in bold font).

Kg N ha^{-1}		Mean (kg ha^{-1})	SD (kg ha^{-1})	CV	% years				
					< 0.25 t ha^{-1}	< 0.5 t ha^{-1}	< 1.0 t ha^{-1}	< 2.0 t ha^{-1}	> 5.0 t ha^{-1}
0	+ 0	192	48	0.25	92	100	100	100	0
	+ 15	368	182	0.50	40	67	100	100	0
	+ 30	382	195	0.51	40	67	100	100	0
	+ 60	390	201	0.52	38	65	100	100	0
	+ 90	394	203	0.52	38	65	100	100	0
	+ 150	398	206	0.52	38	65	100	100	0
15	**+ 0**	**405**	**92**	**0.23**	**7**	**85**	**100**	**100**	**0**
	+ 15	749	393	0.52	7	35	60	100	0
	+ 30	783	418	0.53	7	35	55	100	0
	+ 60	811	437	0.54	7	35	55	100	0
	+ 90	827	449	0.54	7	35	55	100	0
	+ 150	852	503	0.59	7	35	55	98	0
30	+ 0	727	199	0.27	5	12	95	100	0
	+ 15	1246	647	0.52	7	12	43	85	0
	+ 30	1300	697	0.54	7	12	42	83	0
	+ 60	1324	728	0.55	7	12	42	80	0
	+ 90	1329	735	0.55	7	12	42	78	0
	+ 150	1332	740	0.56	5	12	42	78	0
60	+ 0	1271	466	0.37	3	12	23	98	0
	+ 15	1797	1011	0.56	3	12	22	62	0
	+ 30	1871	1084	0.58	3	12	22	57	0
	+ 60	1913	1153	0.60	3	12	22	57	0
	+ 90	1923	1163	0.61	3	12	22	57	0
	+ 150	1928	1173	0.61	3	12	22	57	0
90	+ 0	1788	751	0.42	3	12	22	53	0
	+ 15	2056	1228	0.60	3	12	22	52	0
	+ 30	2125	1342	0.63	3	12	22	52	2
	+ 60	2147	1386	0.65	3	12	22	52	2
	+ 90	2156	1403	0.65	3	12	22	52	3
	+ 150	2158	1410	0.65	3	12	22	52	3
150	+ 0	2227	1229	0.55	3	12	22	52	0
	+ 15	2224	1472	0.66	3	12	22	52	3
	+ 30	2229	1489	0.67	3	12	22	52	3
	+ 60	2234	1500	0.67	3	12	22	52	3
	+ 90	2235	1510	0.68	3	12	22	52	3
	+ 150	2234	1513	0.68	3	12	22	52	3

* Tactical N applied only in the 39 seasons that meet the trigger conditions outlined in section 2.2.

3.2. Economic-risk performance

The magnitude and variability of economic net returns across the full range of N management strategies at the Karoonda site were assessed against eight economic-risk indicators: mean and mode net returns; standard deviation and coefficient of variation of the mean net returns; $P(NR \geq 0)$; $CVaR_{0.1}$; and return on the total/tactical N fertiliser investment (see section 2.6 for detailed descriptions).

Overall, mean net returns varied between –AUD 122 ha^{-1} (0 + 150 kg N ha^{-1}, not shown here) to AUD 228 ha^{-1} (90 + 30 kg N ha^{-1}) (Table 3). The highest returns occurred with mid to high N rates (> 30 kg N ha^{-1}) applied upfront and/or tactically, and the lowest returns resulted from zero N input as well as very high in-season N applications (> 60 kg N ha^{-1}) with poor selection of initial inputs at sowing (either too low or too high) (Table 3).

Table 3. Economic risk measures across a selection of N rates (upfront N on left and extra in-season[*] N on right in first column; current practice in bold font).

Kg N ha⁻¹		Mean (AUD ha⁻¹)	Mode (AUD ha⁻¹)	SD (AUD ha⁻¹)	CV	$P\,(NR \geq 0)$ (%)	$CVaR_{0.1}$ (AUD ha⁻¹)	R_N (A\$NR/A\$N)	R_{NT} (A\$NR/\$N_T)
0	+ 0	-60	-59	12	0.21	0	-77		
	+ 7.5	-37	-72	38	1.02	16	-100	2.9	2.0
	+ 15	-38	-50	41	1.09	19	-106	1.4	1.0
	+ 30	-45	-32	44	0.99	15	-118	0.5	0.3
	+ 60	-63	-78	44	0.70	8	-138	-0.1	0.0
7.5	+ 0	-50	-53	16	0.32	1	-74	1.2	
	+ 7.5	-7	-29	60	8.01	43	-106	3.3	3.8
	+ 15	-6	-11	64	11.36	45	-112	2.3	2.0
	+ 30	-11	18	68	6.16	42	-123	1.3	0.9
	+ 60	-29	-39	69	2.36	32	-145	0.4	0.2
15	**+ 0**	**-30**	**-41**	**24**	**0.81**	**11**	**-68**	**1.9**	
	+ 7.5	27	-42	79	2.92	57	-78	3.7	5.1
	+ 15	27	-61	87	3.21	54	-84	2.8	2.6
	+ 30	24	-91	93	3.84	53	-96	1.8	1.2
	+ 60	10	-96	98	9.92	47	-117	0.9	0.4
30	+ 0	22	31	49	2.22	69	-67	2.6	
	+ 7.5	103	25	123	1.19	79	-78	4.2	7.2
	+ 15	117	40	146	1.24	77	-84	3.8	4.2
	+ 30	118	123	157	1.33	76	-96	2.9	2.1
	+ 60	102	-33	159	1.57	70	-114	1.7	0.9
60	+ 0	106	-2	109	1.02	82	-84	2.7	
	+ 7.5	185	182	203	1.10	82	-149	3.5	6.8
	+ 15	200	162	222	1.11	82	-128	3.4	4.3
	+ 30	206	42	236	1.14	81	-139	2.9	2.3
	+ 60	198	78	260	1.31	77	-150	2.1	1.0
90	+ 0	183	273	171	0.93	83	-125	2.6	
	+ 7.5	208	186	243	1.17	81	-195	2.7	2.2
	+ 15	225	187	274	1.22	80	-167	2.6	1.8
	+ 30	228	57	290	1.27	79	-147	2.3	1.0
	+ 60	215	376	310	1.44	75	-199	1.8	0.3
120	+ 0	178	210	230	1.30	73	-170	1.9	
	+ 7.5	212	107	277	1.30	78	-198	2.1	3.1
	+ 15	220	53	308	1.40	76	-200	2.0	1.9
	+ 30	216	173	320	1.48	74	-209	1.8	0.8
	+ 60	198	53	322	1.63	71	-227	1.4	0.2
150	+ 0	215	307	274	1.27	73	-196	1.8	
	+ 7.5	202	45	323	1.60	72	-222	1.6	-1.8

+ 15	198	-121	328	1.66	71	-222	1.5	-1.1
+ 30	188	73	329	1.75	69	-235	1.3	-0.9
+ 60	171	-32	330	1.94	66	-252	1.1	-0.8

The risk profile of each scenario was further defined by interpretation of the $P(NR \geq 0)$, $CVaR_{0.1}$, R_N and R_{NT} (see section 2.6). In that regard, the probability of breaking even was relatively high ($\geq 50\%$) where high mean net returns occurred and these were typically where mid-high N rates were applied upfront, and with all rates applied tactically after a sowing application of up to 60 kg N ha^{-1}. The probability of generating a profit was low ($< 30\%$) when low or zero rates of N were applied at sowing (Table 3).

Downside risk was assessed with $CVaR_{0.1}$ values up to around –AUD 200 ha^{-1} calculated when high sowing N rates were combined with high N rates in-season (i.e. high downside risk). There were no positive $CVaR_{0.1}$ values for these management strategies, and the smallest negative values were calculated for low-mid sowing N rates. Overall, the highest $CVaR_{0.1}$ value of –AUD 67 ha^{-1} was calculated for 30 kg N ha^{-1} applied upfront, and this value decreased with increasing rates of N applied at sowing (i.e. higher risk of extreme financial loss associated with damaging events) (Table 3).

Finally, the marginal value of the total and tactical N fertiliser was assessed with R_N and R_{NT} values. Considering both yield and price risk, the best value for money invested in total N fertiliser at the start of the season occurred in the scenarios of 30 kg N ha^{-1} at sowing followed by 7.5 or 15 kg N ha^{-1} in-season, with around AUD 4.0 net return for each dollar of N purchased (Table 3). R_N was lowest (-AUD 0.4) in the unlikely scenario of 150 kg N ha^{-1} applied in-season after zero initial N inputs. The lowest value for R_{NT} (-AUD 1.8) was found to result from a small top-dressing application of 7.5 kg N ha^{-1} after upfront 150 kg N ha^{-1}. Interestingly, similar small tactical applications (7.5 or 15 kg N ha^{-1}) after mid-high N rates applied upfront offered the best value for the tactical N fertiliser when compared with other tactical scenarios.

In summary, we assume that the best scenarios overall in terms of economics and risk performance indicators (Table 4) meet all the following conditions:

- Mean NR $\geq$ Mean NR$_{15 \text{ kgN/ha}}$
- CV≤ 1.5

- $P(NR{\geq}0) \geq 50\%$
- $CVaR_{0.1} \geq$ -AUD 150 ha^{-1}
- $R_N \geq R_{N\ 15\ kgN/ha}$ and $R_N \geq$ AUD 2.0 per dollar of N
- $R_{NT} \geq$ AUD1.0 per dollar of N tactical

The potential benefits from high and tactical N fertilization can be evaluated by considering the decision to switch from the Mallee farming standard practice of applying 15 kg N ha^{-1} at sowing (with a negative mean net return of –AUD 30 ha^{-1}) to the best scenarios considered in Table 4.

Whilst a range of tactical N applications performed well, typically those including an initial input of 30 to 90 kg N ha^{-1} with a small in-season application of up to 30 kg N ha^{-1}, were the best (Table 4). For example, one of our best economic-risk scenarios included a tactical N application of 30 kg N ha^{-1} following 60 kg N ha^{-1} at sowing (Table 4). The decision to adopt this strategy on the sandier soils of the farm would see mean net returns increase by AUD 236 ha^{-1}, while reducing the risk by increasing break-even probabilities by 70%, increasing $CVaR_{0.1}$ by AUD 71 ha^{-1} and increasing R_N by nearly AUD 1.0 per dollar of invested N fertiliser. In this case, the coefficient of variation would increase by a relatively small 0.33 relative to the current practice. The results further encourage a small in-season N application (Table 4).

Table 4. Best performing scenarios overall according to pre-defined thresholds of the economic-risk measures (upfront N on left and extra in-season[*] N on right in first column).

Kg N ha^{-1}		Mean (AUD ha^{-1})	CV	P (NR ≥ 0) (%)	$CVaR_{0.1}$ (AUD ha^{-1})	R_N (A\$NR/A\$N)	R_{NT} (A\$NR/A\$N$_T$)
	+ 7.5	103	1.19	79	-78	4.2	7.2
30	+ 15	117	1.24	77	-84	3.8	4.2
	+ 30	118	1.33	76	-96	2.9	2.1
	+ 0	106	1.02	82	-84	2.7	
	+ 7.5	185	1.10	82	-149	3.5	6.8
60	+ 15	200	1.11	82	-128	3.4	4.3
	+ 30	206	1.14	81	-139	2.9	2.3
	+ 60	198	1.31	77	-150	2.1	1.0
90	+ 0	183	0.93	83	-125	2.6	
	+ 30	228	1.27	79	-147	2.3	1.0

* Tactical N applied only in the 39 seasons that meet the trigger conditions outlined in section 2.2.

Despite the encouraging results from higher N rates, the decision to increase N inputs above the district practice of 15 kg N ha^{-1} in the Mallee is likely to depend on farmers' personal attitudes towards risk. Whilst one may opt for a high-return, high-risk scenario, another may

prefer to 'play it safe' by choosing a management strategy with lower return and lower risk. Ultimately, the difference lies in whether the farmer is managing for the good, high-yielding years or simply targeting the average season. In the following section, we reassess some of the apparently best performing scenarios according to farmers' aversion to risk.

3.3. Impact of risk aversion

Our assessment of the N input strategies for a risk-neutral Mallee farmer (i.e. one that neither seeks nor avoids risk) over the 60 years revealed that the strategies of applying upfront rates of 30 to 90 kg N ha^{-1} generated positive net returns in 80% of the years (Figure 2). When a tactical application of up to 30 kg N ha^{-1} followed these initial inputs, profits exceeding AUD 500 ha^{-1} were found in approximately 20% of the years. These split-rate strategies often surpassed their upfront equivalents with relative higher net returns, though with a slightly higher risk.

Assessing the utility to the farmer by the SERF method (see section 2.7), we defined a finite set of net return values (assumed as net wealth), W, in each cumulative density function (Figure 2), which were then converted to their utility via the exponential utility function presented in Equation 6, and the selected value of c (i.e. CARA). For a given utility function, the point at which the farmer or decision-maker becomes indifferent between the value of the strategy and its risky outcome gives the CE of a risky prospect (Hardaker et al., 2004a, 2004b).
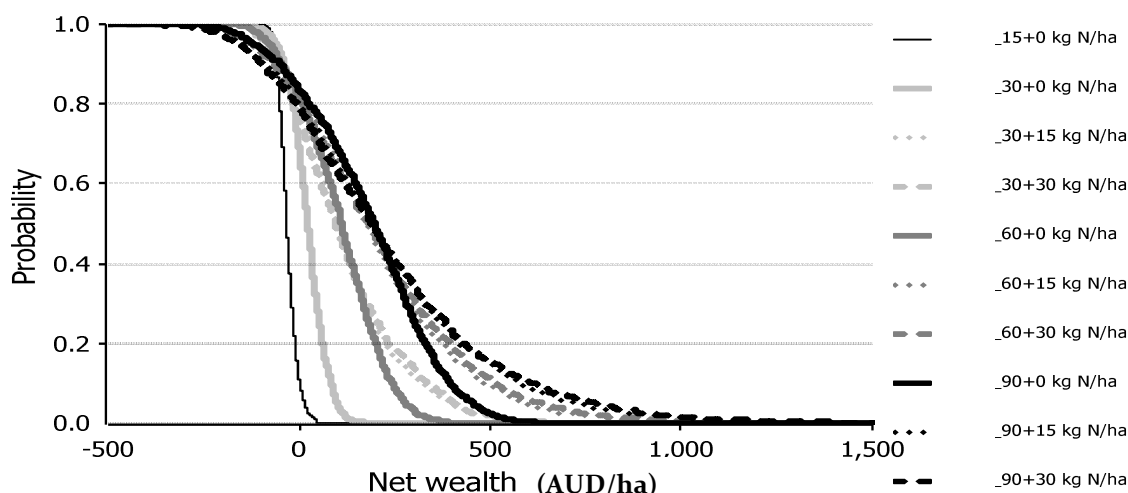

Figure 2. Cumulative density functions for a targeted selection of well-performing economic-risk scenarios.

A range of selected N application strategies for increasingly risk-averse farmers is depicted in Figure 3. Overall, CARA coefficients in this study ranged from 0.000 (risk-neutral) to 0.035 (risk-averse). For each CARA coefficient level, the N strategy with the highest CE is considered the most attractive for those farmers. Generally, there is a shift from higher input strategies to lower input strategies with increasing risk aversion, which is consistent with the premise that most (risk-averse) farmers apply low inputs as they perceive N to be a risk-increasing input.

In addition, it is clear that the more risk-averse a farmer is, the more likely he or she is to favour fixed or upfront strategies (continuous lines) over tactical or split ones (dash lines) (Figure 3), and despite the slightly lower returns. The results seem to show that relying on a late application of N can increase riskiness because of the chance that weather conditions may not allow application of the N within the window of opportunity. As mentioned earlier, in our APSIM-based analysis in-season applications are triggered by a range of soil and agronomic conditions which, while attempting to represent the season, do not guarantee that the in-season N is being applied to a crop with high yield potential.
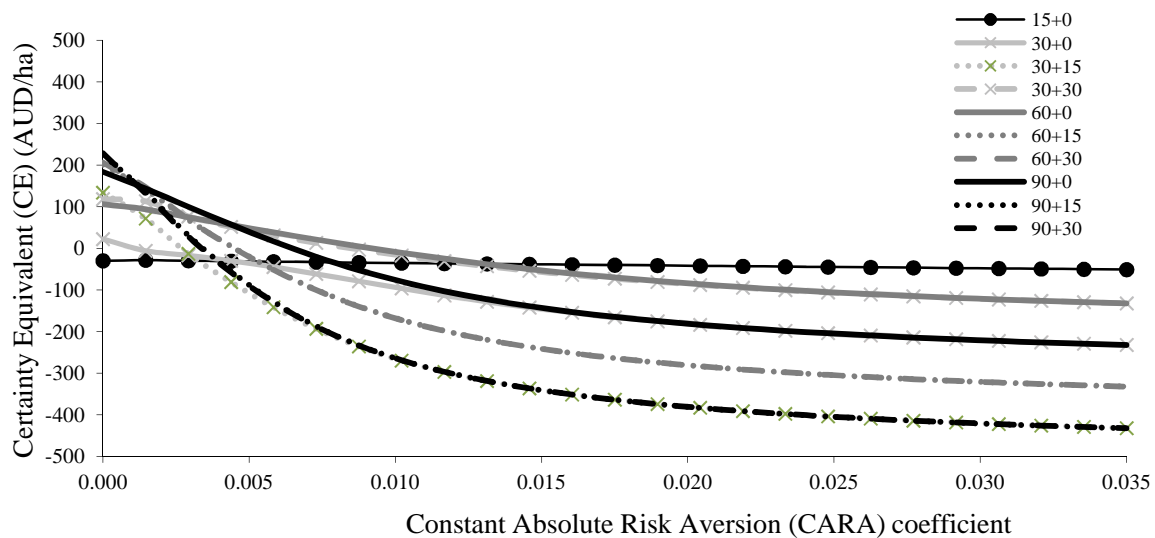

Figure 3. SERF results for a selection of well-performing economic-risk scenarios over the CARA range of 0.00-0.035.

The most attractive economic scenario (90 + 30 kg N ha^{-1}) was outperformed by its upfront equivalents (90 and 60 kg N ha^{-1}) at a risk aversion coefficient of around 0.001 (close to risk-neutral) (Figure 3), meaning that more risk-averse farmers, such as most in the dryland regions of Australia, are not likely to adopt it, but will consider upfront fertilisation or lower tactical applications instead. More interestingly, the overall favourite strategies using lower or split N rates, including 60 kg N ha^{-1} and 30 + 30 kg N ha^{-1} were slightly outperformed by a single low upfront application of 15 kg N ha^{-1} at a relatively high risk-aversion coefficient of 0.015 (Figure 3). Therefore, our results suggest that the average Mallee farmer is likely to sit around the 0.015 level on the CARA scale, based on the average current N fertilization practice in the region.

In summary, applying more than a total of 90 kg N ha^{-1} on the sandier soils is considered by farmers as very risky behaviour, despite the potential very high returns, because these strategies are preferred above any other only at the near-neutral CARA coefficient levels (close to the zero mark), and are almost the only presented options that assumes negative CE values at relatively low levels of risk aversion (up to 0.01). These are also the strategies presented with the highest average change in CE (greater than AUD 500 compared to lower than AUD 100 in some scenarios with lower N rates) as a result of an increase in farmers' risk aversion from 0.000 to 0.035 (Figure 3).

So we conclude that, when taking into account the farmer's attitude to risk, strategies that include total applications of 15 to 60 kg N ha^{-1} are the most likely to be adopted by farmers (assuming a range of risk preferences, even if all considered risk-averse). As expected, typically risk-averse farmers prefer consistent returns and are thus willing to take a somewhat lower, but less variable, expected payoff (Kingwell, 2011).

4. Discussion

The results confirm our hypothesis that dryland farmers, who, currently and persistently, adopt a low N input strategy in an attempt to minimize economic downside risk, are missing out on the returns available from more intense cropping in the good years on at least part of their farm. In other words, when both yield and price risks are factored in over a long time-frame, it becomes evident that farmers are better off if they reduce the probability of under-fertilizing in the dry seasons (hence making a loss), while increasing the probability of sufficiently fertilizing when the season develops well (by providing enough N upfront or

'playing the season' in some cases). Further support for this strategy comes from the possibility that left-over N from potential over-application in the poor years (assuming that is not lost or transformed) may be taken up by the crop in the following season, and the possibility that having extra N in the plant may improve grain quality, and thus its market price, although neither has been accounted for in the analysis.

In comparison with the current practice of adding about 15 kg N ha^{-1}, the use of higher upfront rates up to 90 kg N ha^{-1} is an attractive strategy on the sandy soils of the farm, in terms of both long-term economics and risk. Moreover, several of the tactical N fertilization scenarios can significantly increase farmers' mean net returns while in some cases also reducing income variance, although the full potential of tactical fertilization is likely to be realised when other factors such as grain quality, crop rotation and whole-farm budget are factored in the analysis. Overall, these findings are consistent with previous studies that demonstrate the benefits of tactical N management (Nordblom et al., 1985; McDonald, 1989; Kingwell et al., 1993; Angus, 2001; Broun, 2007; Lobell, 2007; Moeller et al., 2009; Oliver and Robertson, 2009), and provide supporting evidence for the proponents of higher input strategies designed to extract higher returns from marginal dry environments (Babcock, 1992; Asseng et al., 2001; Sadras, 2002; Good, 2004; Sadras and Roget, 2003; Spiertz, 2010).

There are several plausible explanations as to why farmers in low-rainfall environments may be applying what appear to be sub-optimal rates of N. The main reason seems to be that farmers seek to minimise the risk of a costly yield shortfall (and thus reduced profit) arising from over-fertilization with N in poor seasons. In seeking to manage for average seasons, conservative application strategies are being recommended, and these may result, at least partly, from a lack of substantial datasets to support the use of high N rates in dryland regions (Broun, 2007). Importantly, the decision to apply a lower N rate may also be directly linked to the financial health of the farm business at the start of the year when most inputs are purchased, and to the ability to borrow money or cover short-term losses (Pannell et al., 2000; Hardaker et al, 2004b). The additional expenditure on a range of other inputs that would be required to achieve the anticipated crop yields may influence the decision (Broun, 2007), as may a recent history of consecutive poor seasons, as seen in the Mallee from 2005 to 2009. Finally, farmers' concern for the environment and sustainability of their farm may also impact on the rate of N they choose to apply, as an average 30% of applied N is lost from dryland cereal cropping in Australia (McDonald, 1989; Angus, 2001; Chen et al., 2008).

The results produced here must be interpreted with caution, because it is widely accepted that variance of APSIM yield potentials is generally lower than the variance of actual crop yields since the model cannot accurately capture all phenomena, including unpredictable damage by weather, pests, diseases and weeds, or occasional crop failures caused by 'haying off' (i.e. crop damage caused by a combination of water deficit and excess N) in extremely dry seasons (van Herwaarden et al., 1998). Similarly, the model has been fixed to have the same starting N conditions for every season in the chosen soil type, which may in fact vary considerably with prior management. The effect of higher intensity of cropping on increasing initial soil test N values, as well as grain protein, could be captured in a follow-up analysis that tests a range of N starting values across several soil types. If Mallee farmers are able to establish the relevance of this analysis to their own farm and soil conditions by, for example, defining the proportion of the sandy soils on their farm, and relating the analysis to the initial N fertility on their given management unit, then these results could usefully inform individual farmers' decisions.

5. Conclusion

Our economic-risk analysis suggests that, in terms of maximising average returns, farmers in a low-rainfall cropping region such as the Mallee are under-fertilizing with N on a significant proportion of their farm. When accounting for long-term yield and price risks, the use of higher rates of N (applied at sowing and in combination with a subsequent tactical application) can be a risk-reducing strategy in a highly variable dryland environment. Our conclusion challenges the widely held belief that N fertiliser is a risk-increasing input in low-rainfall regions because it increases the farmers' exposure to risk in very dry seasons. Whilst this may be true, we argue that a more complete risk assessment, like the one conducted in this study, reveals that improved economic returns in a marginal region, like the Mallee, arise from reducing the probability of under-fertilizing in the good seasons. To do that, the less risk-averse farmers will need to increase their N rates, and apply tactical in-season N when conditions are favourable. The more risk-averse farmers may prefer a more convenient (and less profitable) upfront approach, while still increasing their rates of N on the sandy soils of their farm.

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