Risk and reward from nitrogen in 2022

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Benefit cost ratio of nitrogen fertiliser on grain crops

The growing season of 2022 has been characterised by high costs of nitrogen (N) fertiliser and volatility in grain prices. The benefit cost ratio (BCR) is simply the benefit of an investment (e.g., grain yield response) divided by the cost (e.g. N fertiliser). Because the number is a ratio, it can be expressed as dollar return for dollar invested. It follows that any BCR below one dollar return per dollar invested is a loss. The BCR for Nitrogen on grain crops is a function of 1) economics expressed as the relative price of grain to the price of N fertiliser, and 2) biology expressed as efficiency of fertiliser recovery in grain.

A common way to express the relative price of grain and N fertiliser is to ask how many tonnes of wheat are required to purchase a tonne of urea. The columns in the left-hand side of Table 1 represent the cost of urea at $450, $1000, $1500 and $2000. The rows in the left-hand side of Table 1 are a range of wheat prices required to match a ratio of the price of a tonne of wheat to the cost of urea. At the time of preparing the presentation, urea was about $1300/tonne and ASW1 wheat was about $388/tonne. At these prices, a grain grower would need about 3.4 tonnes of wheat to pay for a tonne of urea. This is obviously a shock for businesses who are used to less than 2 tonnes of wheat for a tonne of urea.

The columns in the right-hand side of the table shows how the BCR changes from the biological process of the N fertiliser recovery rate. The rule of thumb in N budgeting (40kg N/ha is required for a tonne of wheat) is based on the assumption that 20kg N/ha is removed in the grain and hence, the N fertiliser recovery is 50%. Table 1 shows that an N responsive crop with 50% recovery is a profitable investment even with very high N costs relative to grain prices (greater than $2 return for every $1 invested). What this shows is that there are few better investments on a grain farm than applying N fertiliser to a N deficient crop. As we will discuss, the risk comes from low N fertiliser recovery.

An important consideration is that N fertiliser recovery is often calculated as recovery in the year of application. The strong evidence of at least some of the unused N being available for subsequent years (Smith et al. 2019, Meier et al. 2021) can lead to a situation where recovery might be 30% in year one and 20% in year 2 (Hagan and Bell 2022). Some of the implications of N carryover will be discussed in the presentation.

Table 1: Benefit cost ratio for a combination of N costs, wheat prices and N fertiliser recovery. Any value equal to or below 1 is in **bold** and represents a breakeven point or a loss. The application rate, often $10/ha, is not included in these figures.

Increased N COST →

↓ Decreased price of wheat

Urea price $/t	**450**	**1000**	**1500**	**2000**	*$Urea/*	N Fertiliser recovery %							
Price Kg N	$ 0.98	$ 2.17	$ 3.26	$ 4.35	*$ Wht*	5%	10%	20%	30%	40%	50%	60%	70%
	Wheat price $/t					Benefit Cost Ratio. $ retrun for $ invested in N.							
1 t wht = 1 t urea	450	1000	1500	2000	1.0	1.2	2.3	4.6	6.9	9.2	11.5	13.8	16.1
	375	833	1250	1667	1.2	**1.0**	1.9	3.8	5.8	7.7	9.6	11.5	13.4
	321	714	1071	1429	1.4	**0.8**	1.6	3.3	4.9	6.6	8.2	9.9	11.5
	281	625	938	1250	1.6	**0.7**	1.4	2.9	4.3	5.8	7.2	8.6	10.1
	250	556	833	1111	1.8	**0.6**	1.3	2.6	3.8	5.1	6.4	7.7	8.9
2 t wht = 1 t urea	225	500	750	1000	2.0	**0.6**	1.2	2.3	3.5	4.6	5.8	6.9	8.1
	205	455	682	909	2.2	**0.5**	**1.0**	2.1	3.1	4.2	5.2	6.3	7.3
	188	417	625	833	2.4	**0.5**	**1.0**	1.9	2.9	3.8	4.8	5.8	6.7
	173	385	577	769	2.6	**0.4**	**0.9**	1.8	2.7	3.5	4.4	5.3	6.2
	161	357	536	714	2.8	**0.4**	**0.8**	1.6	2.5	3.3	4.1	4.9	5.8
3 t wht=1 t urea	150	333	500	667	3.0	**0.4**	**0.8**	1.5	2.3	3.1	3.8	4.6	5.4
	141	313	469	625	3.2	**0.4**	**0.7**	1.4	2.2	2.9	3.6	4.3	5.0
	132	294	441	588	3.4	**0.3**	**0.7**	1.4	2.0	2.7	3.4	4.1	4.7
	125	278	417	556	3.6	**0.3**	**0.6**	1.3	1.9	2.6	3.2	3.8	4.5
	118	263	395	526	3.8	**0.3**	**0.6**	1.2	1.8	2.4	3.0	3.6	4.2
4 t wht=1 t urea	113	250	375	500	4.0	**0.3**	**0.6**	1.2	1.7	2.3	2.9	3.5	4.0
	107	238	357	476	4.2	**0.3**	**0.5**	1.1	1.6	2.2	2.7	3.3	3.8
	102	227	341	455	4.4	**0.3**	**0.5**	**1.0**	1.6	2.1	2.6	3.1	3.7
	98	217	326	435	4.6	**0.3**	**0.5**	**1.0**	1.5	2.0	2.5	3.0	3.5
	94	208	313	417	4.8	**0.2**	**0.5**	**1.0**	1.4	1.9	2.4	2.9	3.4
5t wht = 1 t urea	90	200	300	400	5.0	**0.2**	**0.5**	**0.9**	1.4	1.8	2.3	2.8	3.2

Table 1 shows that high costs of urea relative to wheat prices is a source of risk, especially as grain prices remain volatile in 2022. The other source of risk is a low level of N fertiliser recovery. The main reasons for low recovery are as follows:

- a dry spring – this is the most likely reason for low fertiliser recovery and what concerns growers. Wallace et al. (2020) looked at N fertiliser recovery at 29 sites across SE Australia and found that, while soil characteristics and management played a role, seasonal rainfall conditions in spring were the main determinant of crop uptake
- adding N to a soil that has high N fertility – this is rarer in cropping situations but not uncommon after ley pastures
- frost and heat events – some growers on Upper EP and Mallee have said that risks of frost and heat were almost as much of an influence on their N decisions as the chance of a dry spring.
- losses of N associated with very wet conditions – for example, Therese McBeath (pers. comm.) has measured substantial losses on some of the difficult soils in the higher rainfall parts of Eyre Peninsula.

The first three factors describe situations where N supply exceeds crop demand. The fourth, describing low efficiency due to large losses of fertiliser N (the last factor) is relatively rare occurrence on most soils. Research is currently being undertaken to quantify N loss pathways.

Conversations on N topdressing using N budgeting approaches usually start with a target yield. This target yield is converted to an N demand (e.g. 2t wheat = 80kg N/ha) and then this value is subtracted from the amount of N supplied by the soil (e.g. 50kg N/ha). The difference (in this case 30kg N/ha) is the required rate to be supplied by N fertiliser.

When I first came across N budgeting in the mid-1990s, my enthusiasm for computerised decision support tools and models led me to be a bit dismissive. I changed my mind as I saw the power of simple maths in the hands of growers and agronomists (Lawrence et al. 2000). Prior to N budgeting, the N soil test might be measured in ppm (usually of top 10cm of soil), N fertiliser was measured in kg of product and crop demand was expressed in t/ha with a protein percentage. The advantage of generating a budget is that all components are converted to the same unit (kg N/ha) for ease of calculation and comparison.

Dryland growers and agronomists understand that N topdressing is risky because the decision has to be made prior to knowing how the season will finish. It is not uncommon to see some reference to risk appetite in selecting the target yield. A risk averse grower might use a more modest target yield by aiming for a decile 5 finish or below. If the grower is feeling bullish, they might aim for decile 7. This is an informal treatment of risk and overlooks the considerable effort in the applied economic field of Decision Analysis. Working with Barry Mudge (low rainfall grower and consultant), we believe that we can have better conversations about the upside and downside of risky decisions. For a quick explanation, see Rapid Climate Decision Analysis Tool (forecasts4profit.com.au); for a longer discussion, contact Barry Mudge or Peter Hayman. Accessing the sophisticated cropping system model YieldProphet is an obvious choice for considering crop yield potential when dealing with risky N decisions. YieldProphet can be complemented with simple use of deciles in a spreadsheet.

By definition, a risky decision has a range of possible outcomes. If a grower is aiming for a specific decile in January, they have a one in ten chance of success or a 90% chance of being wrong. Given that it is likely to miss the yield target and ideal N rate, it is worth considering the costs of over fertilising and the costs of under fertilising. Each decile or N rate (25, 50 or 75kg N/ha) has upsides and downsides, and we can compare risky choices by comparing the upside and downside. This is hard to do in your head, but relatively easy in a spreadsheet.

Climate risky decisions, such as applying N fertiliser to a wheat crop, can be broken down into four components:

- The decision - the rate of N topdressing which includes the 'do-nothing' option of not proceeding with topdressing. The decision is sometimes worded as selecting which decile to aim for.
- The climatic conditions that create the upside and downside for the decision - primarily driven by spring rainfall, but frost and heat events are also important, along with untimely rain at harvest. Spring rainfall remains the dominant factor, hence the question 'what decile to aim for?'. This also drives the interest in the seasonal climate outlook for spring rainfall and the disappointment when an outlook for a wet spring doesn't eventuate. At the time of topdressing, there is often a range from below 1 to 2t/ha in a dry spring and over 4 to 5t/ha in a wet spring.
- The more optimistic and cautious choice - the optimistic choice might be to aim for decile 7, which is deciding to over-fertilise in 6 years out of 10, adequately fertilise for 1 year out of 10 and under-fertilise 3 years out of 10. A cautious approach is to aim for decile 3, which is to over-fertilise 2 years out of 10, adequately fertilise 1 year out of 10 and under-fertilise 7 years out of 10.
- The rewards and regrets of optimism and caution - by definition, a risky decision is one where future reward or regret is unavoidable. An optimistic choice has the substantial upside reward of fertilising for a wetter-than-average spring and the regret of a dry spring resulting in scarce funds spent on an unnecessary cost of N which was not needed in that year and the

potential for 'hay off' in low rainfall environments. The important work showing that a substantial amount of N that is unused in one year is available for the next season will reduce, but not eliminate, the regret of aiming for a decile 7 spring. The reward of caution is that scarce funds have been saved in a dry year. The regret of caution is missing out on the large upside economic opportunity of fertilising a N deficient wheat crop.

References

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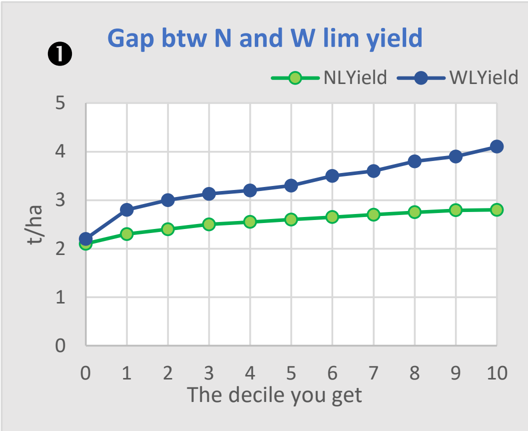
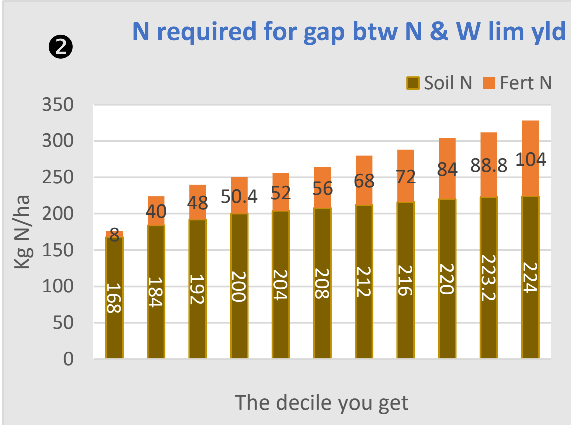
A prototype spreadsheet has been developed to generate discussion on climate risk and N topdressing using the simple rule of 80 kg N required per tonne of canola.

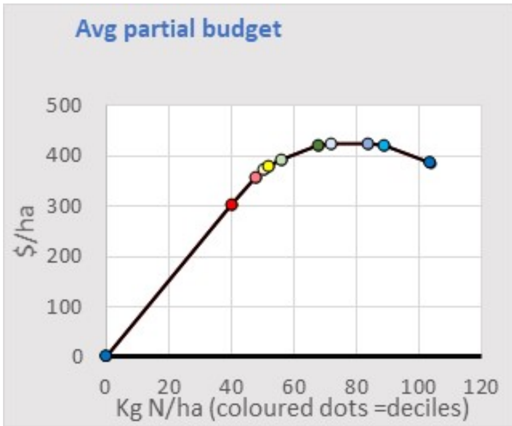
Biophysical graphs	
N req/t canol	80
Yield from Yprophet	
Risk & Return graphs	
Urea $/t	1300
N (yr 1)$/kg	2.8
Applic $/ha	10
Canola $/t	900

The range of yields was derived from Yield Prophet for one of the Resilient EP focus sties showing the N limited and water limited yield ranging from dry to wet deciles (graph 1). The N required for the N limited yield is shown in graph 2 as dark brown. This is the N limited yield in graph 1 multiplied by 80 and reported as N supplied by the soil. The extra fertiliser required to achieve the water limited yield is shown as the upper section of the bar chart in orange.





A simple economic analysis can compare the outcome of aiming for each decile by applying the amount of N in the orange bar (graph2). The shape of the response curve is shown in the black line in adjacent graph with the N rate for the different deciles as the coloured dots.



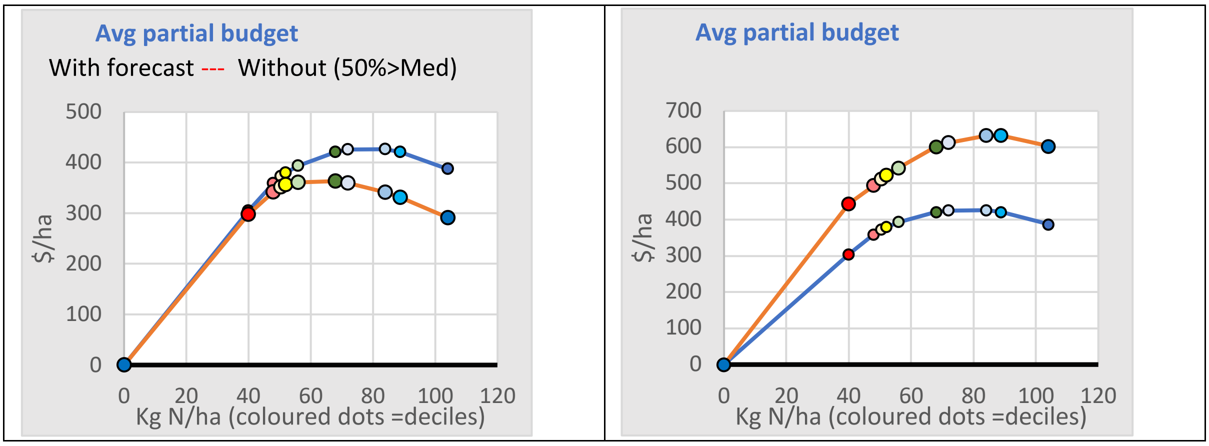
The shape of the economic response to nitrogen shows diminishing marginal returns and a large plateau of a flat response before a reduction. The information contained in the slope of the response curve is well understood by farm management economists and highly relevant to decision making. The UWA economist David Pannell noted the surprisingly limited attention to these principals (Flat earth economics (uwa.edu.au) An increasing number of presentations and fact sheets on nitrogen fertiliser discuss response curves (eg GRDC guide to nitrogen in southern Australia, Unkovitch et al 2020). To my knowledge, it is rare to show an interactive response curve generated from Yield Prophet data and user defined wheat price and N cost.

Under these assumptions, the highest partial budget achieved by aiming for decile 8 and applying 84 kg N/ha. Decile 5 (56 kg N/ha) is 92% of the maximum partial budget. Aiming for decile 8 provides a Marginal Benefit/Marginal Cost of $1.00 extra wheat for each $1.00 spent on N. Although this is commonly referred to as the Economic Optimum N rate (EONR), a more descriptive term is the Partial Budget Maximising N rate. Considering the alternative use of money on a grain farm, a grower might prefer a marginal budget of $1.50. The risk of a negative budget increases with the N rate. However, in this case the risk is relatively low.

IF aim for	Aim D1	Aim D2	Aim D3	Aim D4	Aim D5	Aim D6	Aim D7	Aim D8	Aim D9	Aim D10
by applying KgN/h	40	48	50.4	52	56	68	72	84	88.8	104
THEN AVERAGE OUTCOME INCLUDING CARRYOVER N OF						0%				
Partial Budget($/ha)	304	359	372	380	393	421	426	426	421	387
% of max	71%	84%	87%	89%	92%	99%	100%	Max	99%	91%
Marginal B/MC ($/$)		3.4	3.0	2.6	2.2	1.8	1.4	1.0	0.0	0.0
Risk of neg budget	3.0%	3.0%	4.0%	4.0%	4.0%	5.0%	5.0%	5.0%	6.0%	7.0%

The reason for conducting the economic analysis was to answer the question posed by the agronomist involved in the Resilient EP project “Are the forecast good enough to change N rates?” This requires the question to be flipped “How good do forecasts have to be to change N rates?” A complete answer to this second question requires a study of the psychology of growers, their risk appetite and trust in technical information. A partial answer can be found by analysing the decile a risk neutral grower would aim using climatology (every decile is equally likely) and whether this is changed by the forecast (increased chance or wetter or drier deciles).

This is shown in the figures below (note the difference in the Y axis scale). The blue line is without the forecast (50% chance of exceeding the median). The left-hand graph shows the orange line falling below the blue line with a drier forecast (30% chance of exceeding the median) and the right hand graph shows the orange line shifting above the climatology blue line with a wetter forecast (70% chance of exceeding the median).



To answer the question of whether the forecast changes the optimum rate of N it is useful to look at the table of partial budget information. (see below)

With carryover N of		*0%*		**% chance > med =**		**50%**				
IF aim for	Aim D1	Aim D2	Aim D3	Aim D4	Aim D5	Aim D6	Aim D7	Aim D8	Aim D9	Aim D10
by applying KgN/h	40	48	50.4	52	56	68	72	84	88.8	104
THEN AVERAGE OUTCOME INCLUDING CARRYOVER N OF						0%				
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Marginal B/MC ($/$)		3.4	3.0	2.6	2.2	1.8	1.4	1.0	0.0	0.0
Risk of neg budget	3.0%	3.0%	4.0%	4.0%	4.0%	5.0%	5.0%	5.0%	6.0%	7.0%

Comparison with no N carryover			% chance > med =		70%					
Partial Budget($/ha)	444	494	512	523	543	601	612	632	632	603
% of max	70%	78%	81%	83%	86%	95%	97%	100%	Max	95%
Marginal B/MC ($/$)		3.2	3.6	3.6	2.7	2.7	2.0	1.6	1.0	0.0
Risk of neg budget	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%	2.0%	2.0%	2.0%	2.0%

Comparison with no N carryover			% chance > med =		30%					
Partial Budget($/ha)	297	342	352	356	360	363	359	341	331	291
% of max	82%	94%	97%	98%	99%	Max	99%	94%	91%	80%
Marginal B/MC ($/$)		3.0	2.4	2.0	1.4	1.1	0.0	0.0	0.0	0.0
Risk of neg budget	5.0%	6.0%	6.0%	6.0%	6.0%	8.0%	8.0%	9.0%	10.0%	11.0%

As expected, the Economic Optimum N Rate or GM maximising N rate shifts to a higher decile with the wetter forecast and to a lower decile with the drier forecast. However, a closer look shows that the change in partial budget is minute. This is because the response surface is flat at the optimum rate. The forecast shifts the response curve north or south more than east or west, in other words a positive forecast leads to all N rates being more profitable but, in this case has a surprisingly small impact on the best rate to apply.

The economic results are obviously sensitive to crop price and N cost. These can be easily adjusted. The results are also sensitive to the yield assumptions, especially the yields in the wetter deciles. A suggested sensitivity analysis is to adjust the 'top tail' indicated by Yield Prophet by a user defined percentage.

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