Nitrogen decisions for cereal crops: a risky and personal business

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Abstract
Cereal crops principally require Nitrogen (N) and water for growth. Fertiliser economics are important because of the cost at sowing with expectation of a financial return after harvest. The production economics framework can be used to develop information for ‘best’ fertiliser decisions. But the variability of yield responses for rainfed production systems means that fertiliser decisions are a risky business. How do farmers make such decisions, and can economics give any guidance? Simulated wheat yield responses to N fertiliser applications show tremendous variation between years or seasons. There are strong agronomic arguments for a Mitscherlich equation to represent yield responses. Plots of the 10th, 50th and 90th percentiles of yield response distributions show likely outcomes in ‘Poor’, ‘Medium’ and ‘Good’ seasons at four Australian locations. By adding the prices for Urea and wheat we predict that the ‘best’ decisions vary with location, soil, and (sometimes) season. We compare these predictions with typical grower fertiliser decisions. Australian wheat growers understand the yield responses in their own paddocks and the relative prices, so they are making relevant short-term fertiliser decisions. These are subjective or personal decisions. Myanmar smallholders grow rice and maize in the Central Dry Zone, with relatively low levels of fertiliser and low crop yields. They have pre-existing poverty, high borrowing costs and are averse to risky outcomes. A Marginal Rate of Return (MRR) analysis with a hurdle rate of 100% is illustrated for the Australian locations, and this approach will be tested in Myanmar.

Key words
Nitrogen, yield response, economics, fertiliser decisions

Introduction
In N-limited soils the application of Urea fertiliser to cereal crops is expected, in the absence of other limiting factors, to result in an increase in yield. Because synthetic N fertiliser is costly and yield improvements are valuable, the ‘how much N?’ question has important economic dimensions. But the plant response varies because crop yields depend on both N and moisture (rainfall). We use a data set of simulated Australian rainfed wheat yield responses to investigate fertiliser decisions. How relevant is the economic framework for the ‘how much N’ decision when there is so much yield variability?

Yield responses to Nitrogen
Data from a crop simulator, the Water and Nutrient Management Model, (Li et al. 2007, Barton et al. 2008) were generated for Cunderdin, Rutherglen, Wagga Wagga and Tamworth in southern Australia. The model was calibrated and validated at each site. Wheat yield responses to N were simulated over 40 years of historical climate data, and the responses for Wagga are in Figure 1. There is a general increasing yield trend with added N, and a wide distribution of yields at each N level.

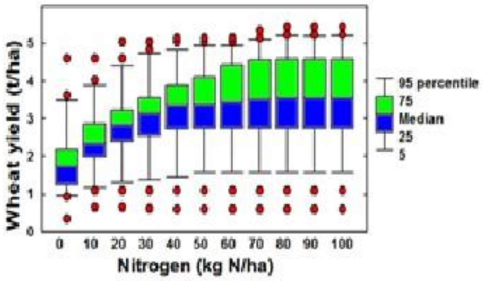

Figure 1. Simulated wheat yield responses to applied N fertiliser, Wagga Wagga

The shape of yield responses
Responses of the diminishing-returns type are common in biology and elsewhere (France and Thornley (1984)). Berck and Helfand (1990) illustrated that the effects of spatial variability in soil conditions (across a field) and temporal variability in crop planting and flowering dates resulted in a Linear Response and Plateau response for individual plants and a concave response more generally. For wheat responses to N in Brazil Lanzer and Paris (1981) used a Mitscherlich function, see also Harmsen (2000).

Including yield variability in the analysis
We fitted the Mitscherlich equation (Y=a(1-exp(-b.N)) to the 10^{th}, 50^{th} and 90^{th} percentiles of the wheat yield distributions to develop algebraic yield responses for Poor, Medium and Good seasons, respectively, at each location. We expect that yields increase with rainfall, but is there an interaction between the type of season and fertiliser decisions? That is, in different crop seasons do the yield responses just move up and down or do they also move across? This has implications for whether the 'best' fertiliser decisions vary with season.

An economic approach to making N decisions
The economic framework for making fertiliser decisions has been set out by Dillon and Anderson (1990), Anderson et al. (1988) and many others. Economic theory relies on production (yield response) functions that are concave, smooth, continuous and differentiable (Dillon and Anderson (1990)) allowing algebraic derivations of optimal decisions. From the production economics framework, the best economic fertiliser decision depends on the rate of change in yield as fertiliser is added and relative prices for wheat and Urea (Fig 2a). If separate yield responses can be described for different season types then the economic decision can be developed for each season. Two possible types of responses for Poor, Medium and Good years are shown in Figures 2b and 2c. If the yield response mainly moves up and down with season then the best fertiliser decision is unlikely to vary much between seasons (Fig 2b). If the yield response moves both up and across with improved seasons then the best N decision may vary between seasons (Fig 2c).

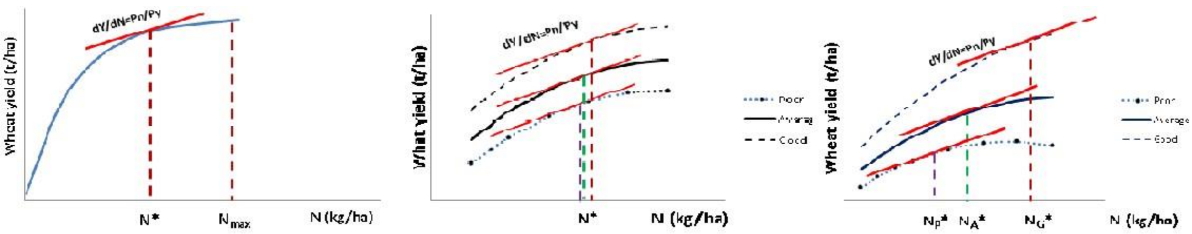

Figure 2. Economic framework for the fertiliser decision (a), and for different season types (b and c)

This production economics framework is valuable in emphasising that decision makers should aim to maximise profit rather than yield (Malcolm et al. 2009). But the flatness of economic response near the economic optimum is well known by economists and others (e.g. see Jardine (1975), Anderson (1975) and Pannell (undated)). Jock Anderson noted that for fertiliser decisions '*precision is pretence and greater accuracy is absurdity*' (Anderson 1975). And there are other good reasons (cash flow considerations, limited capital budgets and risk aversion) why fertiliser applications are personal decisions.

Applying, for a moment, the economic framework to the Poor, Medium and Good algebraic yield responses at each location provides the economic N decisions, see Table 1 and Figure 3. The big picture from Figure 3 is that the 'best' fertiliser decisions are not predicted to vary much with season type at Cunderdin and Rutherglen, but they are predicted to vary with season type at Wagga Wagga and Tamworth. The soil types at Wagga Wagga and Tamworth with enhanced water holding capacity allow rainfall to be stored for crop use, meaning that there is extra yield capacity in better seasons and more N fertiliser can be profitably applied.

Actual fertiliser decisions in Australia
A check with local agronomy extension and research experts (personal communications with Dr. Craig Scanlan, DAFWA; Dr. Cassandra Schefe, Riverine Plains Rutherglen; Dr. Lisa Castleman, NSW Local Land Services Wagga Wagga; and Mr. Bill Manning, NSW Local Land Services Tamworth) gives an idea of typical grower N fertiliser decisions in each district (Table 1). At Cunderdin the typical grower decisions are below the theoretical economic N rates. At Rutherglen information from 11 sites shows that the grower decisions for wheat in 2015 varied from 18–109 kg N/ha (but mainly from 50–100 kg N/ha). Half the

growers used split applications. At Wagga Wagga, N fertiliser is typically applied at mid-late tillering (80-100 kg Urea) and then, depending on the season to determine the level of grower confidence, another 60-80 kg Urea may be added. If the season is poor then the extra fertiliser will not be applied. The top growers may apply up to 200 kg/ha of Urea. At Tamworth typical high-yielding crops will receive 80 units of N, which will be split applications of 40-50 kg N/ha at sowing and the rest as topdressing depending on the season. At Wagga and Tamworth the grower decisions seem to vary more with the type of season, as in Figure 2c.

Table 1. Theoretical and actual N fertiliser decisions

Location	Theoretical economic N rates			Typical grower decisions	MRR for 'Medium' 100% ROI
	Season type				
	'Poor' (10^{th}) KgN/ha	'Medium' (50^{th}) KgN/ha	'Good' (90^{th}) Kg N/ha	Kg N/ha	Kg N/ha
Cunderdin	67	74	65	20 – 50	55
Rutherglen	53	64	62	18 - 109	50
Wagga Wagga	54	54	79	37/46 + 28/37	40
Tamworth	52	85	87	80 (split)	60

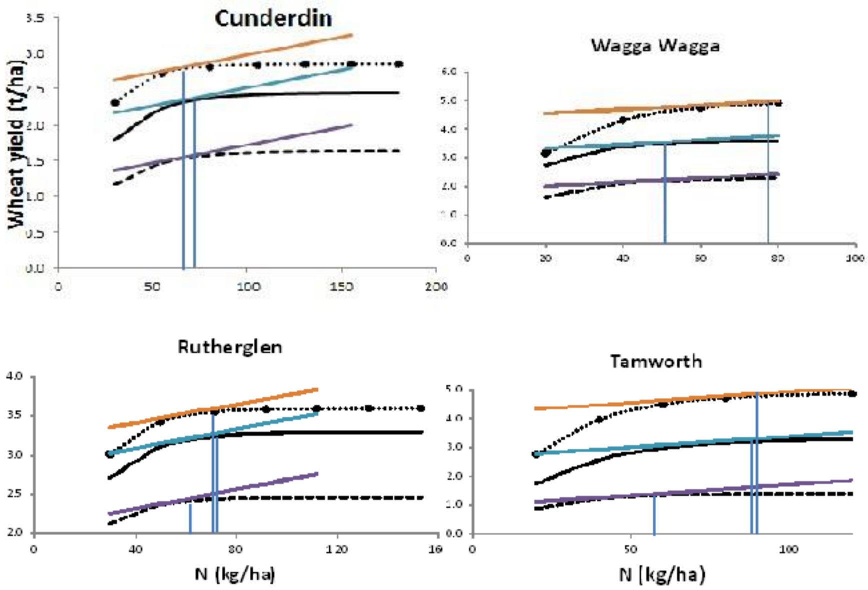

Figure 3. Yield responses and economic N rates for Poor, Medium and Good seasons at four locations

Montjardino et al. (2015) demonstrated the importance of risk aversion in N application rates by Australian cereal growers. They found at four (different) dryland cropping sites across southern Australia that the yield- and profit-maximising N rates can be quite similar but these can be reduced significantly when risk and risk-aversion factors are included, particularly in low rainfall locations.

Cereal growers and agricultural consultants in Australia do not seem to use a formal N optimising economic framework when advising clients (Dr. Rob Norton, International Plant Nutrition Institute, personal communication). But the typical decisions in Table 1 indicate that growers account for yield responses, prices and risk. The economic framework seems to be 'roughly right' in predicting fertiliser decisions.

Fertiliser decisions in a developing country

In Myanmar the average levels of N fertiliser application and crop yields are relatively low (International Rice Research Institute (Undated), Raitzer et al. (2015)). Smallholder farmers may not be aware of potential yield improvements from increased fertility, and typically they are indebted, poor and risk averse, with high borrowing costs. Any decisions about fertiliser will depend on their perceptions of potential yield gains from fertiliser use (i.e. their subjective beliefs, Anderson et al. (1988)), on their attitudes to risk and on borrowing costs. Inadequate management of other crop inputs (e.g. weed control) may also restrict the full expression of cereal yields to added N fertiliser.

CIMMYT (1988) presented a framework for making N fertiliser recommendations to farmers in developing countries. It was based on smallholder subjective (or personal) beliefs about crop yield responses to fertiliser. An analysis of marginal net benefits and marginal costs between incremental fertiliser applications was used to calculate MRRs. These rates can be compared to a target or hurdle rate before any recommendation is made to a farmer group. That is, the above economic framework (requiring information on changes in the rate of yield response equalling the price ratio of input to output) is augmented by a hurdle rate of return to account for high borrowing costs and smallholders making a substantial change to their production systems. CIMMYT (1988) suggest applying a minimum target rate of 50 – 100% return on investment (ROI) before a recommendation is made in developing countries. A 100% ROI is equivalent to receiving $2 (net) for every $1 borrowed. An analysis of MRRs for the Medium seasons with a 100% hurdle at the Australian locations is in Table 1. These rates are near or below the typical grower decision N rates.

Conclusion

N fertiliser decisions are economic decisions, but the degree of variability in agronomic response means that a formal economic decision framework is difficult to apply. Rather, Australian farmers seem to make decisions based on an understanding of production economic principles applied to their own situations and circumstances. The difficulties in applying economics to develop 'best' fertiliser decisions are likely to be magnified in a country such as Myanmar where smallholders may not conceive of the potential for crop yields to be increased with fertiliser application. For them debt, poverty, and risk aversion are added to high borrowing costs, and it is a challenging task to promote increased crop fertility for yield response in such situations.

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