Economic perspectives on N in farming systems

David Pannell, UWA School of Agriculture and Environment, University of Western Australia

Key messages

- Higher rates of nitrogen are usually more risky, not less.
- Precision in choosing nitrogen rates is usually not justified.

Aims

To provide practical insights into the economics of nitrogen application in crops.

Introduction

The global challenge of feeding seven billion people would be more difficult without nitrogen fertilizer. It increases the profitability of individual farmers, although it is over-applied in some cases.

These are, in large part, economic issues. There is an extensive and diverse research literature analysing these issues using the tools and frameworks of economics. In this paper I provide a review and synthesis of this literature. The economic insights that will be discussed are important for making sound decisions about farm-level management of nitrogen, for understanding farmers' behaviour in relation to nitrogen, and for prioritising nitrogen-related research and extension.

The objective is to identify and describe important economic principles, insights and empirical results, and to illustrate how technical aspects of nitrogen fit into the economic, social and policy world. In this world, the technical issues are important, but they underpin a broader set of perspectives, encompassing profitability, risk, learning, human behaviour, human attitudes, human values, fairness, rights, and markets.

Economics of nitrogen as an input to production

The optimal level of nitrogen fertilizer for a farmer to apply to a crop or pasture is case-specific, depending on technical issues (e.g. the type of crop, soil type, rainfall), and socio-economic issues (e.g. the sale price of grain, purchase price of fertilizer, the objective of the farmer). The simplest economic model addressing this question (Figure 1) is based on an assumption that the farmer's objective is to maximise the expected value of on-farm profit, ignoring factors such as production risk and off-farm impacts. The "production function" shows the expected value of yield as a function of fertilizer rate. This function encompasses all of the relevant technical issues that determine the response of yield to fertilizer. Expected profit is maximised where the slope of the production function equals the fertilizer price divided by the grain sale price (Dillon and Anderson 2012).

The production function for nitrogen fertilizer always exhibits diminishing marginal returns – it flattens out at higher fertilizer rates. In certain situations (e.g. a drought late in the growing season) yield may decline at higher nitrogen rates, in which case the expected yield will probably also decline. It is obvious that if the fertilizer rate is so high that expected yield is decreasing, then the fertilizer rate is too high.

Perhaps less obvious is the conclusion that the rate of nitrogen fertilizer that maximises expected profit is less than the rate that maximises expected yield. The gap between those two rates depends on the shape of the production function and the ratio of fertilizer price to grain price. In cases where the production is relatively flat, and/or the ratio of nitrogen price to output price is relatively large, the gap can be large. Clearly, the optimal fertilizer rate depends not just on technical factors but also on prices. If the price of grain rises or the price of fertilizer falls, the optimal fertilizer rate increases (and vice versa), even in the absence of any change in the technical relationship between fertilizer and yield. Therefore, improving nitrogen use efficiency, if it is pursued by adjusting fertilizer rates, is not necessarily in the best interests of farmers. If it involves reducing the fertilizer rate below the profit-maximising rate, the farmer incurs an opportunity cost – he or she makes a lower expected profit than would have been possible at a higher nitrogen rate.

Nitrogen and economic risk

Maximisation of expected profit is a reasonable approximation of the management objective of some farmers (Abadi Ghadim and Pannell 2003), but many are prepared to trade off some expected profit to reduce risk (Antle 1987). If the riskiness of cropping varies at different rates of nitrogen fertilizer, then this would influence the rate preferred by these "risk averse" farmers. Risk aversion can vary from mild to extreme, depending on the psychological make-up and the circumstances of different farmers. Economists generally measure risk as the variance or standard deviation of the probability distribution of outcomes. The greater the variance of the outcome for a practice (e.g. a fertilizer rate), the less attractive it is to risk-averse farmers. The use of variance as the measure of riskiness reflects that there are both downside and upside aspects to risk. Risk-averse farmers give greater weight to the downside, but the upside is not irrelevant to them.

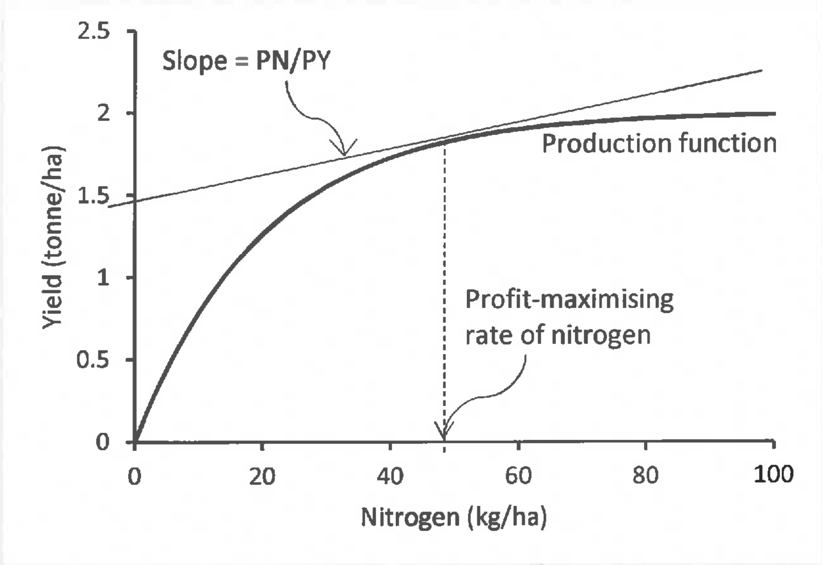

Figure 1. Simple economic model to optimise profit from application of nitrogen fertilizer. PN = price per unit of nitrogen ($/kg), PY = sale price of grain ($/tonne).

There are various sources of risk that can affect farmers' decisions about nitrogen fertilizer. One is unpredictability of the price at which the output will be sold. If this price is subject to risk, then increasing crop yield by applying nitrogen fertilizer will increase the farmer's overall risk, by increasing the variance of income from the crop. This means that, for risk-averse farmers, greater output-price risk results in a lower optimal fertilizer rate. Conversely, policies or contracts that reduce output-price risk may increase fertilizer use, depending on what those policies or contracts do to the expected value of output price.

The other main source of risk relevant to nitrogen fertilizer decisions is the riskiness of crop production. The consequence for optimal fertilizer rate of yield risk is less clear-cut than for price risk. It has sometimes been suggested that the application of nitrogen fertilizer reduces farmers' risks, either by reducing their variance of income or by acting as a kind of insurance policy that reduces the probability of bad outcomes (e.g. Sheriff 2005). However, the weight of empirical evidence contradicts this view (Roosen and Hennessy 2003; Rajsic et al. 2009; Monjardino et al. 2015). Therefore, risks associated with both production and output price both tend to result in reduced optimal nitrogen application rates.

Economics of nitrogen fixation from legumes

Legume rotations provide various benefits to cereal producers, potentially including risk reduction through diversification of income sources, reduced cereal crop disease, diversification of weed management strategies, provision of high-quality livestock feed and fixation of atmospheric nitrogen (Pannell 1995). There is much less research on the economics of nitrogen fixation from legumes than there is on the economics of nitrogen fertilizer. There are various studies that have examined the economics of including legumes in farming systems, including nitrogen-related benefits (e.g. Pannell et al. 2014; Preissel et al. 2015) but these usually do not separate out nitrogen from other factors.

Pannell and Falconer (1988) identified two components of the benefits of nitrogen fixation: (a) reduction in the economically optimal rate of nitrogen fertilizer, and (b) contributing to an increase in yield due to biologically fixed nitrogen that does not act as a direct substitute for nitrogen fertilizer, perhaps because it becomes available to crops more slowly as biological material breaks down. The latter is difficult to distinguish from yield boosts due to other factors, such as disease reductions. The existence of these two components means that the value of fixed nitrogen is not equal to the cost of a similar amount of nitrogen fertilizer, because some fixed nitrogen does not actually substitute for nitrogen fertilizer. For the broadacre farming system of south-western Australia, Pannell and Falconer (1988) found that the value of the yield boost due to legumes (including the yield boost due to nitrogen fixation) was far greater than the value of a reduced need for nitrogen fertilizer. They also found that the contribution to profits from legumes in this farming system exceeded the contribution from nitrogen fertilizer.

The economics of nitrogen fixation and legumes more broadly are highly case-specific (Schilizzi and Pannell 2001). Their contributions to profitability can vary greatly between regions and farming systems, and even between different farms in the same region (e.g., Pannell et al. 2014). In some cases, nitrogen fixation is a relatively minor factor in a decision to grow legumes (e.g. where they are grown primarily for livestock feed), whereas in other cases it is amongst the main reasons.

Flat payoff functions

An under-recognised but important aspect of the economics of nitrogen is the frequent occurrence of flat payoff functions for nitrogen fertilizer (Pannell 2006). There always exists a range of fertilizer rates that are only slightly less profitable than the profit-maximising rate (i.e. a range where the payoff function is relatively flat), and in most cases, that flat range is wide. An equivalent statement remains true if the farmer's objective includes and allowance for risk aversion; the payoff function (including a negative risk premium) is flat within the vicinity of its highest point.

For example, Figure 2 shows profit as a function of nitrogen application rate for several soil types in the central wheatbelt of Western Australia, as represented in the whole-farm bioeconomic model, MIDAS (Morrison et al. 1986; Kingwell and Pannell 1987). Fertilizer ranges that provide profit within 5% of the optimum are +77% to –51% of the optimal fertilizer rate for sandy loam over clay (i.e., any rate between 24 and 88 kg/ha of N gives almost the same profit). Equivalent ranges for the other soils are +75% to –46% for shallow sandy loam over clay, and +55% to –42% for deep yellow sand. Results broadly similar to this are typical almost everywhere that nitrogen fertilizer is applied. Jardine (1975) noted that on presenting information to agronomists about flat profit curves for fertilizers, he "observed such reactions as complete disbelief, blank incomprehension, incipient terror, and others less readily categorized". I suspect that little has changed, but the issue deserves a much higher profile.

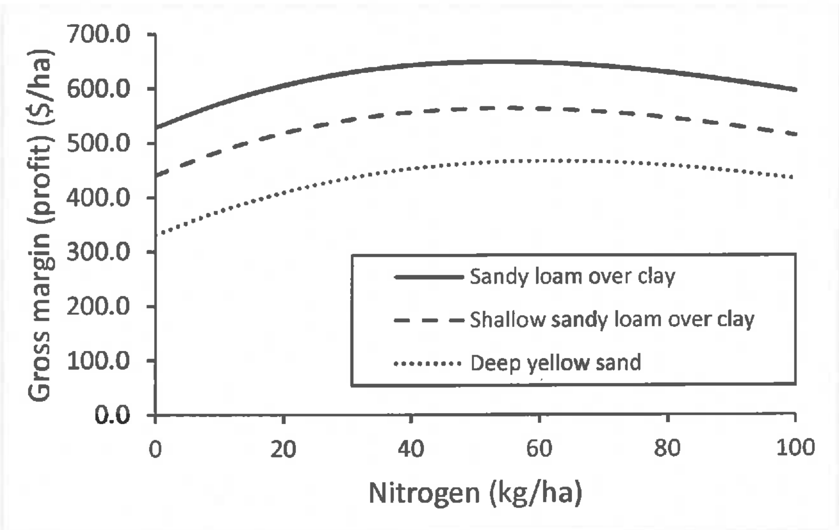

Figure 2. Profit as a function of nitrogen application rate in the central wheatbelt of Western Australia. Production functions, prices and costs from MIDAS model 2015 (Morrison et al. 1986).

The management implications of flat payoff functions are profound. They mean that the farmer has flexibility in choosing the fertilizer rate. If a lower rate would better satisfy another objective (e.g. risk reduction), the farmer can choose that rate with little sacrifice of profit. If a farmer wants to adopt a simple strategy of applying the same nitrogen rate each year, foregoing potentially beneficial adjustments in response to variations in grain price or yield potential, this can be done with little economic sacrifice. If regulators require a moderate reduction in fertilizer rate below the farmer's economic optimum, the cost to the farmer will be small.

A second implication is that the benefits of precision-agriculture technologies that spatially adjust fertilizer rates within a field will usually be small. Before these technologies were imagined, Anderson (1975) argued that "In pursuing ... optimal levels of decision variables, precision is pretence and great accuracy is absurdity". Unless the required rate adjustments within a field are very large, a standard rate is likely to fall within the flat range of the payoff function, meaning that a failure to adjust rates does not result in a large loss of profits. That is why economists evaluating this type of precision technology have found that their benefits are not large. Paz et al. (1999), Babcock and Pautsch (1998) and Thrikawala et al. (1999) all estimated small benefits from variable-fertilizer-rate technology – too small to cover realistic costs of the technology in most cases.

A third implication of flat payoff functions is for agronomists developing recommendations for fertilizer rates: they should not recommend a single fertilizer rate for any particular farming context. Much more relevant and helpful to farmers would be to identify the range of rates that will deliver profits within a certain percentage of the maximum (e.g. within 5%). Farmers can then bring in their own preferences when selecting which rate to apply.

Conclusion

The insights, evidence and principles outlined here are of central relevance to management, policy and research related to nitrogen. However, they are relatively under-utilized in practice. Many recommendations for nitrogen application rates are made without adequate consideration of the economic principles outlined here. The influence of nitrogen application on farm business risk is often perceived inaccurately. The very common occurrence of flat payoff functions is often not recognised. Greater utilization of these economic insights and tools has the potential to increase the benefits to farmers.

Key words

Economics, profit, risk, precision

Acknowledgments

The author is grateful to the ARC Centre of Excellence for Environmental Decisions for funding support.

References

Abadi Ghadim AK and Pannell DJ (2003). Risk attitudes and risk perceptions of crop producers in Western Australia, in B.A. Babcock, R.W. Fraser and J.N. Lekakis (eds), Risk Management and the Environment: Agriculture in Perspective, Kluwer, Dordrecht, pp. 113-133.

Anderson JR (1975). One more or less cheer for optimality. Journal of the Australian Institute of Agricultural Science 41, 195-197.

Antle JM (1987). Econometric estimation of producers' risk attitudes. American Journal of Agricultural Economics 69(3), 509-522.

Babcock BA and Pautsch GR (1998). Moving from uniform to variable fertilizer rates on Iowa corn: Effects on rates and returns. Journal of Agricultural and Resource Economics 23(2), 385-400.

Dillon JL and Anderson JR (2012). The Analysis of Response in Crop and Livestock Production, 3rd Edition, Pergamon, Oxford.

Jardine R (1975). Two cheers for optimality. Journal of the Australian Institute of Agricultural Science 41, 30–34.

Kingwell RS and Pannell DJ (Eds) (1987). MIDAS, A Bioeconomic Model of a Dryland Farm System, Pudoc, Wageningen, 207pp.

Monjardino M, McBeath T, Ouzman J, Llewellyn R, and Jones B (2015). Farmer risk-aversion limits closure of yield and profit gaps: A study of nitrogen management in the southern Australian wheatbelt. Agricultural Systems 137, 108-118.

Morrison DA, Kingwell RS, Pannell DJ and Ewing MA (1986). A mathematical programming model of a crop-livestock farm system. Agricultural Systems 20(4), 243-268.

Pannell DJ (1995). Economic aspects of legume management and legume research in dryland farming systems of southern Australia. Agricultural Systems 49, 217-236.

Pannell DJ (2006). Flat-earth economics: The far-reaching consequences of flat payoff functions in economic decision making, Review of Agricultural Economics 28(4), 553-566.

Pannell DJ and Falconer DA (1988). The relative contributions to profit of fixed and applied nitrogen in a crop-livestock farm system. Agricultural Systems 26(1), 1-17.

Pannell DJ, Llewellyn RS and Corbeels M (2014). The farm-level economics of conservation agriculture for resource-poor farmers. Agriculture, Ecosystems and Environment 187(1), 52-64.

Paz JO, Batchelor WD, Babcock BA, Colvin TS, Logsdon SD, Kaspar TC and Karlen DL (1999). Model-based technique to determine variable rate nitrogen for corn. Agricultural Systems 61(1), 69-75.

Preissel S, Reckling M, Schläfke N and Zander P (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. Field Crops Research 175, 64-79.

Rajsic, P., Weersink, A. and Gandorfer, M. (2009). Risk and Nitrogen Application Levels. Canadian Journal of Agricultural Economics 57, 223-239.

Roosen J and Hennessy DA. (2003). Tests for the role of risk aversion on input use. American Journal of Agricultural Economics 85, 30–43.

Schilizzi S and Pannell DJ (2001). The economics of nitrogen fixation. Agronomie 21(6/7), 527-538.

Sheriff, G. 2005. Efficient waste? Why farmers over-apply nutrients and the implications for policy design. Review of Agricultural Economics 27: 542–57.

Thrikawala S, Weersink A, Kachanoski G and Fox G (1999). Economic feasibility of variable-rate technology for nitrogen on corn. American Journal of Agricultural Economics 81(4), 914-927.