How much is an extra kilogram of nitrogen worth? New information for fertiliser decisions by wheat growers

R.J. Farquharson [a, b], B. Malcolm [a] and Chen, D.[a]

Abstract

Economic information is important for Australian wheat growers when making fertiliser decisions, because urea and grain prices have been changing in recent years. Existing Australian approaches to developing fertiliser recommendations fail to account for economic factors. A new approach to making fertiliser decisions is illustrated in this paper, which accounts for the patterns of crop response as fertiliser is added, and for associated marginal benefits and costs. This decision framework develops information to find the best level of nitrogen fertility to meet the profit objective and allows growers to set a target rate of return that their nitrogen investments might be required to meet, while accounting for factors such as soil moisture at sowing and uncertain in-crop rainfall. It could be used in a new approach to providing decision support to wheat growers about making nitrogen decisions in the Australian cropping zone, and a proposal for further research is outlined.

Keywords: Farm management economics, nitrogen, fertiliser, wheat, decision support, Australia

[a] Melbourne School of Land and Environment
The University of Melbourne, Parkville, Victoria 3010, AUSTRALIA
[b] Corresponding author: bob.farquharson@unimelb.edu.au

International Farm Management Association
17th International Conference: Food, Fiber and Energy for the Future
Bloomington, Illinois USA, 19-24 July 2009

Introduction

The essence of good crop farm management is (1) conducting timely cultural operations, (2) ensuring the crop has adequate soil moisture supply, (3) controlling competitor plants for moisture and nutrients, (4) supplying enough nutrition to the plant so that nutrition is not the limiting factor given the available soil moisture, and (5) taking into account the relative costs of nutrition and value of yield to maximise the net return from the crop. Agronomists are generally strong on emphasising points (1) to (4): farm management economists emphasise points (1) to (5) for profitable crop farming. While achieving high standards in the technical aspects of production of crops is the basis for profitable cropping, good technology is not sufficient. Making farm decisions about profitable cropping requires economic thinking.

Farm management economists have long been critical of their agricultural technology colleagues for neglecting the necessary economic thinking in advising farmers about production decisions (eg Malcolm 2004). The main inadequacy of much technical extension information about agricultural production decisions is the technologists' focus on technical efficiency and averages. Average relationships between physical inputs and outputs are often the focus in extension advice about feeding animals (feed conversion efficiency) and feeding crops (crop feed efficiency). This focus is misplaced on three counts: (1) the input-output level that gives either the maximum total production per land area or the maximum average technical efficiency of the land input is not the input-output level that gives maximum profit, (2) maximising the total production from the variable input, say nitrogen, is greater than the level of the input that should be used for the most crop profit, and (3) the average output per unit of input (average productivity) is not the right metric to use to judge whether or not to use more or less of an input – it is the marginal product compared to marginal costs that needs to be considered.

A focus on maximum production and average productivity of a variable or fixed input is wrong because of the operation of the principle of diminishing marginal returns, where incrementally added input produces less extra yield or, alternatively, a defined extra quantity of output requires increasing amounts of extra input. France and Thornley (1984, p.2) note that responses of the diminishing-returns type are quite common in biology and elsewhere.

This biological principle has following implications:

- Maximising total production from applying a variable input such as fertilizer to a fixed input such as land is only the best thing to do if the extra inputs required are free;
- If the crop is worth growing at all, variable inputs such as fertiliser should be used at least up to the level where the average product of the variable input is at a maximum, and, for maximum profit, the variable input should be used as long as the marginal benefits of extra inputs exceed the marginal costs. Beyond that level, extra units of input are more costly than the value of extra production; and
- The shape of the production response to an added variable input is thus vital information for making a decision about how much input to use. Information about the likely yield response to extra variable input such as fertilizer, plus information on prices of variable inputs and outputs, enables analysis of the effects on profit of the decision about applying fertilizer to crops.

In this paper we demonstrate a case where the yield response of a wheat crop to added nitrogen is estimated using a crop simulation model. The results account for uncertainties associated with the moisture in the soil when the crop is sown and with rainfall when the crop is growing. The analysis is conducted for a particular soil type and location. The marginal economic framework is applied to develop some decision rules about applying nitrogen fertiliser to crops. The economic approach is based on standard economic theory and principles, as shown in Farquharson (2006). We discuss how such an approach can be used in practice in providing extension advice about farm management.

Production responses and marginal changes

These fundamental production relationships are shown in Figure 1. For biophysical input-output (total product) responses that are concave in shape (increasing at a decreasing rate up to the maximum) and smooth (Figure 1(a)), the quantity of input that gives greatest profit is less than the quantity of input that gives greatest production. The average and marginal productivities of the variable input are both initially high, and then decline as more input is added. Multiplying these changes in production by the price of the product gives the average and marginal revenue (Figure 1(b)). Average and marginal revenues decline as average and marginal products decline. The most profit is where the marginal revenue from an extra input of the variable input equals the marginal cost. This is the input level where the change in physical product equals the ratio of input to output price (Figure 1(a)), or where marginal revenue equals marginal cost (Figure 1(b)).

Farmers trying to maximise crop profit use variable inputs such as fertiliser somewhere between where the technical efficiency of the variable input is maximised (maximum average product and maximum average revenue per unit of the input) and where the technical efficiency of the fixed input level is maximised (maximum total product of the land). Much technical extension advice focuses on the two extremes of this range of input use. Neither of these two levels of variable input is likely to be the most profitable level of input to use. The correct advice is to try to apply the variable input as close as possible to the level where the extra revenue from the last unit of input is likely to just exceed the extra cost.

In practice defining precisely the input level that gives maximum profit is difficult because of uncertainty about the response that will apply to extra inputs and uncontrollable effects on yields. But marginal, not average, thinking is the correct way to consider how to get the most profit. Marginal thinking gives the farm decision maker the opportunity to ‘fine tune’ crop feeding decisions, given the uncontrollable factors and uncertainties that are present in the production process.

Why economics?

Nitrogen costs money to apply, its price has recently risen, and the investment of capital needs to be considered against alternative uses for scarce and costly funds. Recent trends in urea and wheat prices from the Australian Bureau of Agricultural and Resource Economics (2007) are shown in Figure 2. The urea price has risen by 39% in real terms since 2000.

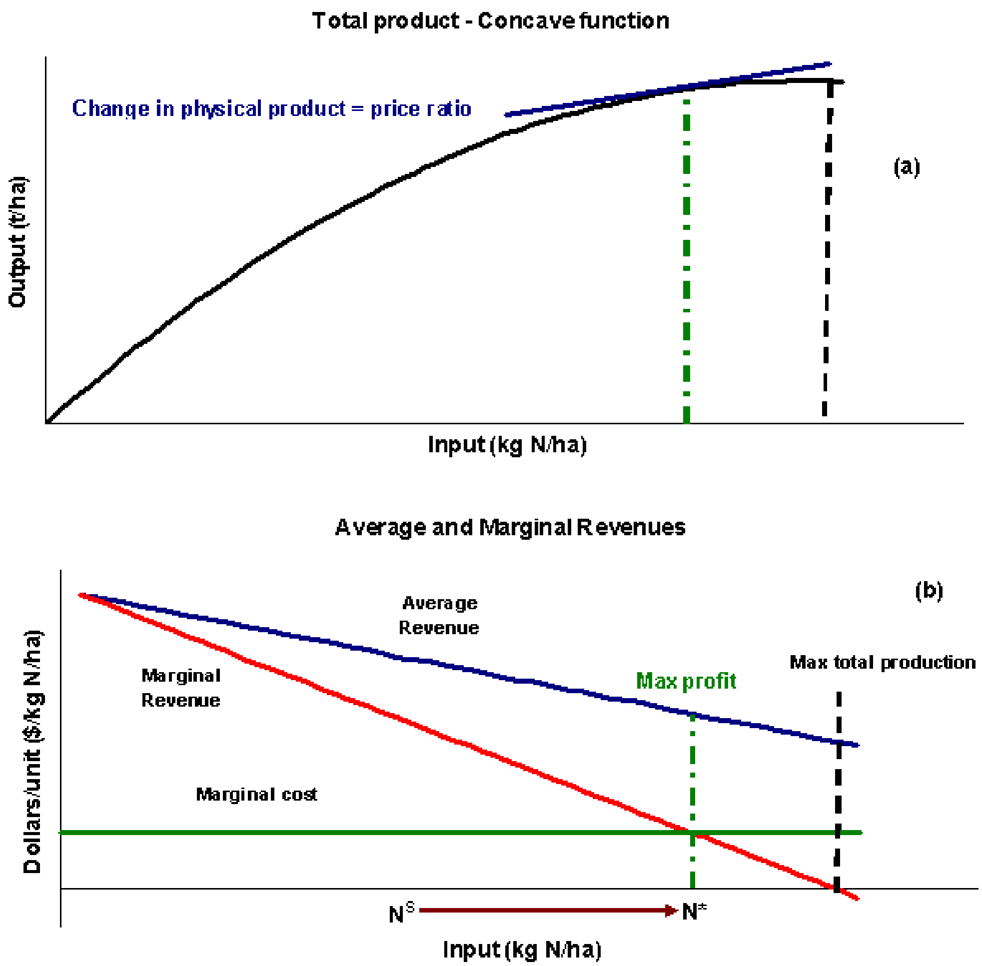

Figure 1. A concave response function and associated marginal and average schedules

In the Australian states of New South Wales and Queensland recommendations about nitrogen applications are currently based on measures of the supply of nitrogen in the soil and the demand for nitrogen (from a grower's target crop yield and protein content). This approach is based on work by Lawrence *et al*. (1996) in Queensland and Martin *et al*. (1996) in northern New South Wales. This nitrogen budgeting approach to the fertilizer decision answers the question 'how much nitrogen is needed to grow the target crop without further running down soil fertility?' The farm management economic question is different – the farm management economic question is 'how much nitrogen should be applied to maximise profit from the crop?'

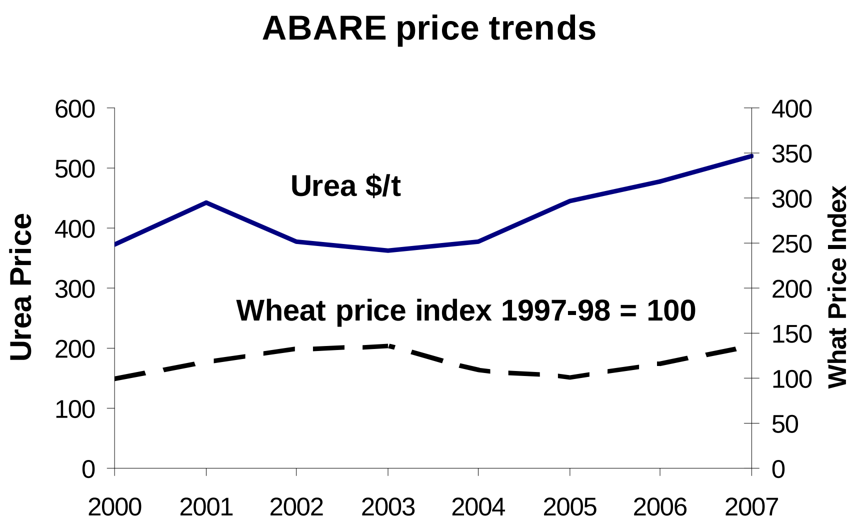

Figure 2. Urea and wheat prices have changed in recent years

An economic approach to the nitrogen decision

A diagram of the nitrogen decision has a range of soil fertility levels shown on one axis and the associated marginal benefits and marginal costs from applying more nitrogen on the other axis (Figure 1(b)).

The level of total nitrate nitrogen available to the crop on the day of sowing is defined as the measure of soil fertility. This is shown as the horizontal axes of Figure 1. On the vertical axis of Figure 1(b) are the economic consequences of adding more nitrogen at each level of soil fertility. These are the marginal benefits and marginal costs of adding more available nitrogen to the crop.

The vital element of this decision is sound estimates of the extra output from added input. In Figure 1(a) a concave response with diminishing marginal gains is shown. The modelled wheat yield and protein responses for northern New South Wales follow this pattern.

For this type of response of extra output to extra input, if there is little soil fertility present at sowing time then adding a kilogram of available nitrogen is likely to have a relatively high impact on the yield and the related economic payoff. If an extra kilogram of nitrogen is added when there is ample soil fertility then the economic payoff from the extra nitrogen is expected to be relatively low and eventually zero. The marginal revenue line in Figure 1(b) shows how crop yield and revenue might change as extra units of nitrogen are added.

The extra costs of adding nitrogen are represented by the marginal cost in Figure 1(b), being the cost of an additional kilogram of nitrogen fertiliser. If making as much profit as possible is the objective then the rule is to apply fertilizer until the extra or marginal benefits of added nitrogen reach the level where they just cover the marginal costs, at N*. The decision about how much nitrogen to apply involves measuring or calculating available nitrogen in the soil (N^S) and applying the difference.

In Figure 1(b) it can be seen that when the urea price rises (i.e. the marginal cost rises) the amount of N that makes the most profit will reduce. If the wheat price rises, the marginal revenue schedule will shift up. This means that more nitrogen should be applied to the crop to maximize profit. The economic framework tells us how much these changes should be.

When the returns to a marginal investment in a variable input are uncertain the decision maker may want to set the ROI at some minimum rate acceptable to farmers (CIMMYT 1988). The rate of return will need to cover the cost of working capital, but will also include any additional returns that will satisfy farmers that their investment is worthwhile. The capital invested in fertiliser is either a direct financial cost (the interest on borrowed funds) or an opportunity cost (the interest foregone on alternative uses of the invested funds). A minimum ROI of 100% (the ‘2 for 1’ return) is considered by CIMMYT (1988) as a crude first approximation, but any rate can be specified in the framework presented here.

Dixit and Pindyck (1994) considered why the actual investment behaviour of firms differs from the perceived wisdom of business schools (invest if net present value is greater than zero), whereby firms expect a project to yield a return in excess of a required or “hurdle” rate. Summers (1987) found hurdle rates of between 8 and 30%. This reinforces the CIMMYT (1988) approach of requiring a ROI above marginal cost, although we don’t know what ROI graingrowers in Australia or elsewhere would require for the nitrogen fertilizer decision.

Method

The approach is based on three important assumptions. First, wheat yield and protein levels at harvest depend largely on different levels of soil fertility (available nitrogen) at sowing, on soil moisture at sowing, and on in-crop climate (rainfall and temperature) patterns. There is a distribution of crop responses according to these variable soil and climate conditions. Second, these distributions of responses are consistent from year to year for each district and soil type. They are biophysical relationships and the pattern of variable response does not change over time (they are stationary). Third, the distributions can be predicted using a process model that simulates crop growth. If these conditions hold, the resulting biological information can be combined with economic information (prices) in a decision tool to calculate and present the economic consequences of nitrogen fertiliser applications for decision makers.

Biological responses (wheat yield and protein content) to different soil fertility levels were predicted using the Agricultural Production Simulator (APSIM) (McCown *et al*. 1996, Probert *et al*. 1998). In the example analysis the model was specified for an unconstrained Vertosol soil (Isbell 1996) at Gunnedah, New South Wales. Ninety years of daily time-step climate information were used as input to the APSIM analysis.

The decisions about nitrogen were specified within APSIM as different levels of available nitrogen in the soil at sowing, ranging from 50 kg to 250 kilograms nitrogen/ha in 25 kg intervals. For each level of available nitrogen the wheat yield and protein content consequences were predicted.

Wheat growers in northern New South Wales and Queensland can readily measure or estimate soil moisture at sowing, but the rain that will fall as the crop grows cannot be known. Therefore situations were investigated as follows:
(1) soil moisture at sowing was evaluated by resetting sowing soil moisture at each of three levels (63, 124 and 222 mm moisture per metre of soil depth, termed ‘very dry’, ‘medium’ and ‘very wet’) for the same sowing date in each simulation year, and
(2) the unknown in-crop rainfall pattern was accounted for by predictions from the 90 years of climate information based on variations in rainfall and temperature, which provided a distribution of yield and protein for each level of nitrogen. The 10^{th}, 50^{th} and 90^{th} percentiles of the in-crop rainfall distributions were termed ‘very poor’, ‘average’ and ‘very good’ seasons.

The results of the analysis consisted of nine sets of predictions, for 3 soil moisture levels at sowing and 3 in-crop rainfall outcomes, representing the distribution of yield and protein outcomes for each nitrogen level. These simulations were for growing the wheat variety Hartog at Gunnedah on a common sowing date, and the resulting crop responses are in Figure 3. They are similar to the concave function of Figure 1.

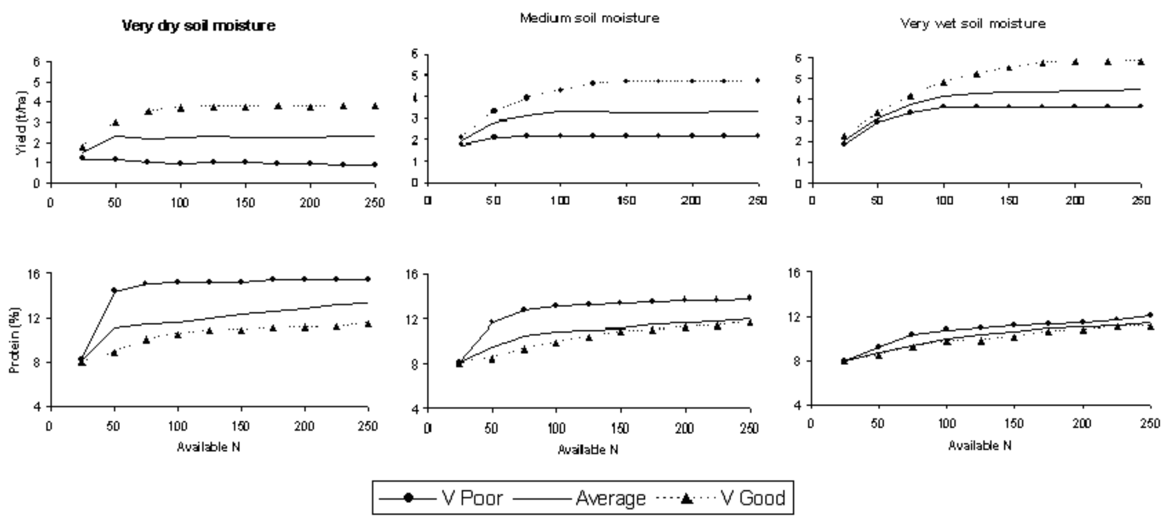

Figure 3. Simulated responses to available nitrogen for very poor, average and very good seasons, wheat on Vertosol soil at Gunnedah

The economic consequence for each decision and outcome was developed by translating wheat protein content into a price (see Figure 4, based on an Australian Wheat Board price grid for Australian Hard wheat in 2007-2008, with 5% screenings and 12.5% moisture) and estimating wheat revenue (price x yield). The cost of fertiliser was set at $1.20/kilogram of nitrogen. The changes in wheat income and cost as extra units of nitrogen are added at each level of soil fertility are in Figure 5, including costs with 100% and 200% ROI criteria.

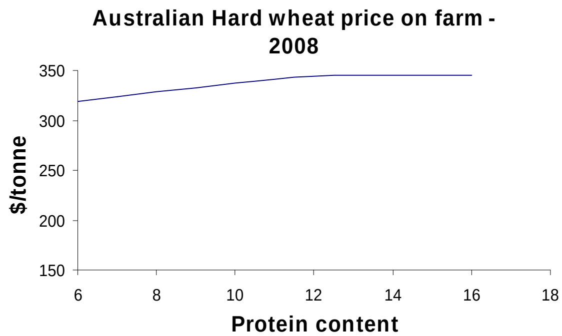

Figure 4. Wheat price according to protein content (2007-2008)

Results

The economic effects of adding nitrogen fertiliser at different levels of soil fertility are shown in Figure 5. As expected, the extra revenue (marginal benefit) schedules are initially high and then decline.

The reason for this decline is the shape of crop responses in Figure 3. Marginal benefits are determined by the rate of change in crop response as more nitrogen is added, in conjunction with the protein price schedule (Figure 4). The flatness of wheat production response (at higher levels of fertility) in Figure 3 is mirrored in the flattening of the marginal revenue responses in Figure 5, but the economic decision also depends on the protein response and wheat price, the fertiliser price and the criterion for required return on capital.

The extra revenue schedules in Figure 5 indicate the amount of nitrogen to apply for maximum profit, based on crop yield responses and prices. Another interpretation is that they are the maximum sums a wheat grower could pay for additional amounts of fertilizer nitrogen. These schedules are input demand functions (Farquharson 2006), which provide valuable economic information for fertiliser investment decisions.

An interpretation of the information in Figure 5 is as follows. If there is around 120 mm of soil moisture (medium) at sowing, and if a 100% ROI is required using 2008 prices, then the optimum nitrogen level is 75 (105, 155) kilograms of nitrogen/ha for an expected very poor (average, very good) season. If there is already 60 kilograms of nitrogen/ha in the soil (N^S in Figure 1(b)) then the relevant amount to add is 15 (45, 95) kilograms, respectively. Table 1 shows how these optimal nitrogen levels vary.

Discussion

Developing an economic decision support tool for different regions and soil types requires once-only simulations of crop responses to increased available nitrogen. Then incremental revenue and cost functions can be regularly updated as prices change.

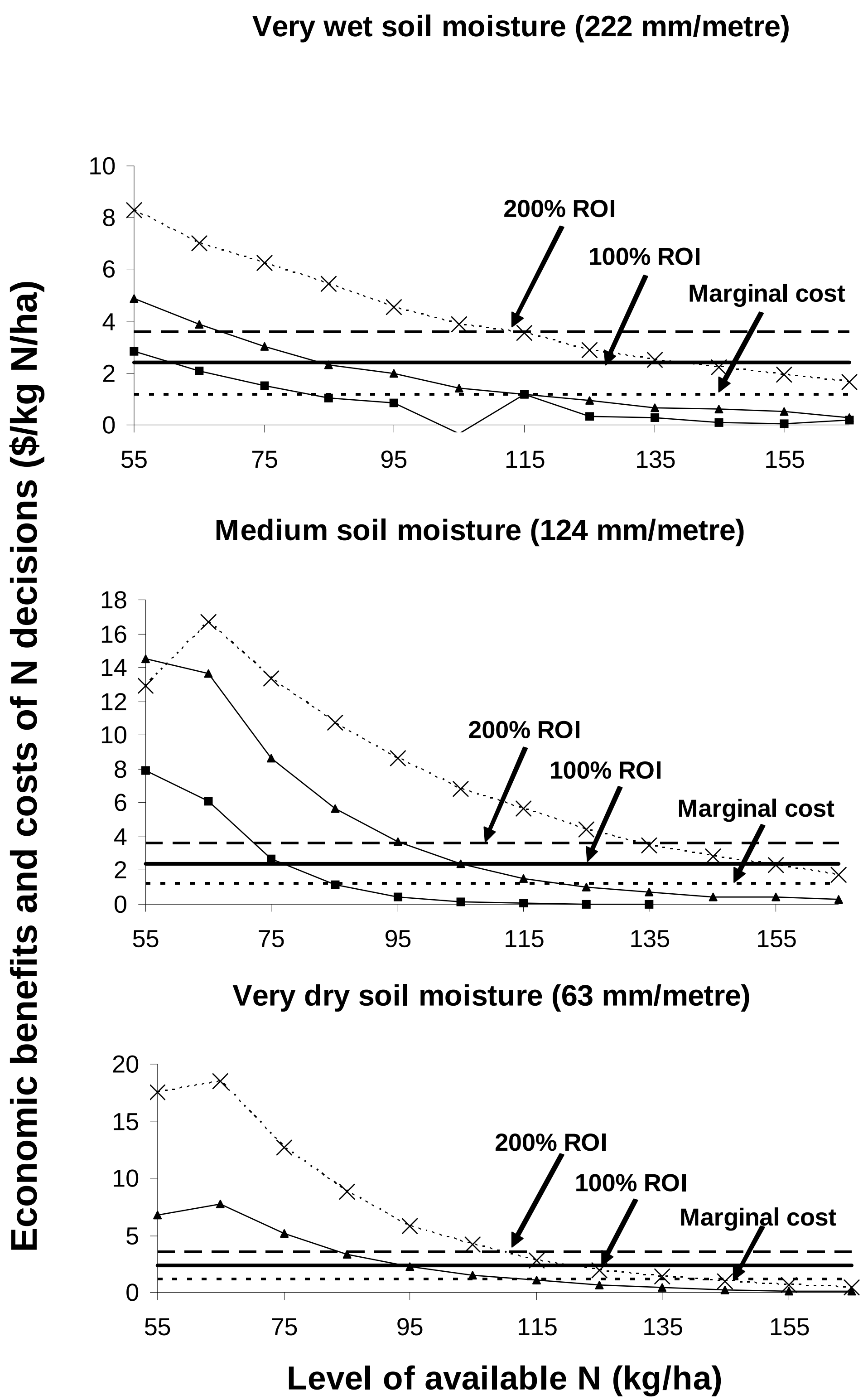

Figure 5. Extra revenue and cost, and ROI, per kg N/ha for wheat on a Vertosol at Gunnedah (very poor, average and very good in-crop seasons denoted by squares, triangles and crosses, respectively)

Table 1. Indicated economic levels of available nitrogen, 100% ROI for different sowing soil moisture levels and in-crop rainfall

Soil moisture	Available nitrogen/ha for 100% ROI according to in-crop rainfall		
	Very poor	Average	Very good
Very wet (222 mm/m soil)	60	85	135
Medium (124 mm/m soil)	75	105	155
Very dry (63 mm/m soil)	-	95	120

This approach explicitly considers incremental benefits and costs based on biological response functions. It also considers the impact of variations in soil moisture at sowing and of growth of the crop varying with rainfall. In contrast the standard nitrogen budgeting (target yield) approach considers only one point on the production response surface and does not address the economic implications of varying that target.

The advantage of this approach is that it utilises an experimental design for the simulation that allows the economic implications of the decision to be made explicit. It also allows considerations of required return on invested capital to be included in the decision-making process and represents the nitrogen decision visually, which has advantages for wider understanding in the wheat industry.

Beyond the farm

Possible effects of nitrogen use beyond the farm also matter. The low recovery of fertiliser nitrogen (rarely more than 40%) and the potential impacts on the environment, such as eutrophication and greenhouse gases (mainly nitrous oxide), are matters of increasing concern in agriculture around the world (Matson *et al.* 1998; Chen *et al.* 2008). Efficient fertiliser management needs to balance economic and environmental considerations. The factors influencing efficiency of fertilizer use and impacts on the environment are complex; they include bio-physical variables such as soil water, temperature (determined by climate) and soil properties, as well as management practices (application rate, time and method). An effective decision support system for decisions about fertilizer use would incorporate consideration of both within-farm and beyond-farm outcomes. The economic model, as shown in this study, could be integrated with process and spatial models to provide comprehensive information for decision makers. Progress has been achieved in this direction with the GIS-based WNMM model and an agricultural decision support system developed for the north China Plain (Chen *et al.* 2006; Li *et al*. 2007).

Conclusion

The approach explained and demonstrated in this paper can be developed to provide information to help wheat growers make nitrogen fertiliser decisions based on both the economic and the biophysical factors. Modelling to incorporate soil types in a spatial representation followed by a program of crop simulations would be required, after which data manipulation and presentation can be developed. Such an approach will incorporate the important bio-physical and economic dimensions of the fertiliser decision for grain growers.

References

Australian Bureau of Agricultural and Resource Economics 2007, *Australian Commodity Statistics 2007*, available online at http://www.abare.gov.au/publications_html/acs/acs_07.pdf.

Chen D., White R.E., Li Y., Zhang J.B., Li B.G., Zhang Y.M., Edis R., Huang Y.F., Cai G.X., Wei Y.P., Zhu A.N., Hu K.L., Li G.T. and Zhu Z.L. 2006. Conservation management of water and nitrogen in the North China Plain. In: *Agricultural Water Management in China*. Eds. Ian R. Willett and Zhanyi Gao, ACIAR Proceedings No. 123, ACIAR, Canberra, pp. 26-38.

Chen D., Suter H., Islam A., Edis R. and Freney J.R. 2008 Prospects of improving efficiency of fertilizer nitrogen in Australian agriculture; a review of enhanced efficiency fertilizers. *Australian Journal of Soil Research* 46: 289–301.

CIMMYT 1988. *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*. Completely revised edition. Mexico, D.F.

Dixit, Avinash K. and Pindyck, Robert S. 1994, *Investment under Uncertainty*, Princeton University Press, Princeton, New jersey.

Farquharson, R.J. 2006. Production response and input demand in decision making: nitrogen fertiliser and wheat growers. *Australian Agribusiness Review*, Volume 14, Paper 5, available online at http://www.agrifood.info/review/.

France, J. and Thornley, J.H.M. 1984. *Mathematical Models in Agriculture: A Quantitative Approach to Problems in Agriculture and Related Sciences*, Butterworths, London.

Isbell, R.F. 1996. *The Australian Soil Classification*, CSIRO Publishing, Melbourne.

Lawrence, D.N., Cawley, S.T., Cahill, M.J., Douglas, N. and Doughton, J.A. 1996. Soil nitrogen decision aid puts farmers in control. *In* Proceedings of the 8th Australian Agronomy Conference, Toowoomba.

Li Y., White R.E., Chen D., Zhang J.B., Li B., Huang Y.F. and Edis R. 2007. A Spatially referenced Water and Nitrogen Management Model (WNMM) for intensive cropping system. *Ecological Modelling.* 203: 395–423.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., and Freebairn, D.M. 1996. APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural Systems*, 50, 255-271.

Malcolm, Bill 2004. Where's the economics? The core discipline of farm management has gone missing! *The Australian Journal of Agricultural and Resource Economics* 48:3, pp. 395-417.

Martin, R., Marcellos, H., Verrell, A. and Herridge, D. 1996. *Nitrogen in '96: Decisions about nitrogen fertiliser for high yield and quality wheat*, NSW Agriculture and GRDC.

Matson, P.A., Naylor, R.L. and Ortiz-Monasterio, I. 1998. Integration of Environmental, Agronomic, and Economic Aspects of Fertilizer Management. *Science* 280:112-115.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., and Strong, W.M. 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems*, 56, 1-28.

Summers, Lawrence H. (1987), "Investment Incentives and the Discounting of Depreciation Allowances", in Feldstein, Martin (Ed), *The Effects of Taxation on Capital Accumulation*, The University of Chicago Press, Chicago.