

Benefits, costs and risks of nutrient use in cropping in the high-rainfall zone of southern Australia

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Abstract

We describe how crop modelling, production economics and Monte Carlo simulation can be used to aid decision-making regarding the profitability and risks of nutrient usage in wheat production in the high-rainfall zone (HRZ) of southern Australia. Given good seasonal conditions, a case-study paddock deficient in P (10 mg/kg soil Colwell P) was shown to have high yield potential, estimated at 9.0 t/ha with profit maximising applications of N (95 kg N/ha) and P (51 kg P/ha). Profit maximising nutrient applications and yields are lower in average seasons and more so in poor seasons. The grower could respond tactically to evolving seasonal conditions by applying N in split applications. P-fertiliser application is best at or before seeding; however growers still have flexibility when considering the uncertain season ahead thanks to the flat response function at the economic optimum. The results suggest that the unrealised potential of crops in the HRZ can, in part, be explained by the cost of nutrient inputs and the risks associated with variable seasons. The analysis optimises one variable input at a time (e.g. N or P, other inputs held constant). The method is being extended to a more realistic analysis that simultaneously examines multi-variable input response processes (such as N and P or S or K) on wheat and canola yields. The purpose of this work is to equip growers and their advisors to confidently assess crop nutrient demands and limitations, predict yield potential and pay-offs associated with high input use in the HRZ environment.

Key Words

Nutrients, high-rainfall zone cropping, response functions, profit maximisation, risk.

Introduction

The HRZ of southern Australia has high yield potential with grain yields for wheat estimated at 4.5 t/ha in W.A. to 11 t/ha in south eastern Australia and 3 t/ha to 5 t/ha for canola depending on location (Christy *et al.* 2013). However, current on-farm yields are often only half to a third of these values averaging 2.7 t/ha for wheat and 1.4 t/ha for canola (Christy *et al.* 2015). Part of this unrealised potential may be because nutrient inputs are too low due to knowledge gaps and inexperience on the part of advisors and croppers. However, closing yield gaps is not necessarily economic regardless of growers' technical knowledge and skills. What are the benefits, costs and risks of nutrient use in cropping in the HRZ of southern Australia? What part of this biological yield gap can be attributed to the economics and risks of the nutrient use decision? These questions are explored in this paper for modelled N and P responses on a case-study wheat crop.

Method

The profit maximising level of N and P

The economic decision rule to maximise profit from using a variable input, such as N or P, is to apply the input up to where the revenue from an extra kilogram of nutrient applied just exceeds its cost.

Mathematically, the profit maximizing level of applied N and P can be estimated by equating the derivative of their respective response functions (d_y/d_x) to their inverse price ratios (p_x/p_y) (Bishop and Toussant 1958). The ratio is the unit price of the input delivered and spread, divided by the unit price of wheat ex farm at the time of harvest. This profit maximising rule assumes full information, no constraints on capital, and all other inputs held constant. The opportunity cost of capital is omitted for simplicity.

Modelled crop yield responses

Yield responses to applied N and P were derived from crop modelling with the Catchment Management Tool (CAT) (Christy *et al.* 2013) for a case-study paddock at Inverleigh in Victoria. This paddock is one of the trial sites in the Nutrient Omission Field Experiments currently being conducted by Agriculture Victoria in collaboration with Southern Farming Systems (SFS) and MacKillop Farm Management Group (MFMG).

CAT was run over 50 years for numerous scenarios involving three levels each of N and P. Nitrogen was applied as urea in two split applications totalling 166 kg N/ha, 55 kg N/ha and 0 kg N/ha. Initial P soil levels were set at 'low' (Colwell P 10 mg/kg soil), 'marginal' (20 mg/kg) and 'sufficient' (30 mg/kg). In translating soil P levels to applied P, we assumed that 2.7 kg P/ha is required to raise soil test values by 1 mg P/kg soil (Burkitt *et al.* 2001; Burkitt *et al.* 2002). Mineral N and soil water were reset each year at planting (the former to 160 kgN/ha); there was no carry-over between seasons. CAT modelling provided sufficient data points to estimate one-variable response functions for both applied N and P that exhibit the diminishing marginal returns necessary for economic analysis.

Response functions were determined for three climatic conditions, 'poor', 'normal' and 'good' years based on quartiles of consecutive yield outcomes. We used an exponential Mitscherlich function with an asymptotic plateau as specified by Hannah *et al.* (2016). We used the "Solver" add-in in Excel to simultaneously find parameter values that minimised the sum of the squared differences ($\sum\chi^2$) between yields predicted from the Mitscherlich function and those from the CAT model. We assumed no substitution possibilities between N and P in the production of wheat.

Seasonal risk and probability of breaking even

The Option\$ calculator (GRDC 2014) was used to quantify the expected net benefits of three P application decisions taking into account the seasonal risk. The three P decisions are the profit-maximising P rates in 'poor', 'normal' and 'good' years.

The Option\$ calculator relies on the grower's subjective estimates of potential yields and yield penalties, and uses Monte Carlo simulation to generate cumulative distribution functions (CDF) of the net benefits of the alternative mitigation strategies. The strategy that generates a CDF that lies furthest to the right is the one that makes most efficient use of the grower's capital, and is said to be 'stochastically dominant' (Hardaker *et al.* 2004). The Option\$ calculator provides estimates of the expected return and the probability of breaking even for each strategy and the 'best-bet' decision given the seasonal risks.

Instead of using gross margins, only the costs and benefits that change with the P treatment are considered when calculating the net benefits of the various P treatments; these being (1) the expected farm-gate wheat price, and (2) the cost of P fertiliser delivered and spread. The Option\$ calculator leaves crop and fertiliser prices static, but these variables could be subjected to sensitivity analysis by changing them one at a time; which we have not done due to space limitations.

Data

Data on wheat prices, fertiliser costs, profit maximising nutrient applications and yields by climatic condition are contained in Table 1. These data were compiled from market sources as stated in the footnotes and according to the methods described above. The additional information on yield penalties required for the Options\$ calculator are superimposed on Figure 2.

All data shown relate to the following decision, "*My soil is low in P, and I intend to apply nutrients to maximise my profits from growing wheat. I will split my N in case the season doesn't pan out well, but what is my 'best-bet' P investment?*"

Results and discussion

The modelled case-study paddock has high yield potential, estimated at about 9.0 t/ha given economically optimal applications of N and P and good seasonal conditions (Table 1 and Figure 1). It is not financially viable for the grower to chase a higher yield by applying more N than 95 kg N/ha or more than 51 kg P/ha even in the best of times. The reason being that beyond these points, the grower would be losing money. With less benign seasonal outcomes, profit-maximising yields fall to 6.8 t/ha in normal years and 2.4 t/ha in poor years.

These results will change when biophysical or economic parameters change. For example, the initial soil N used in the simulations was 160 kg N/ha, which is relatively high for commercial paddocks that have been in cropping for an extended period.

The optimal N rates shown in the table give an indication of how growers could split their N applications during the growing season to synchronizing nitrogen supply with the crop's ability to utilise nutrients (The Fertiliser Institute, 2016) – say, three splits of 40%, 40% and 20%.

Table 1. Crop-related prices and costs and profit maximising N and P rates and yields for modelled case-study paddock.

	Climatic conditions		
	Poor	Normal	Good
Wheat yield at profit maximising N and P inputs (t/ha)	2.4	6.8	8.9
Wheat price, net, on-farm post-harvest (\$/t) ¹	256	256	256
Profit maximising N inputs (P unlimiting)			
- Urea unit cost delivered and spread (2 applications) (\$/t) ^{2,1}	689	573	552
- N unit cost delivered and spread (\$/kg N)	1.50	1.24	1.20
- Profit maximising N application rate (kg N/ha)	37	77	95
Profit maximising P inputs (N unlimiting)			
- DAP unit cost delivered and spread (\$/t) ^{2,1}	722	722	722
- P unit cost delivered and spread (\$/kg P) ³	3.61	3.61	3.61
- Profit maximising P application rate (kg P/ha)	16	45	51

¹ 2016 Farm Gross Margin Guide (GRDC, 2016)

² Bruce Lewis, Vickery Bros (pers. comm.)

³ Calculated from the DAP price, after accounting for the value of N as determined from the price of Urea. Urea: 46% N. DAP: 18% N, 20%P.

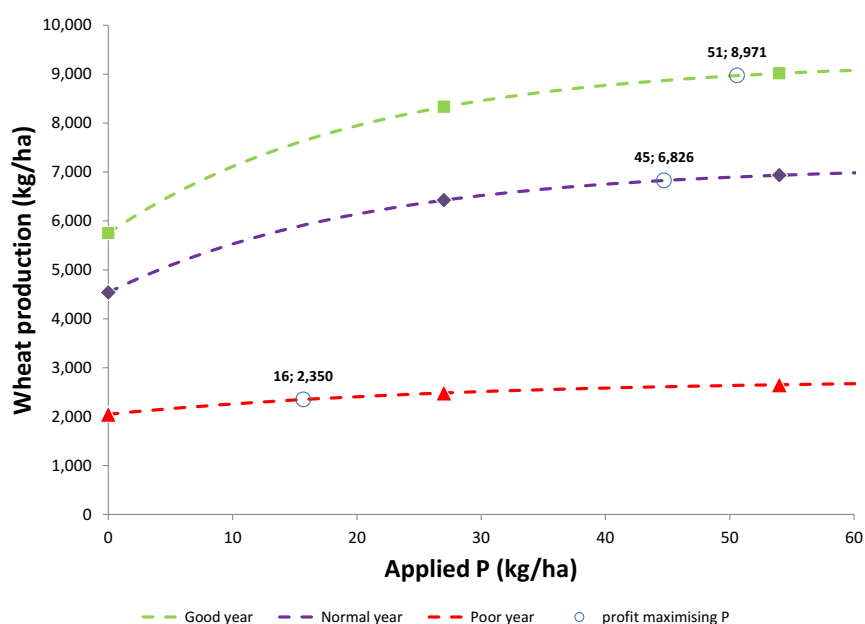


Figure 1. Profit maximising P rates (open circles) with 'low' starting soil P (10mg/kg Colwell-P), under a range of seasonal conditions. Solid shapes represent modelled data points.

Option\$ calculator inputs	Seasonal Conditions			P expenditure (\$/ha)
	Poor	Normal	Good	
Probability of seasonal outcome (%)	25	50	25	
Wheat price, net, on-farm post-harvest (\$/t)	256	256	256	
Wheat yield at profit maximising P (t/ha)	2.4	6.8	9.0	
Yield penalty with 'low' initial soil P (10mg/kg Colwell-P) (%)				
- do nothing (control)	22	34	36	0
- apply 16 kg P/ha	11	14	15	62
- apply 45 kg P/ha	1	1	1	163
- apply 51 kg P/ha	0	0	0	184

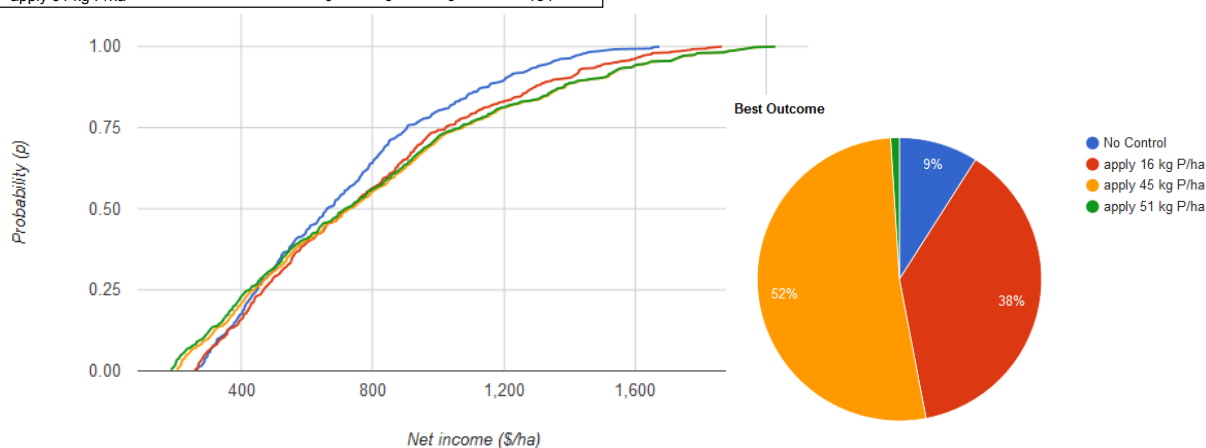


Figure 2. Best outcome and net income CDF for the decision to apply 16, 45 or 51 kg P/ha with unknown seasonal outcomes. The CDF shows the probability (y-axis) that net income (\$/ha) would be less than or equal to a particular value (x-axis).

With an unknown seasonal outcome, the best-best P decision made by a risk-neutral producer at or before seeding, would be to apply 45 kg P/ha (Figure 2 pie chart). This is the best-bet outcome on 52% of occasions, and would achieve expected yields in good, normal and poor years, respectively, of 8.9, 6.8 and 2.6 t/ha. Even in good years, it is seldom worth the additional cost of upping the P rate to 51 kg P/ha, as the lower rate is already very close to the optimum on the flat part of the response curve where decision-makers often have a wide margin for error (Pannell 2006). The second-best option is to apply a more modest 16 kg P/ha, as the lower returns achieved in poor years would be more than offset by lower P-fertiliser costs.

Any applied P left in the soil at end of the planning horizon is ignored in this analysis, which is meant to be carried out on a stepwise fashion through time. This means that after the end of the planning horizon new soil tests are undertaken and the situation reviewed.

Summary

Making use of existing tools, we showed how CAT modelling, production economics and Monte Carlo simulations with the Option\$ calculator can be used to examine the profitability and risks associated with single-input usage (N or P, other nutrients unlimiting) under a variable climate for a case-study wheat crop in the HRZ of southern Australia. Growers can use the information to respond tactically to evolving seasonal conditions, or to weigh up the pros and cons of their decisions where this is not possible. The analysis optimises one variable input at a time (e.g. N or P, other inputs held constant) using the response equation method of production economics. The method is being extended to a more realistic analysis that simultaneously examines multi-variable input response processes, (such as N and P or S or K) on wheat and canola yields. The purpose of this work is to equip growers and their advisors to confidently assess crop nutrient demands and limitations, predict yield potential and pay-offs associated with high input use in the HRZ environment.

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