# A bioeconomic framework for phosphorus deep-placement decisions

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## Abstract

Research indicates potential yield benefits from replenishing phosphorus (P) in sub-surface layers (10-30cm) if soil tests indicate a deficiency; however, it was unknown if amelioration has economic merit. Deep-P placement is a longer-term decision due to initial application and P fertiliser (MAP) costs with potential benefits that can last for many seasons. However there are risks due to unknown future season types. The fundamental question of deep-P placement is "how much P and how often?" We developed a bio-economic framework and used a case study in the Goondiwindi region with a deep-soil Colwell-P of 5 mg/kg to demonstrate the risk and benefit of applying different amounts of MAP at depth for a "short-rotation" (3-years) and "long-rotation" (7-years). The results indicate: (a) the optimal MAP rate was 135 kg/ha and 270 kg/ha for the short- and long-rotations, respectively, resulting in real-annual returns of $43/ha/year and $76/ha/year; (b) the short-rotation risked a loss of -$14/ha/year compared to $6/ha/year for the long-rotation (worst case); and (c) due to the lower investment cost with the short-rotation, the expected return on investment was 142%, compared to 67% p.a. for the long-rotation. The payback period for both decisions was around 2-years. As with all risky decisions, the farmer will have to weigh up the benefits, risks and their financial situation. Economic results will change when biophysical or pricing parameters change. As our knowledge of deep-P responses improve they can be incorporated into this bio-economic framework.

## Key words

Phosphorus, deep-P, long-term nutrient decision, economics, risk, framework

## Introduction

Phosphorus (P) is an increasingly important nutrient for northern grains region (NGR) (Bell et al., 2012; Singh et al., 2005). Small amounts of P are needed during early crop growth, to establish yield potential through high grain number initiation. Thus starter P is applied at the time of planting. However, as the plant develops it needs increasingly larger amounts of P to establish a high tiller density (in cereals), and to promote vigorous root systems, increase plant biomass and ultimately fill grains (in all species). Historically this P has been available from native subsoil P reserves, but years of grain P removal has diminished subsoil P reserves. Starter P fertiliser meets the demands of young seedlings with very small root systems but doesn't meet the demands of well-established plants growing on subsoil moisture later in the season. During this time the plants need to access nutrients such as P where the moisture is, in the lower soil layers.

Economic nutrient decisions can broadly be categorised into short- and long-term decisions (**Table 1**). Application of P deeper in the soil will inevitably result in some moisture loss and soil disturbance, so deep-P applications need to be done well before planting to allow time for replenishment of the surface soil moisture and restoration of seed bed conditions. In addition, the cost of deep P application and the high application rate requires economic analysis for more than a single season. This is in contrast to starter P and N rate decisions that are based on crop requirement in the current season.

**Table 1: Factors involved with short and long-term fertilizer decisions**

| Starter P and N<br>Short-term decisions | Deep-P<br>Long-term decisions |
|---|---|
| <ul><li>Main benefit in current season</li><li>Unknown season type or yield but known starting moisture</li><li>Fixed N and P prices at application</li><li>Assume no other nutrient constraints</li></ul> | <ul><li>Benefits for many seasons</li><li>Unknown future season types, soil water & yields</li><li>Unknown future P and N prices</li><li>Need to assume future decisions will provide sufficient starter P & N</li><li>Fixed P prices at time of the decision</li><li>Time value of money ($$$ in the ground vs bank)</li></ul> |

When considering the outcomes of long-term decisions there are two fundamental economic considerations: *risk* and the time *value of money*. The further we look into the future the greater the uncertainty and therefore the risk. However, the longer we have to wait for a reward the lower its current value, and impact on our decision. The outcome in a 100 years is very risky but of little value, or impact, for many of us. Most long-term farm-level decisions are limited to 10-20 years in the future. Therefore a bio-economic framework is needed to obtain the optimal application rates and the associated risk for up to 10 crops.

**Research method**

We developed a framework using APSIM and Excel® for 12 regions within the Northern Grains Region (NGR). The optimal deep-P application rate is driven by both biophysical and economic components of cropping systems (**Figure 1**).
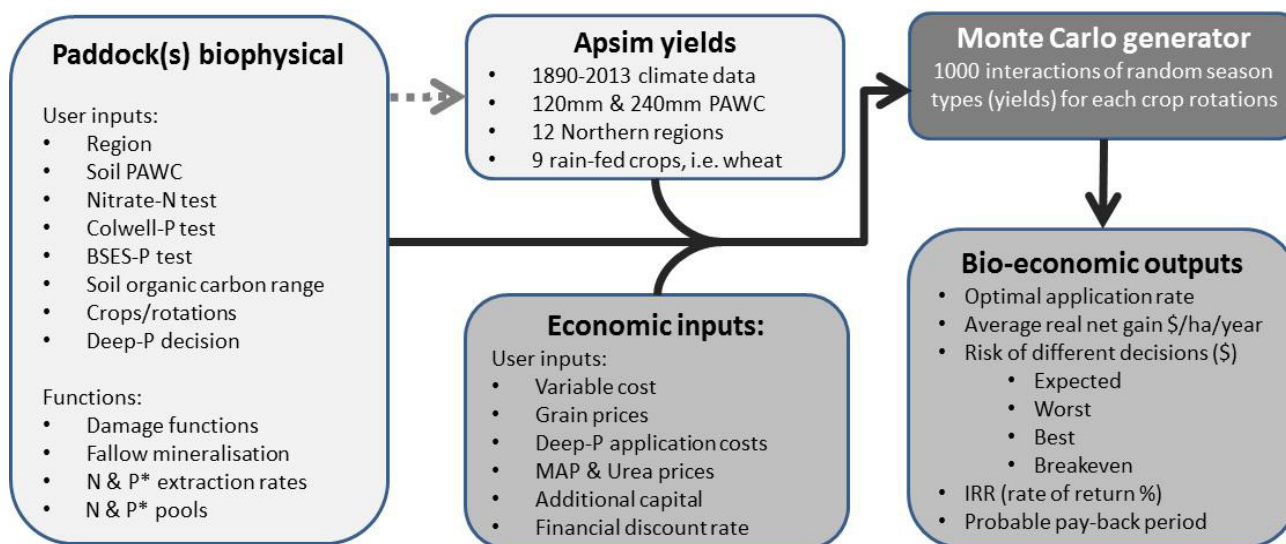


**Figure 1: Schematic of the bio-economic framework of long-term decisions of deep-P placement using APSIM®
and Excel®**

Based on previous research (Bell et al., 2014), we have assumed that soil will be responsive to deeper-applied P when Colwell P is <10 mg/kg and BSES P is < 30 mg/kg in the 10-30cm layer, PBI <150, and any residual applied deep-P will remain available in the short term (~5 years). In this study we have assumed that 1 mg/kg Colwell P represents 1 kg plant-available P/ha in a 10cm layer and that all applied P enters the plant available pool. The 10-30cm soil test layer represents two soil bands 10cm thick (10-20 and 20-30 cm), therefore the amount of P in that layer is twice the soil test value.

There is little historic data in the NGR on responses to deep P for any crops – other than what we have generated in the last few years. Therefore we have used three basic season types, with characteristics that influence crop response to deep P, as suggested by Bell et al. (2014):

- Dry start – those years with little or no effective rainfall from planting until after tillering;
- No stress – no severe crop stress; and
- Late stress – those with enough rain to ensure good early growth, but serious finishing water deficits.

**Case study**

The case study is based on a paddock in the Goondiwindi region (Qld), producing sorghum (**S**), chickpea (**CP**) and wheat (**W**) on soil with a plant available water capacity (PAWC) of 180 mm, starting nitrate-N of 50 kg N/ha, soil organic carbon of 0.9%, Colwell-P soil test in the 10-30 cm of 5 mg/kg, BSES-P of 15 mg/kg and PBI of 100, meaning the soil is very likely to be P responsive. We compared the benefits and risks of applying varying rates of MAP at depth for a short-rotation of **S CP – W – W** to a long-rotation of **S CP – W – W – – S CP – W – W**. Goondiwindi climatic records (1890-2013) are used to estimate season types and to run APSIM. Deep-P placement was with a John Deere® 8400 tractor and planter attachment set at a soil-depth of 200-250 mm at a cost of $31.58/ha and MAP (P = 22%) was costed at $730/t. Additional assumptions are shown in (**Table 2**).

When dealing with long-term investments we need to consider the time value of money, which includes the opportunity cost of not investing elsewhere or financing and project risk. We do this by discounting future cash flows into net present values (NPV). Assuming bank financing and climatic risk, the discount rate is 10% p.a. To compare long-term investments of different time horizons, we need to convert NPVs into annuities, i.e. the average annual net benefit ($/ha/year) over the project life. The investment horizon starts at the time of deep-P application just prior to planting. Another long-term investment measure is the internal rate of return (IRR), i.e return on investment over the project life. Any P depleted from or left in the soil at the end of the time horizon is ignored. This deep-P framework is to be used in a stepwise fashion through time and deep-P decisions re-evaluated based on changes to subsurface P reserves.

**Table 2: Input criteria relating to P and N removed, the yield damage (discount) from P deficiency (from Bell et al. 2014) and crop-related costs and prices**

| Crop | Removal of N & P from soil (kg/t grain) | | Damage (discount) to crop when Colwell-P<10mg/kg (average of trial results) | | | | | | Variable costs | Farm gate prices |
| | | | 120mm PAWC | | | 240mm PAWC | | | | |
| | P | Net N | Dry start | No stress | Late stress | Dry start | No stress | Late stress | $/ha | $/t |
| Chickpea DC | 3.8 | 0 | 5% | 10% | 15% | 30% | 10% | 25% | 342 | 409 |
| Sorghum LF | 2.3 | 17 | 5% | 15% | 10% | 10% | 15% | 25% | 462 | 230 |
| Wheat | 2.6 | 23 | 5% | 15% | 10% | 10% | 15% | 25% | 319 | 257 |

## Results

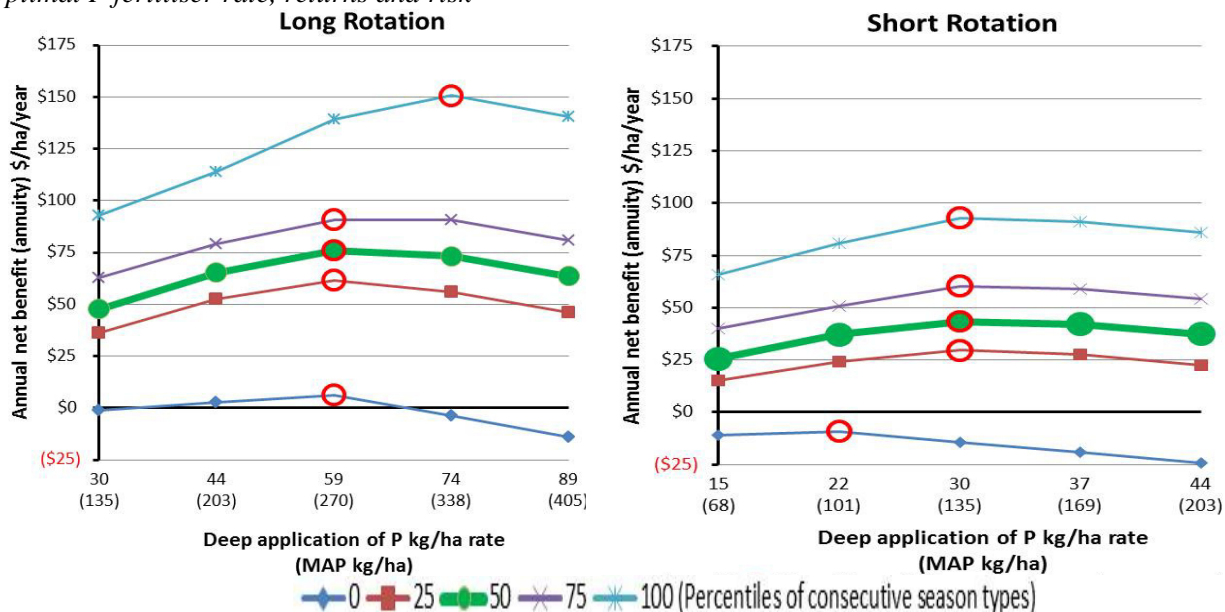*Optimal P fertiliser rate, returns and risk*



**Figure 2: The real annual net benefit of deep-P (MAP) placement of a short and long rotations with respect to different seasonal outcomes: percentile = 0 is the worst-case scenario, 100 is the best case, and 50 is the expected outcome. The red circles indicate the optimal application rate for the given seasons.**

Based on the expected (median or 50 percentile) outcomes, the optimal deep-P application rate for the short- and long-rotations are ~135 kg/ha and 270 kg/ha of MAP with an annual net benefit of $43/ha/year and $76/ha/year, respectively for this case study (**Figure 2**). Under the worst-case scenario (0 percentile), being a series of poor seasons, the optimal application rate for the long-rotation did not change but resulted in the annual net return of only $6/ha/year; however, for the short-rotation the optimal rate decreased to 101 kg/ha of MAP and resulted in -$9/ha/year. Under the best-case scenario (100 percentile), rain when you want it, the optimal application rate was 338 kg/ha of MAP for the long-rotation resulting in $150/ha/year, but this rate was excessive for all other seasons. Although not presented, there was 7% probability of not breaking even for the short-rotation; the long-rotation was almost certain to breakeven. The long-rotation had stochastic dominance and therefore always resulted in a higher annual net return.

120   The internal rates of return (IRR) for the short- and long-rotation were 142% and 67% p.a. respectively, which were both far greater than the opportunity cost of 10% (**Figure 3**a). Although the annual returns of the long-rotation were higher under all situations, the expected (median) IRR was lower due to the higher initial financial investment. However, the risk (uncertainty) associated with the short-rotation was greater. Under the worst-case scenario it was possible to have an -18% IRR and there was a 5% chance of getting a negative

125   IRR. The higher uncertainty of the short-rotation was also indicated by the high IRR under the best-case scenario of 750% compared to the long-rotation 224%. In summary, the IRR of the long-rotation was lower, but was less variable and was almost guaranteed to have a positive IRR. Although not shown, both the short- and long-rotation have about an 85% chance of getting >10% (the assumed opportunity cost). The expected payback period of both the short- and long-rotations was two-years (**Figure 2**). There was a greater

130   probability of the short-rotation decision being paid back sooner due to the lower P rate and hence a low initial investment cost, but this was countered by a 1% chance of never receiving a payback.
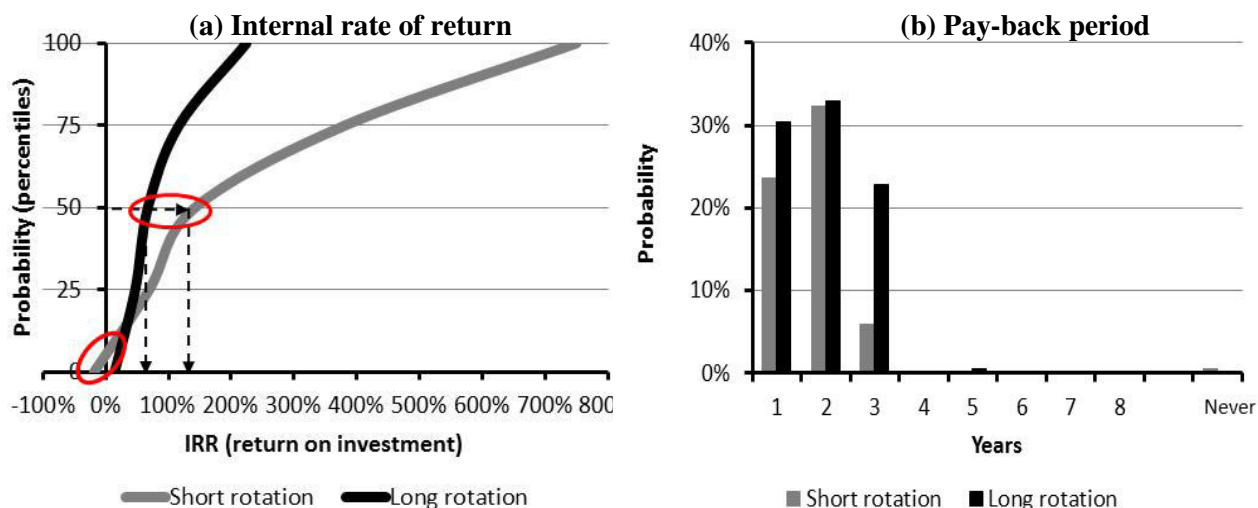


**Figure 3: (a) The distribution of internal rates of return for the short- and long-rotation option: percentile = 0 is the worst-case scenario, 100 the best-case, and 50 the expected. (b) The frequency of which the initial investment**
135   **is paid back in a particular year. "Never" indicates that it was never fully paid back.**

**Discussion**

Deep-P decisions differ to most fertiliser decisions because they involve a single high application of fertiliser product that is aimed to supply financial benefits over a number of seasons for which future climatic

140   conditions are unknown. Several technical and economic factors need to be included in the analysis. The decision to apply deep-P has the following considerations that this economic framework (calculator) can address: (i) Is deep P required?; (ii) What is the optimum deep-P rate to apply for a given time horizon?; (iii) How much P, how often and what is the risk?; and (iv) What is the internal rate of return and payback time?

145   The framework can be used to examine the cost/benefit trade-offs of deep-P decisions over time and the implications of expected prices, costs and crop rotation practices. Moreover this framework can also be used by farmers to communicate the potential returns and even the risk (worst-case scenarios) to financial institutions, when seeking additional finance. This case study of different application rates is only one example for which this framework could be used, and while the assumptions underlying P response in

150   different seasonal types and the longevity of residual benefits of deep P are rudimentary, they can be updated and refined as further experimental evidence accumulates.

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