# Economics of nitrogen fertilization of eucalypts for pulpwood

Philip Smethurst[1, 2], Sarah Jennings[1,3] and Anna Matysek[1,3]

[1]Cooperative Research Centre for Sustainable Production Forestry and
[2]CSIRO Forestry and Forest Products,
GPO Box 252-12, Hobart TAS 7001, Australia; corresponding author email: Philip.Smethurst@ffp.csiro.au
[3]School of Economics, University of Tasmania

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## Summary

We evaluated the net present value and internal rate of return of investing in N fertilization of eucalypt plantations managed for pulpwood, particularly around the period of canopy closure. We found that, given our base case assumptions, N fertilization is currently profitable when applied to plantations expected to have a medium-to-high response in wood yield. Furthermore, even though our analysis was limited to pre-tax stumpage values, our results suggested that the investment would be profitable on a wider range of sites for many combinations of variables if there were favourable movements of key variables from current values within realistic ranges, for example, for wood value and the cost of fertilizer. However, actual growth responses need to be quantified more precisely for a range of conditions and care should be taken to select the most responsive sites to be fertilized. Estate-wide optimization of the investment and prevailing economic circumstances should also be considered.

## Introduction

Although not widely documented, nitrogen (N) deficiency has been identified or suspected in many temperate eucalypt plantations growing on ex-native forest and ex-radiata pine sites. Research during the past few years has focused on the application of N fertilizer to stands during the early phase of canopy development; 1995; Bennet (Cromer *et al.* (Bennett *et al.* 1997;) and applications of N fertilizer during this stage of the crop are common on these types of sites. In the CRC for Sustainable Production Forestry, current research on fertilizer management is also aimed at developing options for increasing leaf development and wood yield by fertilizing with N at later stages, that is, post-canopy-closure.

To improve our understanding of the economic circumstances under which N fertilization is appropriate, and to assist in the development of priorities for future research, a preliminary economic evaluation of N fertilizer options for established eucalypt plantations was required.

## Methods

We initially evaluated simple base case scenarios in which N fertilizer applied to a crop at age 7 years led to a low, medium or high growth response that was captured at the end of a 15-year rotation. Rather than evaluating the overall economic viability of the plantation, we instead limited our analysis to an assessment of the financial viability of investing in N fertilizer once the crop had been established. The scope of the analysis was limited to stumpage values, that is, value of standing timber, thereby avoiding complications of including harvesting and transport costs as explicit variables in the analysis. We instead captured the effects of these costs by evaluating a range of stumpage values. We also limited our analysis to pre-tax conditions, which could vary considerably between investors. Investors with several plantations, that is, an estate, would also need to extend the analysis to include estate-wide variables.

Two indicators of economic value were used: the net present value (NPV) and internal rate of return (IRR) of the investment. These indicators have been used for decades in the evaluation of forestry investments and were explained succinctly by Fraser *et al.* (1977). Also evaluated was the sensitivity of these indicators to variations in the key management and economic variables.

### NPV and IRR

The NPV ($ ha$^{-1}$) of fertilization was calculated by subtracting the extra discounted costs associated with fertilization from the extra discounted revenues attributable to fertilization. For example, if we assumed that it cost Ct ($ ha$^{-1}$) to fertilize the stand in year t, and the projected additional returns from harvesting that stand in n years time was Rn ($ ha$^{-1}$), we defined the NPV of treatment as:

$$NPV = \frac{R_n}{(1+i)^{n+t}} - \frac{C_t}{(1+i)^t}$$

where i was the discount rate (%)/100, t was the age of the stand (years) at the time of fertilization and n was the investment duration (years). Thus, n+t was the age of the stand at harvest. A positive NPV indicated a profitable investment opportunity in the sense that it generated a return on funds invested in excess of the discount rate, that is, the forest grower's opportunity cost of capital. Consequently, an investment should only be made if the NPV is positive. The NPVs calculated throughout this report are for a single investment cycle and reduce all costs and revenues to their year zero equivalents, unless otherwise indicated.

The IRR (%) of an investment is the annual percentage rate at which the initial outlay or cost of the investment would need to grow throughout the investment period to equal the value of the final return:

$$IRR = \left(\frac{R_n}{C_t}\right)^{\frac{1}{n}} - 1$$

An investment should be made if the estimated IRR for the project exceeds the investor's required rate of return.

The NPV and IRR of investing in fertilization have been calculated for the three base case fertilizer response scenarios corresponding to low, moderate and high predicted wood yield responses. The three scenarios are defined as responses of 5, 10 and 20 $m^3$ of merchantable wood per hectare per 100 kg of N applied, respectively. All calculations reported are per hectare of forest.

**Values of key variables**

Determining the financial viability of investments required information on several key variables:

- rate of fertilization,
- cost of applying fertilizer,
- growth response to fertilization,
- value of the wood,
- duration of the investment, and
- discount rate

We drew heavily on the personal experience of our colleagues (see acknowledgements) in determining the values of these variables to use in the various scenarios.

Gerrand *et al*. (1993) provided realistic values of growth and rotation length without post-canopy-closure N fertilizer treatment for eucalypt plantations under Tasmanian conditions. They suggested 300 $m^3$ $ha^{-1}$ could be produced during a 15-year rotation, that is, a mean annual increment of 20 $m^3$ $ha^{-1}$ $year^{-1}$. A linear growth response to N rate in the range 0 to 500 kg N $ha^{-1}$ applied in three applications during the first 3 years after planting has been observed at several sites in Tasmania and, for single applications, a rate of about 400 kg N $ha^{-1}$ maximized growth at one site (R.N. Cromer *pers. comm*., G.K. Holz *pers. comm*.). A significant response in growth to 400 kg N $ha^{-1}$ at several other sites has also been achieved. If investment in N fertilizer is profitable, it was assumed that the need to maximize the profit margin will encourage managers to apply fertilizer at the high end of the range over which a positive response has been observed. Hence, a rate of 400 kg N $ha^{-1}$ was chosen for the base-case scenarios.

Urea was the only form of N fertilizer considered because it had the lowest cost on a $ per kg N basis and it is very effective at increasing the availability of ammonium-N, which is the preferred form of N for eucalypts (Shedley *et al*. 1995; Garnett and Smethurst 1999). Use of urea also minimizes nitrate production and concomitant losses by leaching and denitrification. The cost of urea has decreased substantially during the past two decades, including significant decreases during the past year. For example, between 1980 and 1991 the cost of urea in 1990 US$ $ton^{-1}$ (fob) fell from 310 to 170 (Bumb 1995). Prices for April 2000 were at historically low levels of 105 to 133 (FMB Consultants, Middlesex, England; http://www.fmb-group.co.uk), and further downward movement was likely (Fertilizers Online Inc., Florida, USA; http://www.ferti-world.com/guests/fertiwatchindex.htm). The cost of urea (including application) for large contracts in Tasmania during 1999 was about Aust$70 per 100 kg N (note that all $ values referred to subsequently are Aust$), which we accepted as the value for the base-case scenario, with a range of $20 to $80 per 100 kg N considered in the sensitivity analysis. Because urea is 46% N, this base-case price equates to $322 $tonne^{-1}$ (or $292 $ton^{-1}$) of urea applied.

Response to N fertilization was defined as the additional wood volume arising between fertilization and harvesting, and it was expressed as total additional wood volume per 100 kg N applied. Experience at several sites in Tasmania indicates that responses in the volume of stem wood to the application of 200 kg N $ha^{-1}$ applied to 4- to 6-year-old plantations range from 0 to 40 $m^3$ $ha^{-1}$ (G.K. Holz and C.C. Baillie *pers. comm*.), that is, 0 to 20 $m^3$ $ha^{-1}$ per 100 kg N. We defined 5 $m^3$ $ha^{-1}$ per 100 kg N as a low response, 10 $m^3$ $ha^{-1}$ per 100 kg N as a medium response, and 20 $m^3$ $ha^{-1}$ per 100 kg N as a high response, recognizing that actual responses in harvestable volume may be larger or smaller than this range. These responses can also be considered in terms of mean annual increment (MAI). In calculating MAI for any scenario, rotation length equals the age of fertilization plus the duration of the investment. For example, an additional volume of 40 $m^3$ $ha^{-1}$ harvested at age 15 years and resulting from the application of 200 kg N $ha^{-1}$ at age 3 years implies a response of 20 $m^3$ $ha^{-1}$ per 100 kg N, a 12-year duration of investment, and an increase in MAI of 2.7 $m^3$ $ha^{-1}$. All experiments on which these responses to N were based included phosphorus fertilization soon after planting.

The value of eucalypt pulpwood achieved in some individual sales is published regularly as the ANU Forestry Market Report in *Australian Forest Grower*. Currently, a stumpage of about $10 $m^{-3}$ is common, and a realistic range for the future is $8 to $25 $m^{-3}$, but individual sales will be highly dependent on fluctuations in world prices and on harvesting and transport costs. Piece-size factors were not considered in this analysis, but they can affect the volume of harvestable pulpwood, that is, minimum limits on length and small-end diameter of pulpwood may render some stems unharvestable without fertilization. Note that solid wood products have not been considered in the present analysis[1] .

The duration of investment is determined by the ages at fertilization and harvesting. Our experience has been mainly with fertilizing stands younger than 6 years of age, but a growth response was recorded in one stand when fertilizer was applied at 7 years of age (G.K. Holz *pers. comm*). Rotation length for pulpwood in Tasmania is expected to be 15 years. Hence, an investment period of 8 years may be necessary but, if earlier harvesting is possible or if responses can be achieved with later applications, shorter durations of investment will be possible.

The choice of discount rate is guided by the expectation of future returns on alternative investments. Fraser *et al*. (1977) considered discount rates in the range 7%-16%. Gerrand *et al*. (1993) arrived at a base-case discount rate of 6% by noting that the long-term annual bond rate for equities and bonds was around 4%, and that a 2% risk premium was thought appropriate for forestry investments. To be quite conservative, we added a further 2% risk premium to our analysis, that is, a discount rate of 8% was considered realistic for the base-case scenario, and a range of 4% to 15% was considered for the sensitivity analysis.

[1]Some organisations are contemplating the possibility of selling some solid or reconstituted timber from temperate eucalypt plantations. However, the expected increase in wood value per m3 would need to be offset against an increase in harvest age required to achieve piece-size targets. The analysis of N fertilization in regimes involving significant amounts of such products warrants an extension of the analysis presented here.

The upper end of this range is consistent with returns on investment quoted for some forestry investments, for example, 13%-18% (Tasforestry Limited 1999). Discount rates implicit in recent sales of plantations are 9%-11% pre-tax and 8%-9% post-tax (Manley 1999).

Values of key variables and variations considered in subsequent sensitivity analyses are summarised in Table 1.

**Table 1.** Values of key variables used in the base case scenario and sensitivity analyses

| Variable | Unit | Value in the base case | Other values evaluated |
|---|---|---|---|
| Cost of fertilizer[1] | $ per 100 kg N | 70 | 40, 60, 80, 100 |
| Rate of fertilization | kg N $ha^{-1}$ | 400 | 0, 200, 300 |
| Response to fertilizer[2] | $m^3$ per 100 kg N | 5, 10, 20 | 0, 30 |
| Value of wood | $ $m^{-3}$ | 10 | 8, 12, 15, 20, 25 |
| Duration[3] | years | 8 | 4, 6, 10, 12 |
| Discount rate | % | 8 | 4, 6, 10, 15 |

[1]Including application costs
[2]Measured as the additional harvestable volume of wood
[3]Duration of investment; add age when fertilized to calculate rotation length

## Results and discussion

### Base case

The NPV and IRR of the investment for each of the three response scenarios for the base case fertilization regime are provided in Table 2. We refer to these results throughout the rest of this paper as the 'base case' results. Values in Table 2 are based on one investment cycle; when calculated over a perpetual series of investment cycles, the NPV of the investment is equivalent to the difference in 'site value' between the treated and untreated stands. A low-response site had a site value ($ $ha^{-1}$) of –146, medium response –54, and high response 130. Fertilization was a profitable investment only on sites where a high yield response was possible. More particularly, fertilization returned an NPV of $89 $ha^{-1}$ and IRR of 14% for stands where a high growth response was anticipated. However, in cases where the growth response was low or moderate, fertilization reduced the value of wood production compared to the unfertilized case.

**Table 2.** Base case results for NPV and IRR

| Investment criteria | Yield response ($m^3$ per 100 kg N) | | |
|---|---|---|---|
| | Low | Medium | High |
| | 5 | 10 | 20 |
| NPV ($ $ha^{-1}$) | -100 | -37 | 89 |
| IRR (% $year^{-1}$) | -4 | 5 | 14 |

A more detailed examination of NPV in relation to yield response indicated that, under the conditions of the base case, the investment would be profitable at or above a yield response of 52 $m^3$ $ha^{-1}$, that is, 13 $m^3$ per 100 kg N and an MAI increase of 3.5 $m^3$ $ha^{-1}$ (Fig. 1). The relatively high yield response required for profitability implies that we need to be quite accurate about choosing only medium-to-high yield response sites to be fertilized. This result is not surprising and it is consistent with the fact that optimum selection of sites for N fertilization is also required for *Pinus radiata* plantations that are grown for solid products of high value (Turner and Knott 1991).

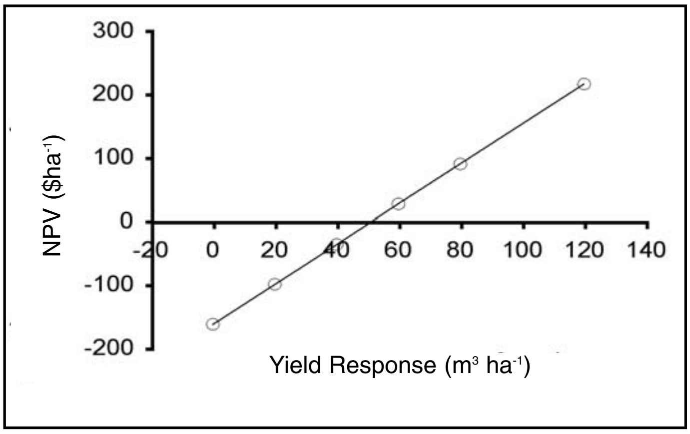


**Figure 1**. Relationship between NPV and yield response for the base-case scenario

### Sensitivity to economic variables

We then investigated the sensitivity of the profitability of fertilization to changes in the value of the economic variables, that is, cost of fertilizer, discount rate and wood value.

***Cost of fertilizer***

As expected, the NPV and IRR of fertilization declined with increasing costs of fertilization under all growth response scenarios (Fig. 2). For a site where a high growth response was

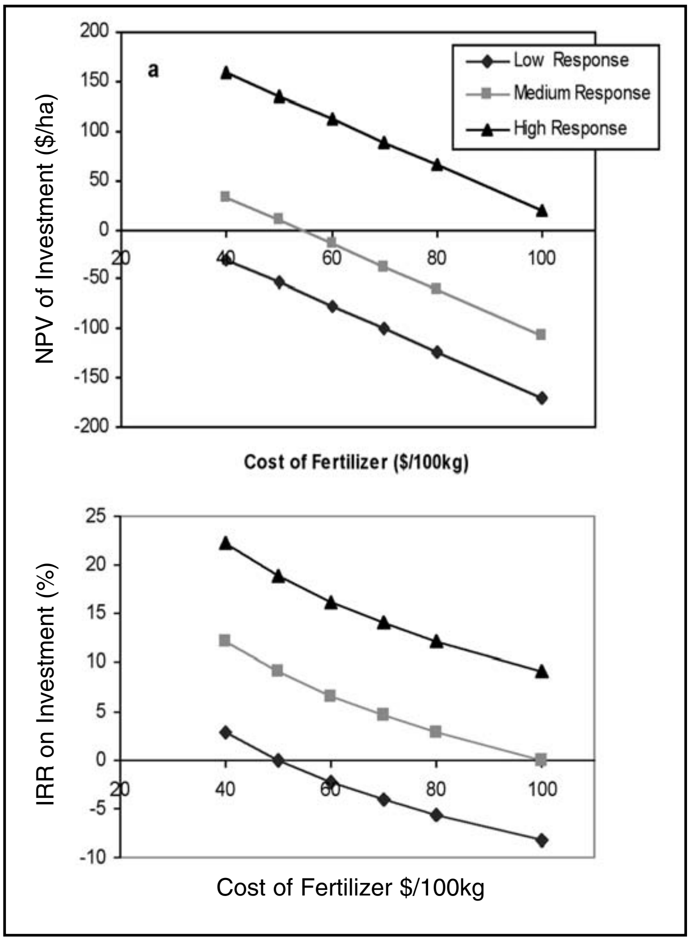


**Figure 2.** Effect of cost of fertilizer on the NPV (a) and IRR (b) for three levels of yield response.

anticipated, NPV fell from $159 to $19 ha$^{-1}$ as the cost of N fertilizer increased from $40 to $100 per 100 kg N. This corresponded to a decline in the IRR from 0.22 to 0.09. While the NPV of fertilization remained negative on low-yield sites over the entire range of fertilization costs, fertilization of moderate-yield sites was profitable for a fertilization cost of $54 per 100 kg N or less.

### *Discount rate*

The discount rate reflects the opportunity cost of investment funds, or the real rate of return on the next best alternative investment. In general, higher discount rates were associated with lower NPVs and reflected a less profitable investment opportunity (Fig. 3). While a higher discount rate reduces the present value of both costs and benefits, the effect on the present value of benefits is more pronounced as they are realised later in the investment period. Note that the NPV increased slightly as the discount rate increased for low-response stands. In this case, investment benefits were very small and the advantages of a high discount rate in reducing the present value of the cost of 'unfertilized' wood dominated the NPV calculation. If forest growers faced an opportunity cost of capital in excess of 14%, fertilization was unprofitable under all yield response scenarios.

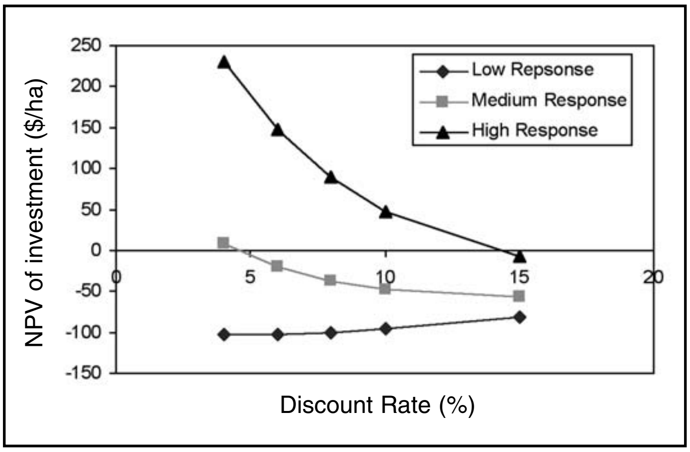


**Figure 3.** Effect of discount rate on the NPV for three levels of yield response.

Because the discount rate is not part of the calculation of IRR, IRR was unaffected by the discount rate (data not presented).

### *Wood value*

As expected, NPV increased as wood values increased for all yield scenarios (Fig. 4a). For example, at a wood price of $15 m-3, the NPV for the high-yield scenario was about $200 ha$^{-1}$, while fertilization became profitable on sites where only a moderate growth response was anticipated at a wood value of $13 m$^{-3}$ and above. Fertilization of low-yield sites, however, remained unprofitable for all wood values in the range investigated. In terms of our IRR calculations, this result suggested that fertilisation of medium response sites would be attractive for a wood value of $13 m$^{-3}$ only if the forest grower's opportunity cost of capital was 8% or less (Fig. 4b).

### **Sensitivity to fertilizer treatment regime**

The base-case results related to a standard treatment regime in which N fertilizer was applied at the rate of 400 kg N ha$^{-1}$ at age 7 years and the harvest occurred at 15 years. We then considered some alternative treatment regimes to determine the effects of early harvesting and variations in the intensity and timing of fertilizer application.

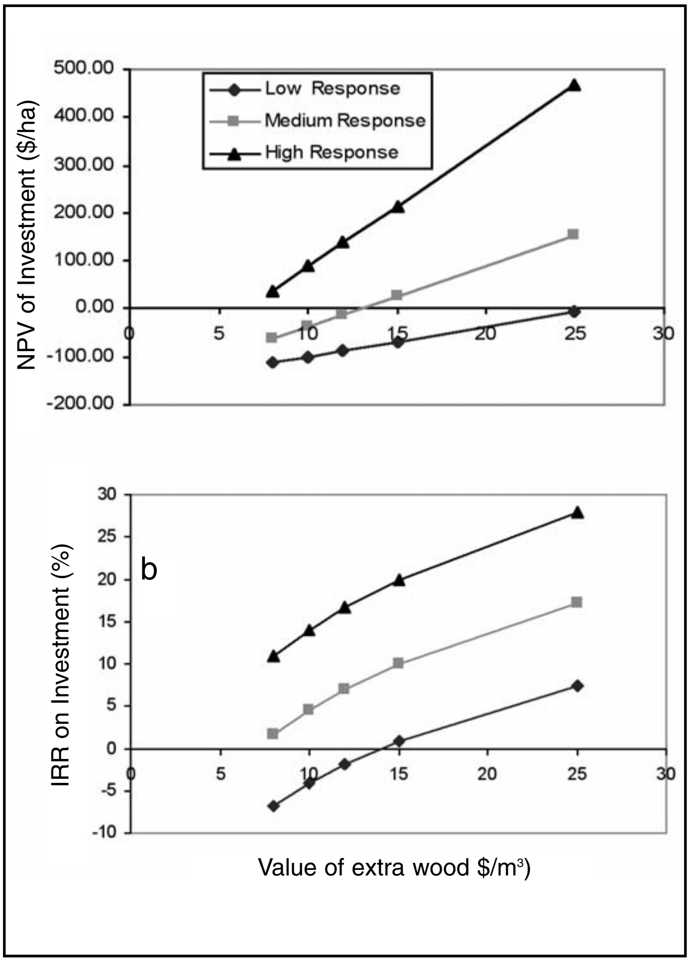


**Figure 4.** Effect of wood value on the NPV (a) and IRR (b) for three levels of yield response

Low rates of fertilization minimised losses and gains, and, conversely, losses and gains were maximised at high rates of application (Table 3). Such a conclusion will continue to hold as long as the relationship between fertilization and growth response is generally positive and linear as assumed in this analysis. However, the true relationship is likely to be curvilinear and even parabolic over the range of interest, reflecting eventual diminishing physical returns to fertilization.

Early application of fertilizer was associated with deleterious effects on NPV under all response scenarios because the present value of costs was systematically higher under such a regime; the converse was true for late application of fertilizer or early harvesting (Table 3).

An evaluation of the effect on NPV of the interaction between wood value and early harvesting[1] indicated that, for a medium response site, the investment was profitable at a wood value of about $13 m$^{-3}$ for a harvest age of 15 years and $10 m$^{-3}$ for a harvest age of 13 years (Fig. 5; both fertilized at 7 years).

This analysis suggests that minimising the period between fertilization, that is, the investment, and harvesting, that is, the return, would maximise profitability. However, Whiteman

**Table 3.** Values of NPV (\$ $ha^{-1}$) and IRR (%, in parentheses) for alternative management regimes to the base case scenario.

| Management regime | Yield response | | |
|---|---|---|---|
| | Low | Moderate | High |
| Base case (from Table 2) | -100 (-4) | -37 (5) | 89 (14) |
| Low fertilization (200 kg N $ha^{-1}$) | -50 (-4) | -19 (5) | 44 (14) |
| High fertilization (500 kg N $ha^{-1}$) | -125 (-4) | -47 (5) | 111 (14) |
| Late fertilization (year 9, investment duration 6 years) | -77 (-5) | -14 (6) | 112 (19) |
| Early fertilization (year 3, investment duration 12 years) | -160 (-3) | -96 (3) | 30 (9) |
| Early farvest (year 13, investment duration 6 years) | -80 (-5) | -6 (6) | 141 (19) |

(1998) noted that harvesting early was sub-optimal in many circumstances because it increased the frequency of the cost of reestablishment, reduced piece-size and per unit wood values, increased harvesting costs per unit of wood volume, and decreased wood quality, none of which were considered in the present analysis.

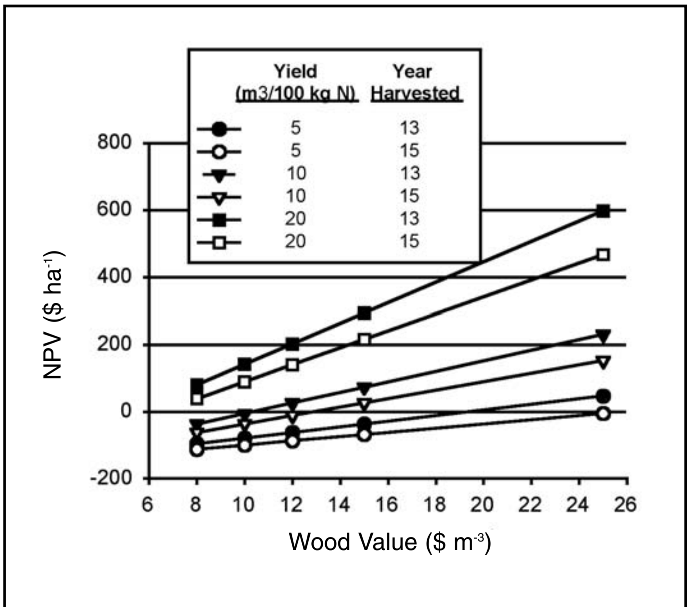


**Figure 5.** Effect of wood value on NPV for harvest ages of 13 and 15 years, which corresponds to investment periods of 6 and 8 years, respectively. Values of other variables were as described for the base case.

## Optimistic and pessimistic scenarios

To put an upper boundary on positive expectations from investment in N fertilizer, we calculated the NPV of investing in the base case treatment regime (400 kg N $ha^{-1}$ applied), when all other variables were highly favourable, that is, cost of fertilizer \$40 per 100 kg N, yield response of 30 $m^3$ per 100 kg N, wood value of \$25 $m^{-3}$, a 4 year-investment period, and a discount rate of 4%. The NPV of such an investment was \$1562 $ha^{-1}$, which is about 2.6 times more value than the most optimistic of the previous scenarios (e.g. Fig. 5). Although many of the single-factor sensitivity analyses suggested that N fertilization was profitable within the range of expectation, it is possible that several variables will change simultaneously. This optimistic scenario suggests that N fertilization would be quite profitable if there was some change in several variables in a favourable direction. Such a scenario is not unrealistic because there is currently a downward trend in the price of urea fertilizer and the value of pulpwood on the world market is expected to increase above current low values.

A somewhat pessimistic scenario was envisaged where all variables except growth response were set at base-case values, that is, cost of fertilizer \$70 per 100 kg N, application of 400 kg N $ha^{-1}$, an 8-year investment period, and discount rate of 8%, and we assumed there was no response to fertilization. Not surprisingly, such an investment was not profitable, having an NPV of -\$163 $ha^{-1}$.

To put a lower boundary on negative expectations from investment in N fertilizer, we calculated the NPV of investing in fertilizer (400 kg N $ha^{-1}$ applied) when all variables were highly unfavourable, that is, cost of fertilizer \$100 per 100 kg N, no yield response, wood value of \$8 $m^{-3}$, a 12-year investment period, and discount rate of 15%. The NPV of such an investment was -\$263 $ha^{-1}$.

## Conclusions

We drew several important conclusions from the present analysis:

1. Under our base case scenario, N fertilization is currently profitable when applied to plantations expected to have a medium-to-high response in wood yield, that is, more than 13 $m^3$ per 100 kg N applied. Hence, indicators of N-responsiveness will be very important for selecting plantations to be treated.

2. Profitability was sensitive to assumptions about economic variables, yield response and fertilizer treatment regime. For example, fertilizing medium-response sites became profitable for quite reasonable values of all economic variables.

3. Fertilizing low-response sites was profitable only if wood values were very high and early harvesting was possible.

4. Under all N fertilization scenarios examined, harvesting early maximised profitability, but further work is needed to optimise rotation length with respect to the total investment in the plantation.

The profitability of any specific investment option needs to be evaluated in terms of prevailing circumstances and future expectations, which may vary greatly between sites and from one organisation to another. Hence, the results presented here can be used only as a general guide to the profitability of investing in N fertilization.

Our preliminary investigation of the economics of N fertilization in eucalypt pulpwood plantations has suggested the following directions for future research:

1. N applications versus wood yield. More data are needed on relationships between the rate of N applied and wood yield,

especially for applications after 6 years of age.

2. Identification of optimal N fertilization regimes. In this report we calculated the financial return to various N fertilization regimes, assuming all other aspects of stand management remained constant. A more comprehensive analysis would involve identifying the pattern of stand management, including the timing and intensity of fertilization, and the rotation length, which maximises site value.

3. Other considerations. The fact that N fertilization of eucalypt plantations at 2-6 years is already common implies that NPV and IRR are not the sole criteria for deciding to invest in N fertilization. For some investors, wood yield, stand health, estate-level optimisation, and economies of scale may all be important considerations. Within-company economic analyses may also have generally assumed more favourable circumstances than those used in the present analysis, for example, tax benefits. An improved understanding of decision-making for investments in the forest plantation industry is required to support an extension of this economic analysis.

## Acknowledgements

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