Potential returns and risk of growing aluminium-tolerant lucerne in a grazing system with acidic soils located in the high rainfall zone

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Abstract

The benefits, costs and risk from introducing aluminium-tolerant lucerne (alfalfa) into a sheep grazing enterprise, consisting of a perennial ryegrass-based pasture, located in the high rainfall zone of Victoria, Australia, were estimated using a discounted cash flow analysis. Two 'what if' scenarios were compared for a modelled representative case study farm; 1) where aluminium toxicity occurred in the top-soil, and 2) where aluminium toxicity occurred in the sub-soil. Discrete seasonal pasture growth scenarios were examined, and price variability was captured using Monte Carlo simulation. Growing aluminium-tolerant lucerne on 10% of the farm area was consistently more profitable than continuing to graze the perennial ryegrass pasture, returning an extra $7-28/ha/year of profit for the 9 year analysis period. However, if the use of conventional lucerne with liming was a viable option for incorporating lucerne into the grazing system, the advantage of the aluminium tolerance ('Al Tol') technology was minimal. The results of this analysis suggest that aluminium-tolerant lucerne could be a profitable option for livestock graziers in the high rainfall zone, and is likely to be more beneficial when aluminium toxicity occurs in the sub-soil compared to the top-soil.

Keywords: alfalfa, pasture improvement, economics.

Introduction

The sensitivity of lucerne (*Medicago sativa* L.) to high concentrations of available aluminium in the root zone limits its use for grazing in the high rainfall zone of Australia (Scott *et al*. 2008). The conversion of aluminium into available forms is a complex process, and is linked with soil pH (Marschner 1986). The critical pH at which available aluminium reaches toxic levels depends on factors including the type of clay minerals present, amount of organic matter in the soil, and the plant species being considered (Hosking *et al*. 1986). For lucerne, soils with a pH_{CaCl2} below 5.5 may cause available aluminium to reach toxic concentrations, and result in inhibited nodulation and root growth (Bouton 2012; Humphries *et al*. 2009; Marschner 1986). Lucerne with nodulation and root growth inhibited by aluminium suffers restricted uptake of nutrients, which limits plant growth and persistence in acidic soils (Bouton 2012). Around 50% of surface soils used for agriculture in Australia have a PH equal to or below 5.5, with 7-9 million hectares (approx. 50-65%) of Victorian surface soils below this optimal pH level (Dolling *et al*. 2001). While lucerne can perform well in acidic soils without high concentrations of aluminium (Humphries and Auricht 2001), the soils of the high rainfall zone of Victoria have been shown to be both acidic and to have high concentrations of exchangeable aluminium. About 25% of samples tested exceeded the toxic aluminium level for lucerne of 50 mg/kg (Dolling *et al*. 2001; Hosking *et al*. 1986; Scott *et al*. 2000). However, the proven ability of lucerne to contribute to the profit of grazing enterprises (Lewis *et al*. 2012; Moore *et al*. 2009; Trapnell *et al*. 2006) makes it worth investigating ways to reduce the limiting effects of acidic soils, and associated aluminium toxicity, on lucerne production.

Introducing perennial pastures such as lucerne into whole farm systems of the high rainfall zone can improve farm profitability (Lewis *et al*. 2012). This is because of the extra summer and autumn feed produced by lucerne, which can be particularly beneficial for sheep enterprises with prime lamb production (Behrendt and Young 2010; Young *et al*. 2010). For sheep enterprises in south west Victoria, experimental studies and modelling have compared pasture systems which include lucerne, with typical perennial-ryegrass based pastures. This work has shown that there is often enough extra DM, of sufficient nutritive value, supplied by lucerne to extend the growth of prime lambs beyond the traditional December turn-off date (Ward *et al*. 2013; Clark *et al*. 2013; Warn 2011). Extending the turn-off date and growing prime lambs for longer increases the total liveweight produced per ha, which may increase returns for the farm business. However, risk could also increase, due to the economic phenomenon of increasing risk and return (Hardaker *et al*. 2004; Malcolm *et al*. 2005). Risk and return must both be accounted for when making decisions about introducing, and subsequently utilising, lucerne in grazing systems.

Introducing lucerne successfully into a grazing system with acidic soils and aluminium toxicity depends on the management options available. These options in turn depend on where in the soil profile the acidity occurs (Scott *et al*. 2000). In the top-soil, the standard management practice is to apply lime prior to lucerne establishment (Hosking *et al*. 1986; Scott *et al*. 2000). Applying lime to increase soil pH causes the available aluminium to be converted into less toxic forms, reducing the adverse effects on the growth of plant roots (Bouton 2012). The adverse effects of available aluminium in the top-soil are expected to become negligible for lucerne growth once soil exceeds pH 5.5 (Marschner 1986).

Liming of top-soils is not a complete solution for the high rainfall zone because sub-soil acidity, below the limed top-soil, can also limit lucerne production (Bouton *et al*. 1986; Pinkerton and Simpson 1986; Scott *et al*. 2008). Sub-soil liming beyond 30cm is costly and impractical (Marschner 1986; Scott *et al*. 2000). Consequently, developing acid-tolerant cultivars of forage species, such as lucerne, has become a serious focus of research efforts worldwide (Bouton 2012; Humphries *et al*. 2009; Kochian *et al*. 2004). Traditionally bred aluminium-tolerant cultivars have shown annual DM yields in acid soils of 20-30% of the yield shown for lucerne grown in the same soil with the addition of lime (Bouton 2012; Hartel and Bouton 1991). Because of this low yield potential from traditional plant breeding approaches, biotechnology now plays a major role in research efforts, and is showing promise (Bouton 2012). Acid-tolerant cultivars could improve the productivity of the large areas of the high rainfall zone of Australia with acidic sub-soils (Scott *et al*. 2000).

The potential benefits to livestock producers from adopting aluminium-tolerant lucerne is the focus of this paper. Manganese sensitivity and nodulation failure have also been identified as potential limitations to lucerne production in acidic soils, however they are not considered in this analysis (Scott *et al*. 2008). The analysis here is concerned with what it would mean to producers if aluminium tolerance in lucerne could be achieved, rather, than a specific mechanism of aluminium tolerance. To establish potential benefits to livestock producers, a representative case study farm in the high rainfall zone of south west Victoria is used. Acidic soils have been shown to limit the establishment of lucerne in this region, with soil tests showing exchangeable aluminium concentrations ranging from <10 to 160 mg/kg (McCaskill *et al*. 2009).

A model of the representative case study farm was originally developed in Microsoft Excel by Lewis *et al*. (2012). The case study farm does not currently grow lucerne. In this paper, options for incorporating lucerne into the case study farm system are explored. The lucerne with the aluminium-tolerant trait is referred to as 'Al Tol' lucerne.

There are currently no data publically available about the performance of aluminium-tolerant lucerne under the management and climate conditions likely to be experienced in the grazing systems of south west Victoria. Consequently, 'what if' options were compared for the case study farm. Two distinct scenarios for the farm were investigated; one assuming the farm had an acidic top-soil only, and a second assuming that sub-soil acidity was also present.

For both scenarios, a partial budget analysis was used to assess the risk and return of the options for incorporating lucerne into the case study farm. The case study farm developed by Lewis *et al*. (2012) was extended to incorporate stochastic Monte Carlo simulation to capture the risk implications in the partial budget analysis.

Research questions

The questions of interest were:

1. Where aluminium toxicity exists, will introducing 'Al Tol' lucerne to a

proportion of a farm be more profitable than grazing the current pasture base of the representative farm?
2. Where aluminium toxicity exists, what DM yield does 'Al Tol' lucerne need to achieve to be more profitable than grazing the current pasture base?
3. If options are available to alleviate aluminium toxicity and grow conventional lucerne on the representative farm, will growing 'Al Tol' lucerne be more profitable?
4. Will 'Al Tol' lucerne be a more profitable option when used to manage aluminium toxicity in the sub-soil, compared to the top-soil toxicity?

Question 5 relates to the sub-soil scenario only:

5. Does including 'Al Tol' lucerne in the system and increasing the production of lamb liveweight per hectare by growing some lambs out to the end of January increase profitability and risk, compared to grazing perennial ryegrass alone and selling all lambs a month earlier?

Method

Assumptions of the Analysis

There are no data available on how an 'Al Tol' lucerne would perform in the soils of south west Victoria. A production scenario was constructed for each analysis, using the following assumptions:

(a) Aluminium toxicity in top-soil

In this scenario, the growth of current cultivars of lucerne is assumed to be severely limited by acidic top-soils and aluminium toxicity. However, top-soil acidity can be corrected with the application and incorporation of lime prior to the establishment of lucerne. Two lime application options were tested; first where 2 t/ha is required to provide a soil pH of 5.5 at sowing, and second, where 5 t/ha of lime is required to provide a soil pH of 5.5 at sowing. These two lime application options are based on the work of Dolling *et al*. (2001) who found that approximately 60% of surface soils from the Glenelg and Hopkins river basins of south west Victoria recorded a pH 4.3-4.8, and approximately 20% recorded a pH 4.8-5.5. Approximately 50-70% of these surface soils with a pH below 5.5 would require 2-5 t/ha lime to raise them to pH_{Ca} 5.5 (Dolling *et al*. 2001).

(b) Aluminium toxicity in sub-soil

In this second scenario, the conventional cultivar of lucerne cannot be grown because of acidic sub-soils and aluminium toxicity. Current options available to alleviate acidic sub-soils, such as deep ripping and application of lime in the sub-soil prior to sowing, have been deemed cost prohibitive and impractical for uptake by graziers (Marschner 1986; Scott *et al*. 2000). Alternatively, application of lime to the soil surface often requires substantial lead time (>2 years) before effects are seen in the sub-soil, and ultimately this long-term approach has been shown to only increase sub-soil by 0.1-0.3 pH units (Scott *et al*. 2000). Therefore, it was assumed that there is currently no commercially viable option available to amend acidity and aluminium toxicity in the sub-soil.

(c) Land suitable for lucerne

If aluminium toxicity of lucerne could be overcome, 10% of the farm area is suitable to grow lucerne with no other likely limitations to the performance of the lucerne (e.g. waterlogging).

(d) Agronomic performance of 'Al Tol' lucerne

Firstly it was assumed that 'Al Tol' lucerne grown in acidic soils with aluminium concentrations that would be toxic to conventional lucerne, would grow as well as a conventional lucerne without acid soil limitations, showing moderate winter growth, based on the pasture accumulation data of Ward *et al*. (2013) recorded at Hamilton, Victoria, for SARDI 7 lucerne. This assumption was then subjected to breakeven analysis.

(e) Establishment costs

establishment costs, including seed costs, for 'Al Tol' lucerne were the same as for establishing the current common lucerne cultivar, without lime application costs where applicable. This assumption then subjected to breakeven analysis.

(f) Lamb growth

Lambs would grow at the same daily growth rate on 'Al Tol' lucerne as on conventional lucerne.

'Base Case' representative farm and analysis scenarios

The 'Base Case' (Table 1) reflects current farm practice (Berrisford and Tocker 2009; Lewis *et al*. 2012). The 800ha case study farm has wool and first cross prime lamb activities; Merino ewes (70% as a self-replacing flock lambing in September, and 30% of ewes producing first cross prime lambs, lambing in July). Stocking rate was

16.2 DSE/ha. All prime lambs were weaned at the start of December.

Monthly sheep demand and pasture supply, and subsequent supplementary feeding, was calculated as described by Lewis *et al*. (2012). In any month where sheep demand exceeded pasture supply, a ration comprised of barley, lupins and pasture hay was fed to sheep to meet their nutrient requirements (Lewis *et al*. 2012).

The performance of the farm in the 'Base Case' was compared to farm performance in the following scenarios.

Scenario 1: Acidic top-soil with aluminium toxicity

A summary of the Scenario 1 comparison is shown in Figure 1.

In this scenario it was assumed that the conventional lucerne could be grown on the 'Base Case' farm if lime is applied to the top-soil. The amount of lime required to raise soil to the critical pH of 5.5 for lucerne growth depends on the initial pH of the soil. Liming rates of 2 and 5 t/ha were tested.

For Scenario 1, performance of the 'Base Case' was compared with how it could perform under three different potential situations:

- *'Base Case + 2t Lime + Luc':* 2t/lime/ha required to raise top-soil pH to 5.5. This enables conventional lucerne to be established and grown on 10% of the farm area.
- *'Base Case + 5t Lime + Luc':* 5t/lime/ha required to raise top-soil pH to 5.5. This enables conventional lucerne to be established and grown on 10% of the farm area.
- *'Base Case + Al Tol Luc':* 'Al Tol' lucerne established and grown on 10% of the farm area without the need for lime.

Scenario 2: Acidic sub-soil with aluminium toxicity

A summary of the Scenario 2 comparison is shown in Figure 2.

In this scenario sub-soil acidity cannot be viably amended with the management options currently available, so it is not possible to grow conventional lucerne. The 'Al Tol' lucerne is, however, a viable option. By growing 'Al Tol' lucerne, more lambs can be carried for longer to finish and be sold at the end of January. The net benefit of this change to how the farm operates can be attributed solely to the 'Al Tol' technology in this scenario.

For Scenario 2, the performance of the farm in the 'Base Case' was compared to two options:

- *'Base Case + Al Tol Luc':* 'Al Tol' lucerne established and grown on 10% of the farm area without any lime needed. It was assumed that there was no change in the average growth rate of lambs, and no difference in the turn-off weights, from that of the 'Base Case'.
- *'Base Case +Al Tol Luc + Lambs':* 'Al Tol' lucerne established and grown on 10% of the farm area without the need for lime, *and*, second draft prime lambs, which were to be sold at 44 kg liveweight, are retained until the end of January and sold at 50 kg liveweight (22.5 kg carcass-weight). This liveweight requires lambs to grow at 200 g lwt/day throughout January (Hall *et al*. 1985; Hirth *et al*. 2004; Niezen *et al*. 1995). The price per kg liveweight of lambs was the same in December and January.

In eastern Australia, from 2005-2009 there appears to have been no difference in prices received per kg for lambs sold in December compared to lambs sold in January (MLA 2013). This situation is assumed to apply for this study.

Discounted cash flow analysis and Monte Carlo simulation

A 9-year time period was used for the analysis, assuming one year for initial establishment of the lucerne followed by eight years of full production (Clark *et al*. 2013). To achieve the eight years full production from lucerne, it was assumed that best-practice grazing management was imposed, and that annual maintenance requirements were strictly followed (Crawford and Macfarlane 1995). Annual maintenance costs for lucerne were included in the analysis to account for this assumption. While this level of production has been shown to be realisable in the region by local producers, if it is believed to be unachievable irrespective of best-practice management, then the results of this study must be modified accordingly.

A partial discounted cash flow budget was used to estimate the extra benefits of each alternative, compared to the 'Base Case', minus the extra costs of the change, over the 9-year period. When 10% of the farm was established to lucerne, the extra benefits were savings of supplementary feed purchases. In 'Base Case + Luc + Lambs', the extra benefits were savings of supplementary feed purchases plus the value of the extra month of prime lamb liveweight grown in January.

Variable cost assumptions are as described for sheep in Lewis *et al*. (2012). This included the cost of over-sowing (as opposed to full renovation) of 10% of the 'Base Case' pasture area per annum, to allow stocking rate to be maintained for the whole 9-year time period. For lucerne, variable costs included costs for weed control every 3 years (Naji 2011).

Establishing the 'Al Tol' lucerne cost $323/ha, which accounted for the cost of seed, insecticide, herbicide and fertiliser. For conventional lucerne the establishment cost was the $323/ha, plus the cost of lime at $32/tonne and lime application of $25/ha. It was assumed the lucerne would be established using on-farm labour and machinery, with the machinery operating costs for spraying ($3.50/ha), spreading ($25/ha) and sowing ($11/ha) accounted for. The establishment costs were included in the first year of the analysis for each scenario, plus the cost of agisting stock off the 80 ha for 9 months while the lucerne established. A capital cost of $15,000 for fencing, gates and water troughs was required in year one to enable rotational grazing of the lucerne. The salvage value of the lucerne in year nine was assumed to be 20%, and 10% for initial capital costs.

The net present value (NPV) of extra annual net benefits and the modified internal rate of return (MIRR) of the extra investment were calculated for the 9-year period at a real discount rate of 5% (Malcolm *et al*. 2005). The NPVs of the net benefits in each scenario were converted to annuity equivalent values to reflect the potential net benefits on an annual basis for the 9-year analysis period (Malcolm *et al*. 2005). The MIRR was calculated using a re-investment rate of 4% real. The MIRR accounts for re-investment of returns at the market rate of capital, and indicates the return on capital over the life of the investment. Monte Carlo simulation using the @Risk program (Palisade Corporation 2012) was undertaken to generate distributions of potential NPV's and MIRR's of the extra benefits from growing lucerne. Mean-standard deviation analysis (E,S analysis) as described by Hardaker *et al*. (2004) was used to compare returns and risk of the situations analysed.

Seasonal variability and price uncertainty

Data from the EverGraze experiment at Hamilton for 2007-2009 seasons were used for the lucerne DM accumulation rates (kg DM/ha/day) and estimated metabolisable energy (ME) figures (Clark *et al*. 2013; Ward *et al*. 2013). The annual rainfall of 2007 was a 78th decile year, with a 69th decile growing season (Apr-Dec) rainfall recorded. In 2008, a 35th decile annual rainfall total was recorded, with a 41st decile growing season. The 2009 year had a 45th decile annual total with a 63rd decile growing season. These rainfall deciles are based on data from the DEPI Hamilton weather station from 1963 to 2011 (S. Clark pers. comm.)

It was assumed 'Al Tol' lucerne would perform the same as the winter active lucerne cultivar used in the EverGraze experiment. The perennial ryegrass / subterranean clover (*Trifolium subterraneum* L.) pasture was modelled for the same seasons as described in Lewis *et al*. (2012), using GrassGro (Moore *et al*. 1997). For all scenarios, a run of the three years was repeated three times to establish the pasture production over the 9-year period (Lewis *et al*. 2012). The difference in the total ME supply per hectare between the 'Base Case' pasture containing no lucerne, compared to the alternative options which contain 10% lucerne, for each of the three years is shown in Figure 3. By including 10% lucerne, the supply of ME per hectare was consistently increased during summer, and this trend continued through the autumn period. This translated into the supplementary feed savings which occurred during the late summer –early autumn period as shown in Figure 4. This highlights the benefit of extra DM of including lucerne in the case study environment.

Four different combinations of seasonal conditions were tested here:

- Run of Years 1: 2007, 2008, 2009
- Run of Years 2: 2009, 2008, 2007
- Run of Years 3: 2008, 2009, 2008
- Run of Years 4: 2007, 2009, 2007

Uncertain key price parameters were described using probability distributions. Parameters (mean, s.d.) were lamb price $/kg cwt ($3.60, $1.55), merino ewe price $/head ($112, $43), wether price $/head ($90, $33), 18 micron wool prices c/kg clean

(1233 c, 111c), barley price \$/t (\$235, \$69) and lupin price \$/t (\$250, \$38).

Sensitivity testing

Sensitivity testing was used to explore how specific price and production scenarios influenced the expected returns of carrying lambs over ('Base Case + Al Tol Luc + Lambs'). An increase in the percentage of the farm in lucerne was tested at 20 and 30 percent. Barley and lamb price distributions were independently fixed, firstly at the 20th and secondly at the 80th percentile.

Breakeven analysis

Breakeven analysis is helpful when there is uncertainty about parameter values, as it helps to assess whether the critical value of a variable falls within the range of values considered to be reasonable (Pannell 1997). Breakeven analysis was conducted to estimate how high the DM yield of 'Al Tol' lucerne would need to be before there was no net benefit from growing 'Al Tol' lucerne. A second breakeven analysis was conducted to test additional establishment cost, which include seed costs, again to estimate how much establishment costs would need to increase before there was no net benefit from 'Al Tol' lucerne. For 'Scenario 1', breakeven analysis was conducted in reference to the 'Base Case + Lime + Luc' options. For 'Scenario 2', breakeven analysis was conducted in reference to the 'Base Case' pasture.

Results

It was consistently more profitable to manage aluminium toxicity and introduce lucerne to the 'Base Case' representative farm, compared with the *status quo* situation of grazing the perennial ryegrass / subterranean clover pastures over the 9 year analysis period. This result is based on the assumption that the management options investigated successfully solved the problem of aluminium toxicity, and there were no other limitations to the growth of lucerne.

If aluminium toxicity was present in the top-soil only, the additional profit from growing 'Al Tol' lucerne was comparable to the profit of liming and subsequently growing conventional lucerne (Table 2). The variation in seasonal conditions resulted in profit being more variable within each option, compared with between options. For example, the mean annuity of NPV for the 'Base Case + Al Tol Luc' option ranged from an additional \$7/ha/year to \$28/ha/year under 'Run of Years 3' and 'Run of Years 4' conditions respectively. In contrast, there was a difference of \$1-3/ha/year between the 'Base Case + Al Tol Luc' and the 'Base Case + 5t Lime + Luc'. For the 'Base Case + Al Tol Luc' the marginal return on the extra capital invested, as measured by mean MIRR, was slightly greater than for both of the liming alternatives.

The breakeven analysis for Scenario 1 (Table 3) showed that 'Al Tol' lucerne would need to produce at least 93-97 percent of the DM of the conventional lucerne to be competitive with the liming options. Establishment costs could increase by around 25-78 percent before the advantage of 'Al Tol' over conventional lucerne plus liming was lost.

If aluminium toxicity was present in the sub-soil, incorporating 'Al Tol' lucerne for grazing generated higher mean annual net cash flows compared with the 'Base Case', with slightly less risk, as shown by the mean-standard deviation results (Figure 5). The mean annual net cash flows of the 'Base Case +Al Tol Luc + Lambs' option was similar to that of the 'Base Case +Al Tol Luc' option, however it showed similar levels of risk to the 'Base Case' with no lucerne.

In addition to generating higher annual net cash flows, both the 'Base Case + Al Tol Luc' and 'Base Case + Al Tol Luc + Lambs' were more profitable to the 'Base Case' option over the 9 year period. That is, the extra capital invested to make the change and use 'Al Tol' lucerne improved the performance of the 'Base Case' and showed returns on capital that exceeded opportunity costs (Table 4). There was little difference in the additional profit (mean annuity of NPV) generated by either the 'Base Case +Al Tol Luc' and the 'Base Case +Al Tol Luc + Lambs' options. Both also showed similar marginal returns on the extra capital invested (mean MIRR).

Table 5 shows the breakeven analysis for Scenario 2, for the 'Base Case + Al Tol Luc' option. As conventional lucerne was not an option in Scenario 2, the 'Al Tol' technology needed to produce DM yield ranging from 44 to 72 percent of conventional lucerne to be an attractive alternative to the 'Base Case' pasture. Establishment costs for 'Al Tol' lucerne could increase substantially before the advantage of incorporating lucerne into the 'Base Case' was lost.

The results of the sensitivity analyses of key parameters for the sub-soil scenario are shown in Table 6. The 'Base Case + Al Tol Luc + Lambs' was more profitable than the 'Base Case +Al Tol Luc' at a high lamb price

(80th percentile) for the 9 year period, and slightly more profitable at a low barley feed price (20th percentile). At the low barley price, the additional profit achieved from having 'Al Tol' lucerne in the system was reduced from around $14-15/ha/year to $8-10/ha/year. In addition, increasing the proportion of the farm sown to 'Al Tol' lucerne increased the mean annuity of NPV generated above the 'Base Case' for both scenarios. However, this did not alter the difference between the 'Base Case +Al Tol Luc' and the 'Base Case + Al Tol Luc + Lambs' markedly, nor did it alter the marginal return on additional capital invested.

Discussion and conclusions

All of the management options explored to address aluminium toxicity, and, to subsequently grow lucerne, were more profitable than continuing to graze the 'Base Case' pasture over the 9 years.

For Scenario 1 (acidic top-soil), both liming options and the 'Base Case + Al Tol Luc' option produced similar levels of extra profit over the 9 year period. Over the same 9 year period, the marginal return on extra capital invested was slightly higher for the 'Base Case + Al Tol Luc' option, because no liming was required during the lucerne establishment period.

For the sub-soil scenario (Scenario 2), the use of 'Al Tol' lucerne to deal with the problem of aluminium toxicity was also consistently more profitable. This was because the 'Base Case + Al Tol Luc' option had more feed in the summer and early autumn period compared with the 'Base Case', which resulted in higher net cash flows. The summer and early autumn period has previously been identified by Moore *et al*. (2009) as a key feed gap for grazing enterprises in south west Victoria. The reduction in supplementary feed costs resulted in an extra $7 – $28/ha/year over the whole farm for the 9 year period for the 'Base Case + Al Tol Luc' option.

As expected, the additional net benefits of 'Al Tol' lucerne were greatest when aluminium toxicity occurred in the sub-soil compared to the top-soil scenario. For the top-soil scenario, the difference in extra profit from growing 'Al Tol' lucerne, compared to the alternative management option of liming and subsequently growing conventional lucerne, was negligible. This small difference occurred because the benefit of 'Al Tol' lucerne simply equates to the cost saving of not applying lime, as all other establishment costs were assumed to be equal between conventional and 'Al Tol' lucerne. This cost of applying lime to the top-soil during the pasture establishment phase was $1-3 ha/year over the whole farm over the 9 years, and is minor compared to the savings in supplementary feed from having lucerne in the system.

Conversely, it was assumed that in the sub-soil scenario there was no management practice available to viably deal with acidity and aluminium toxicity in the sub-soil, and subsequently growing conventional lucerne as a productive pasture for grazing. Under these circumstances, the extra profit generated of $7– 28/ha/year by growing 10 % lucerne on the farm, compared to the 'Base Case', can be fully attributed to the 'Al Tol' cultivar. This finding supports previous recommendations for the use of pasture varieties with aluminium tolerance on the deep acidic soils of the high rainfall pasture zone of Australia (Scott *et al*. 2000). Because of a lack of alternative management options for growing conventional lucerne, the additional net benefits of aluminium-tolerant lucerne is greater for farm systems with aluminium toxicity in the sub-soil compared to the top-soil.

The breakeven analysis showed that if the 'Al Tol' technology is expected to compete with conventional lucerne and the use of lime, 'Al Tol' lucerne DM yields would need to be over 90 percent of those of conventional lucerne. However, for circumstances where liming is not a viable alternative, 'Al Tol' lucerne DM yields could be substantially less and still remain an attractive alternative to the 'Base Case' pasture of perennial ryegrass and sub clover. This is an important finding for plant breeders focused on improving aluminium tolerance in lucerne.

By overcoming aluminium toxicity in the sub-soil, 'Al Tol' lucerne provided the option to profitably increase lamb liveweight production per hectare compared to the 'Base Case' option. In the 'Base Case' option all lambs were sold by the end of December, whereas with the 'Al Tol' lucerne, 40% of lambs could be carried over until the end of January and sold at heavier liveweights. The 'Base Case + Al Tol Luc + Lambs' option generated extra profit compared to the 'Base Case', with similar levels of annual net cash flow risk. The carry-over of lambs increases feed demand during the summer period, and would be expected to increase risk as a result (Chisholm 1965). However, in the scenario tested, including lucerne in the grazing system mitigated the expected increase in risk by limiting the amount of extra supplementary feed required to achieve the additional lamb growth over the summer period. There may be other forage options available for producers to similarly carry lambs through to the end of January, such as summer fodder crops. These were not explored in this analysis.

Compared with growing 'Al Tol' lucerne and maintaining the current level of lamb production ('Base Case + Al Tol Luc' option), using the 'Al Tol' lucerne to produce additional lamb liveweight per ha through January ('Base Case + Al Tol Luc + Lambs' option) was similarly as profitable and marginally more risky. The similar level of extra profit between the two options was the result of the diversion of pasture, which would have been available during the summer and early-autumn period in the 'Base Case + Al Tol Luc' option, to additional lamb liveweight production during January in the 'Base Case + Al Tol Luc + Lambs' option. Subsequently, extra supplementary feed was required for the 'Base Case + Al Tol Luc + Lambs' compared to the 'Base Case + Al Tol Luc' option. However, the additional income from lamb sales in the 'Base Case + Al Tol Luc + Lambs' option was able to compensate for the cost of the extra supplementary feed required, and returned similar net cash flows, NPV's and MIRR's over the 9 year period.

The sensitivity analysis showed that for the 'Base Case + Al Tol Luc + Lambs' to be more profitable than the 'Base Case + Al Tol Luc' option either a low barley price or high lamb price would be required. An 80th percentile lamb price and 20th percentile barley price were tested here. Reducing barley price to the 20th percentile also reduced the advantage of both 'Al Tol' scenarios compared to the 'Base Case', as the supplementary feed cost savings achieved by having lucerne in the system were comparatively smaller when barley price is low. The barley and lamb price sensitivity analysis presented here provides an example of how the relative profitability of carrying lambs to the end of January can alter. In reality, individual producers may implement their own techniques to the management of lucerne, for example tactical grazing with the lambs, which could also alter the relative profitability of such an option. If 'Al Tol' lucerne is to be used to increase the lamb liveweight produced per ha, the expected additional income must be evaluated against the likely increase in supplementary feed required for the whole farm system and the implications for risk.

The risk and return from incorporating 'Al Tol' lucerne into the farm system was examined here for a representative case study farm using a range of 'what if' options. Factors, such as change in farm system complexity, increase in management skill required and preference of the individual producer were not included in this analysis. However, in practice, these factors may be equally, or even more important in the adoption decisions of livestock producers.

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Appendix

Table 1

Description of the 'Base Case' pasture and prime lamb activity used in the representative farm case study model.

Pasture system	**Prime lamb av. growth rates from weaning** (g lwt/day) (% of total prime lambs in draft)	**Prime lamb sale targets** (kg lwt/cwt)
100% of land area perennial ryegrass / subterranean clover with some capeweed	1st draft: 210 (40%) 2nd draft: 190 (60%)	1st draft: start of December @ 40/18 kg 2nd draft: end of December @ 44/20 kg

Figure 1

Summary diagram of 'Scenario 1: Acidic top-soil with aluminium toxicity' comparison.

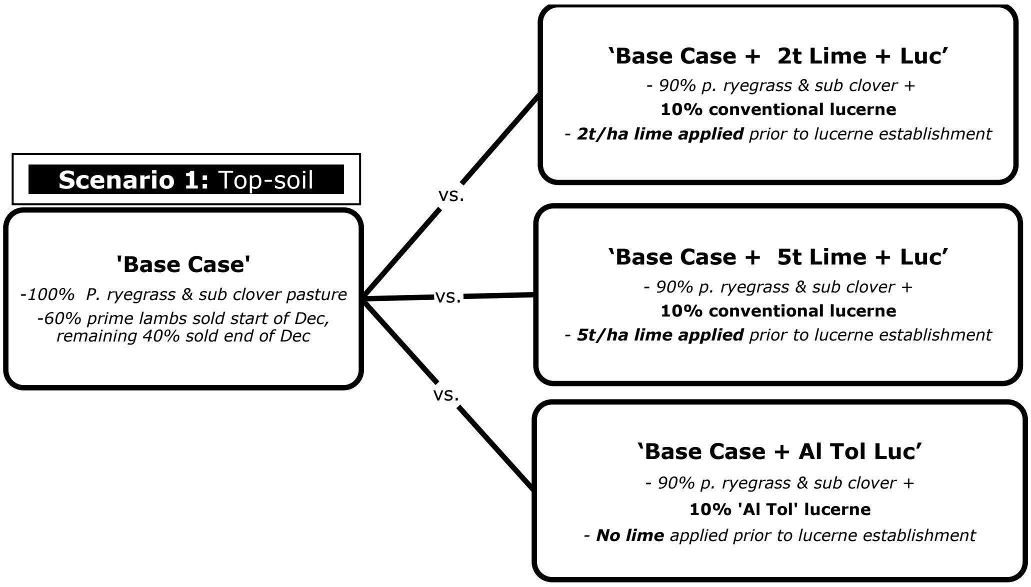

Figure 2

Summary diagram of 'Scenario 2: Acidic sub-soil with aluminium toxicity' comparison.

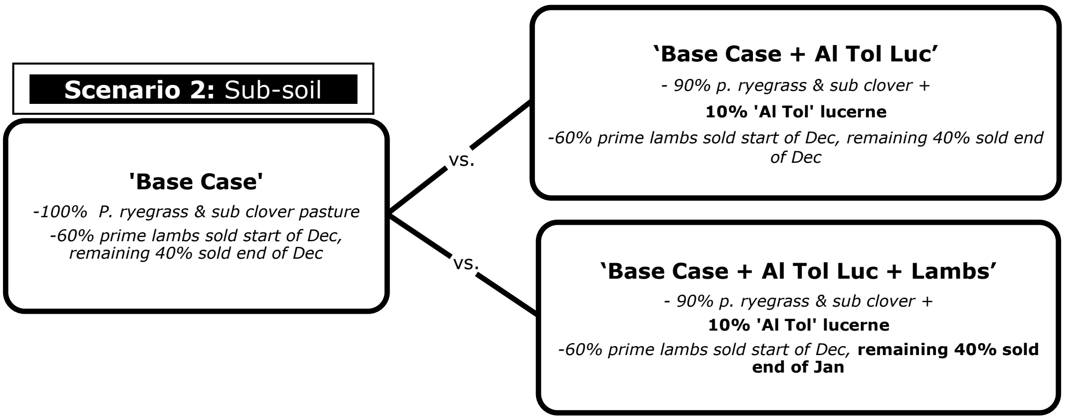

Figure 3

Difference in the total ME supply per hectare (MJ ME /kg DM multiplied by kg DM grown/ha/month) between the 'Base Case' pasture containing no lucerne, compared to the alternative options which contain 10% lucerne, for each of the three years.

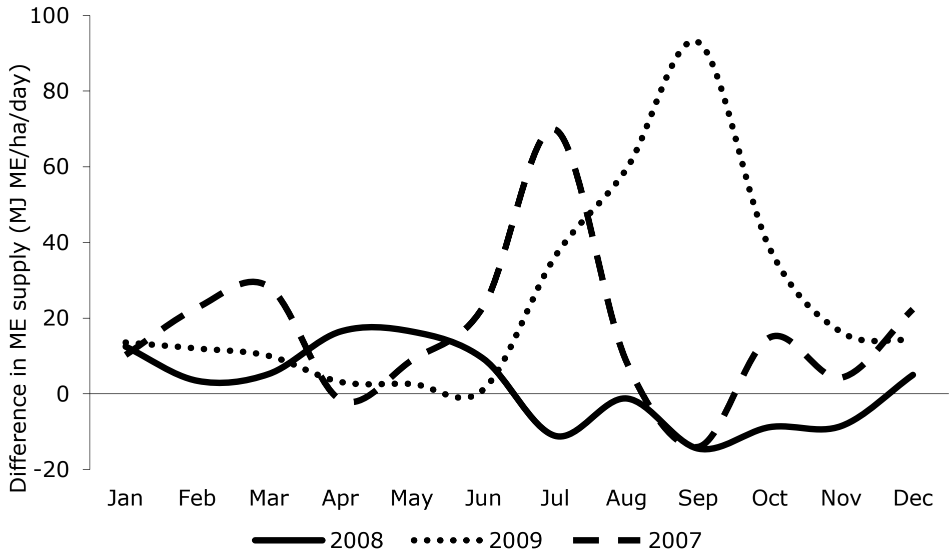

Figure 4

Difference in supplementary feed costs ($/DSE/month) between the 'Base Case' pasture containing no lucerne, compared to the alternative options which contain 10% lucerne, for each of the three years based on the 'Run of Years 1: 2007, 2008, 2009'. February, March and April were the only months where supplementary feed was required for all scenarios tested. Median prices for supplementary feed were assumed.

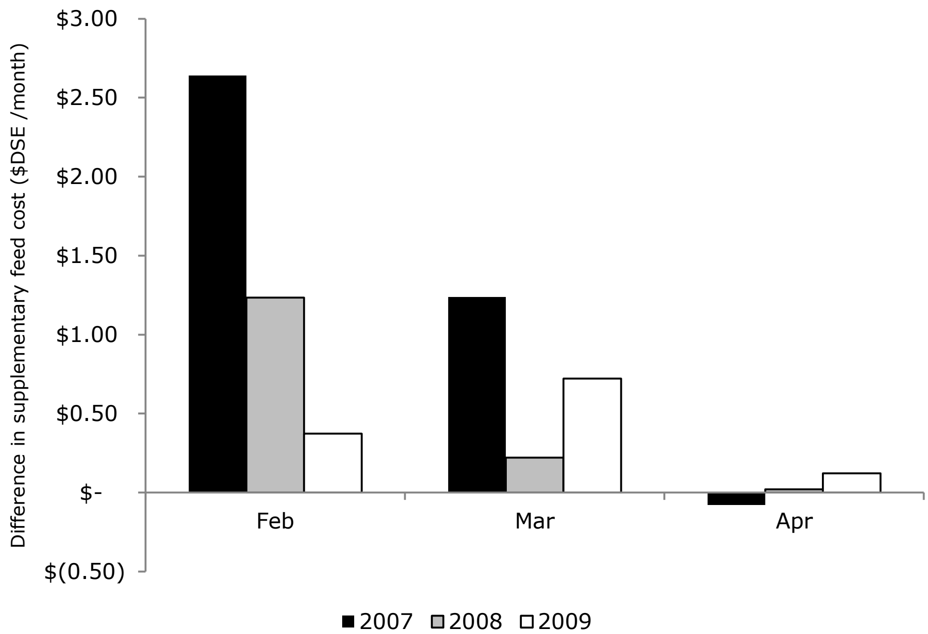

Table 2

Scenario 1: Acidic top soil with aluminium toxicity. Additional annuity of NPV over the 9 year period, and MIRR, results for each option, assuming lucerne was sown over 10% farm area. All figures are real after tax of 15%. The additional benefits of each option compared to the 'Base Case' over a range of seasonal conditions.

	Run of Years 1: 2007, 2008, 2009	**Run of Years 2:** 2009, 2008, 2007	**Run of Years 3:** 2008, 2009, 2008	**Run of Years 4:** 2007, 2009, 2007
'Base Case +Al Tol Luc'				
Mean annuity of NPV 5% real ($/ha/yr)	14	17	7	28
Mean MIRR (%)	22	24	16	30
'Base Case + 2t Lime + Luc'				
Mean annuity of NPV 5% real ($/ha/yr)	13	16	7	26
Mean MIRR (%)	20	21	14	27
'Base Case + 5t Lime + Luc'				
Mean annuity of NPV 5% real ($/ha/yr)	12	15	6	25
Mean MIRR (%)	18	20	12	25

Table 3

Breakeven analysis of Scenario 1 : Acidic top soil with aluminium toxicity. 1) 'Al Tol' lucerne DM required (% of conventional lucerne DM production) no benefit* from 'Base Case + Al Tol Luc' compared to the alternative options, 2) Relative increase in 'Al Tol' lucerne establishment costs for no benefit* from 'Base Case + Al Tol Luc' compared to the alternatives e.g. 125% reflects a 25% increase in establishment costs compared to the alternative. Assumed lucerne was sown over 10% farm area. Range calculated across the four seasonal scenarios.

	Alternative Options for Scenario 1	
	'Base Case + 2t Lime + Luc'	**'Base Case + 5t Lime + Luc'**
'Al Tol' lucerne DM production required for no benefit (% of conventional lucerne DM)	96-97	93-94
'Al Tol' lucerne establishment cost required for no benefit (% of conventional lucerne establishment cost)	125-148	155-178

* mean NPV of 'Base Case + Al Tol Luc' to equal alternative option

Figure 5

Mean-standard deviation (E,S efficiency) analysis of annual net cash flow over a range of seasonal conditions for the acid sub-soil scenario.

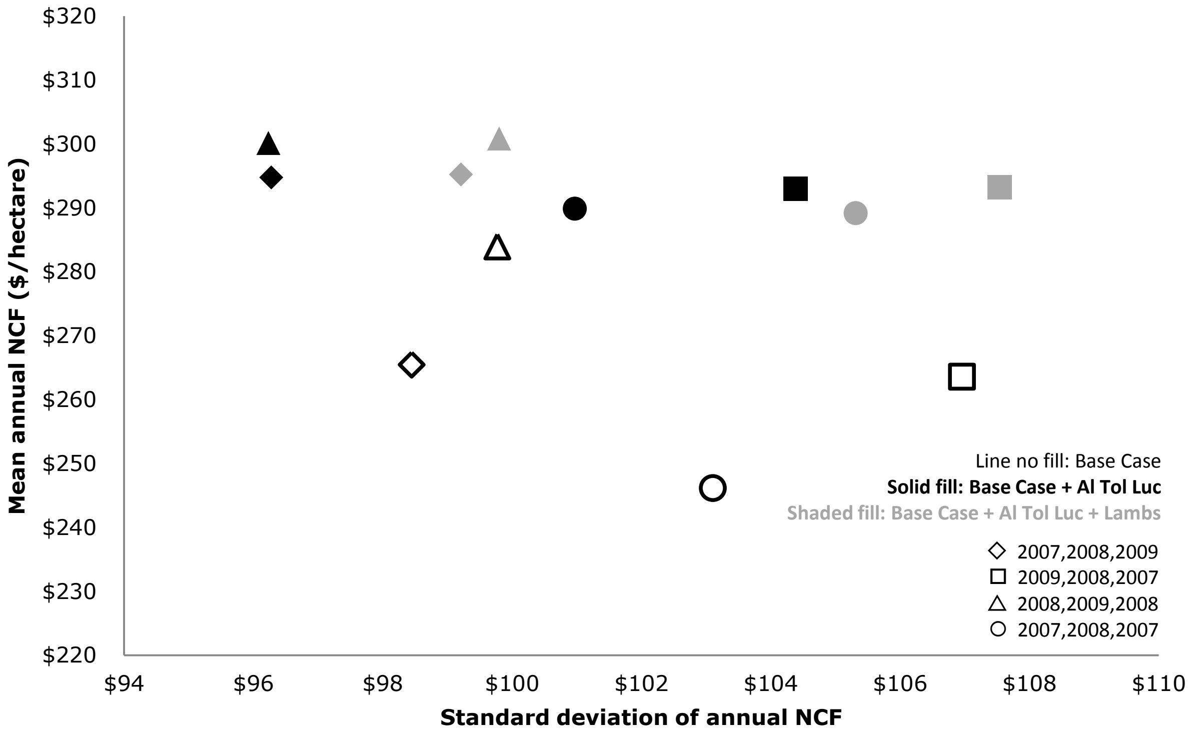

Table 4

Scenario 2: Acidic sub soil with aluminium toxicity. Additional annuity of NPV over the 9 year period, and MIRR, results for each option, assuming lucerne was sown over 10% farm area. All figures are real after tax of 15%. The additional benefits of each option compared to the 'Base Case' over a range of seasonal conditions.

	Run of Years 1: *2007, 2008, 2009*	**Run of Years 2:** *2009, 2008, 2007*	**Run of Years 3:** *2008, 2009, 2008*	**Run of Years 4:** *2007, 2009, 2007*
'Base Case +Al Tol Luc'				
Mean annuity of NPV 5% real ($/ha/yr)	14	17	7	28
Mean MIRR (%)	22	24	16	30
'Base Case +Al Tol Luc + Lambs'				
Mean annuity of NPV 5% real ($/ha/yr)	15	17	8	27
Mean MIRR (%)	23	24	17	30

Table 5

Breakeven analysis of Scenario 2 : Acidic sub soil with aluminium toxicity. 1) 'Al Tol' lucerne DM required (% of conventional lucerne DM production) no benefit* from 'Base Case + Al Tol Luc' compared to the alternative option, 2)) Relative increase in 'Al Tol' lucerne establishment costs for no benefit* from 'Base Case + Al Tol Luc' compared to the alternatives e.g. 323% reflects a 223% increase in establishment costs compared to the alternative. Assumed lucerne was sown over 10% farm area. Range calculated across the four seasonal scenarios.

	Alternative Option for Scenario 2
	'Base Case'
'Al Tol' lucerne DM production required for no benefit (% of conventional lucerne DM)	42-72
'Al Tol' lucerne establishment cost required for no benefit (% of conventional lucerne establishment cost)	323-928

* mean NPV of 'Base Case + Al Tol Luc' to equal alternative option

Table 6

Sensitivity testing of Scenario 2: Percentage of farm in lucerne, lamb price and barley price. Prices were fixed one at a time for the 9 years of the analysis, removing the associated price risk of the individual parameter. All other variables were left unchanged. Assumed 'Run of Years 1: 2007, 2008, 2009' seasonal conditions. Additional annuity of NPV over the 9 year period, and MIRR, results for each option. All figures are real after tax of 15% on taxable income.

	Farm in lucerne (%)		*Barley price ($ t)(percentile)*		*Lamb price ($ kg cwt)(percentile)*	
	20	**30**	**170 (20th)**	**297 (80th)**	**2.15 (20th)**	**4.95 (80th)**
'Base Case +Al Tol Luc'						
Mean annuity of NPV 5% real ($/ha/yr)	28	39	8	20	14	14
Mean MIRR (%)	23	23	18	26	22	22
'Base Case + Al Tol Luc + Lambs'						
Mean annuity of NPV 5% real ($/ha/yr)	29	41	10	19	12	17
Mean MIRR (%)	23	23	19	26	20	25