

Economic evaluation of establishing pasture legumes in the Brigalow Belt

2026

Queensland Government

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Summary

The Brigalow Belt is the largest cattle producing region in Queensland but faces challenges with pasture rundown and seasonal variability affecting grazing quality in the dry season. Building pasture resilience by integrating legumes into grazing pastures increases pasture productivity and utilisation, carrying capacity, and liveweight gains particularly in the dry season, which can enable access to premium markets. Past research has shown that integrating legumes into grazing pastures can improve farm profitability. However, the extent of legume establishment is relatively low, which highlights the prevailing opportunity to unlock these benefits.

This report extends on this work by evaluating the economic implications of establishing legumes on a 500-hectare production paddock across several land productivity types using a range of establishment methods. The objective was to identify profitable legume establishment options to help guide perceptions and inform future investment decisions. This study was a collaborative partnership between specialists in pasture agronomy, economics and beef extension.

The evaluation was completed by identifying the best range of options currently available to producers and defining the processes and costs associated with pasture establishment, additional ongoing expenses and the impacts on pasture and cattle production and gross margins. Twenty-nine scenarios were modelled across high, moderate, and low productivity (and non-arable) land types, comparing leucaena, desmanthus/stylo and medics using long term averages of grass, legume and cattle production obtained from research trials and commercial experience. The establishment methods included one-pass planting (low cost), full cultivation and planting across the whole paddock (high cost), and planting in cultivated strips. Failure rates were factored into the modelling to reflect the risks associated with different methods in combination with fallows and upfront and maintenance phosphorus (P) fertiliser application to increase the likelihood of establishment and long-term yield potential.

Investment analyses were undertaken by completing a series of discounted cashflow analyses to determine key measures of investment performance. Each analysis of legume pastures compared the marginal differences in cash flow between the base scenarios for each productivity zone and the legume establishment scenarios over the 30-year investment period, using a discount rate of 5%. Cash flows were calculated from the numbers of cattle sold, sale weights and the corresponding cattle prices, along with variable costs associated with weaner purchases, transport, animal husbandry, selling and pasture maintenance.

Legume species

Leucaena is best suited to land with moderate to high production potential but has high upfront establishment costs ($238,900-$279,900 for the 500 ha paddock) and additional ongoing expenses to prune, inoculate cattle and apply maintenance P fertiliser (on moderately productive land). However, the pasture and cattle production benefits of including Leucaena were substantial relative to retaining buffel-only pastures. Once fully established, steers were turned off 6-8 months faster, total dry matter (DM) intake was reduced by 1,650-2,150 kg/head (due to improved digestibility and faster weight gain), steer sales increased by 153-265 head/year and gross margins improved by $114,100-$180,400/year in different land types across 500 ha of improved paddock. The investment analysis revealed that establishing leucaena increased profitability by $62,400-$103,400/year, produced an annual rate of return of 25-31%, and had a payback period of 9-10 years (five years after planting finished). However, the peak cash flow deficit was high at -$246,900 to -$415,500 (in year 6), which a producer would need to be able to sustain.

Desmanthus and stylo are suited to a broader range of land types than leucaena as they have lower P requirements. Upfront establishment costs varied widely depending on the establishment method and P application ($76,300-$360,300). The only legume maintenance expenses were incurred with applying maintenance P fertiliser to sustain optimal yields on low and moderate productivity land types. Similarly to leucaena, the establishment of desmanthus and stylo into buffel grass pastures improved pasture and cattle production as well as gross margins. Once fully established on high productivity land types, turnoff times decreased by 4 months, total DM intake decreased by 1,049 kg/hd (due to improved digestibility and faster weight gain), steer sales increased by 140 hd/yr and the gross margin improved by $131,700. Less productive land types without P application had similar proportional improvements in pasture and cattle production but larger decreases in total DM intake (-1,300 to -2,400 kg/hd) and steer turnoff times (-5 to -10 months). Applying adequate maintenance P fertiliser grew steer sales and gross margins further.

The investment analysis as summarised in Table 1 revealed that establishing desmanthus and stylo increased profitability in all arable land type scenarios. Strip planting consistently outperformed the other establishment options increasing profitability by $25,300-$79,700/year and generating a 38-513% rate of return, payback of 6-8 years (one to three years after planting finished) and peak deficit of -$2,900 to -$116,100. The high-cost full cultivation option also performed well increasing profitability by $17,100-$75,900/year, producing a 14-33% rate of return and paid back in 9-14 years, however the peak cash flow deficit was relatively high (-$175,500 to -$407,300). The worst performing option was the low-cost method, which on arable land increased profitability by the least amount ($700-$10,300/year) and had the lowest rates of return (6-16%) and longest payback (10-25 years). Nonetheless, its peak deficit was relatively low on some land types (-$75,700 to -$100,600), which might appeal to some producers who have constrained cash flow. Applying upfront and maintenance P fertiliser where needed improved investment performance further (adding $33,000-$43,700/year). On non-arable land types, the low-cost option decreased profitability, but the strip planted option increased profitability by $5,600/year and had a 15% rate of return, 19-year payback and peak deficit of -$58,400.

Medics are best suited to southern parts of the Brigalow Belt. Less animal performance data has been compiled on medics so the analysis should be considered preliminary. Both options examined had relatively low upfront establishment costs (direct seeding and strip planting). Additional ongoing expenses included treating cattle with anti-bloat oil along with applying maintenance P fertiliser (on moderately productive land types). Similarly to desmanthus/stylo, the pasture and cattle production benefits from establishing medics were large relative to undeveloped buffel pastures. Steers were turned off 4-5 months faster, total DM intake reduced by 1,050-1,300 kg/head, steer sales increased by 102-135 head/year and gross margins improved by $89,000-$118,000/year. Applying adequate P fertiliser grew steer sales and gross margins even further. The investment analysis revealed that strip planting medics performed better than the low-cost option increasing profitability by $56,200-$69,000 per year, 35-159% rate of return, 7-9 year payback and peak deficit of -$19,800 to -$172,800. The low-cost option increased profitability by much less, had lower rates of return and a similar payback.

Establishment method, land type, fertiliser and recommendations

Comparing all the legume species (leucaena, medic and desmanthus/stylo) identified no consistent winners across the performance metrics given varying performance with the different establishment methods, land types and fertiliser requirements. Comparing the different establishment methods showed that establishing pastures using strips generated slightly higher profitability than the whole paddock high-cost establishment option but generated much higher rates of return, faster paybacks

and lower peak deficits. The whole paddock low-cost option had the lowest returns and longest payback. High and moderate productivity land types generated relatively stronger returns and faster paybacks than low productivity land. The arable low productivity land type had the next best returns, while non-arable land had the weakest investment performance. Applying P fertiliser improved profitability when using effective establishment methods but performed best on low productivity land.

Key learnings

- High productivity land: leucaena increased profitability the most, while desmanthus or stylo in strips had the 2nd largest increase in profitability, highest rate of return and a fast payback.
- Moderate productivity land: establishing desmanthus or stylo in strips with or without P performed well across all metrics. Leucaena generated the largest increase in profitability but did not rank as well in the other measures.
- Low productivity arable land: establishing desmanthus or stylo in strips performed well across all metrics (particularly with P), while the high-cost desmanthus or stylo option (whole paddock) had the 2nd largest increase in profitability but ranked lower in other measures.
- Non-arable land – stylo in strips performed the best across all metrics.

This project has identified combinations of legume types and establishment methods that work well on different land types along with investment measures that help producers identify options that suit their business circumstances. While assumptions for the analysis were informed by research and field experience and provide a guide as to the relative potential of each management option (shown in Table 1), the results of this analysis should not be interpreted as financial advice. Each grazing business is unique in its circumstances and therefore the parameters and assumptions used in this report reflect theoretical situations only. Consideration of individual circumstances must be made before applying these scenarios to another situation.

Table 1: Key investment results compiled from section 4.3

Produ-ctivity	Legume types[A]	Establishment method	NPV ($/yr)	Rate of return (%)	Years to Payback	Peak deficit ($)
High	Leucaena Strip	Strips-10m centres	$91,800	25%	10	-$415,500
	Des/Stylo Lo$ NoFal	Whole paddock	$10,300	16%	10	-$100,600
	Des/Stylo Hi$ MidFal	Whole paddock	$75,900	29%	9	-$289,100
	Des/Stylo Hi$ LngFal	Whole paddock	$73,000	21%	10	-$407,300
	Des/Stylo Strip	Strips-15m centres	$79,700	62%	8	-$116,100
	Medic Lo$ NoFal	Whole paddock	$19,000	39%	8	-$49,400
	Medic Strip	Strips-15m centres	$69,000	35%	9	-$172,800
Moder-ate	Leucaena Strip	Strips-10m centres	$62,400	28%	9	-$246,900
	+P	Strips-10m centres	$103,400	31%	9	-$326,000
	Des/Stylo Lo$ NoFal	Whole paddock	$5,600	13%	12	-$75,700
	Des/Stylo Hi$ MidFal	Whole paddock	$46,900	33%	9	-$175,500
	Des/Stylo Hi$ LngFal	Whole paddock	$43,900	20%	10	-$278,900
	+P	Whole paddock	$87,700	26%	9	-$317,400
	Des/Stylo Strip	Strips-15m centres	$53,000	513% (est)[B]	6	-$2,900
	+P	Strips-15m centres	$95,100	337% (est)[B]	6	-$3,900
	Medic Lo$ NoFal	Whole paddock	$15,100	63% (est) [B]	6	-$15,200
	+P	Whole paddock	$18,800	23%	9	-$98,400
	Medic Strip	Strips-15m centres	$56,200	159% (est) [B]	7	-$19,800
	+P	Strips-15m centres	$83,400	85% (est) [B]	7	-$50,200
Low arable	Des/Stylo Lo$ NoFal	Whole paddock	$700	6%	25	-$80,500
	Des/Stylo Hi$ MidFal	Whole paddock	$17,100	14%	14	-$254,100
	+P	Whole paddock	$50,100	22%	10	-$292,500
	Des/Stylo Strip	Strips-15m centres	$25,300	38%	8	-$57,500
	+P	Strips-15m centres	$58,400	50%	8	-$68,500
Non-arable	Stylo Lo$ NoFal	Whole paddock	-$2,500	No return	No payback	-$178,500
	Stylo Strip	Strips-20m centres	$5,600	15%	19	-$58,400

[A] Des/Stylo refers to desmanthus or stylo. Abbreviations such as 'Lo$' or 'Hi$' refer to the relative cost of establishment, while 'NoFal', 'MidFal' or 'LngFal' refer to the length of fallow period preceding planting of the new pasture. '+P' indicates the same establishment method as the scenario above it, but with additional P fertiliser. These abbreviations are explained further in Section 3.2 and Appendix 1.

[B] These unusually high IRRs arise because establishment costs were largely offset by cattle sales during implementation, resulting in very small net capital outlays.

Contents

1 Introduction 1

2 Background 3

2.1 Climate zone 3

2.2 Benefits of establishing legumes 5

2.3 Extent of legume establishment in the Brigalow Belt 6

2.4 Methods of legume establishment 6

2.5 Economic analyses and adoption of pasture legumes 7

3 Methodology 8

3.1 Baseline pasture scenarios 8

3.2 Legume establishment scenarios 9

3.2.1 Legume species 10

3.2.2 Legume establishment methods 11

3.2.3 Maintaining or re-planting grass 14

3.2.4 Phosphorus (P) fertiliser 15

3.3 Investment analysis 16

3.3.1 Cattle prices 16

3.3.2 Variable costs 17

3.4 Carrying capacity during establishment 18

3.5 Establishment costs 21

3.6 Additional expenses 23

3.7 Pasture production 24

3.8 Carrying capacity and liveweight gains 26

4 Results 28

4.1 Cattle production 28

4.2 Revenues, costs and gross margins 29

4.3 Investment analysis 30

4.3.1 High productivity land types 30

4.3.2 Moderate productivity land types 31

4.3.3 Arable low productivity land types 32

4.3.4 Non-arable, low productivity land types 33

4.4 Establishment method 33

4.5 Land type 33

4.6 Phosphorus (P) fertiliser 34

5 Sensitivity Analysis 36

5.1 Cattle price premium 36

5.2 Productive life of legumes 37

5.3 Failure rate for low-cost options 39

5.4 Pruning frequency 40
6 Discussion 41
6.1 Legume species 41
6.1.1 Leucaena 41
6.1.2 Other tropical legumes (desmanthus and stylo) 41
6.1.3 Medics 42
6.2 Which option is “best”? 43
6.3 Sensitivity Analysis 44
6.4 Recommendations for producers 44
6.5 Contribution of this report 46
7 Limitations 47
8 Conclusion 48
8.1 Legume species findings 48
8.2 Establishment method, land type and fertiliser findings 48
8.3 Key grazier recommendations 49
8.4 Usefulness for industry 49
9 Future Recommendations 50
9.1 Animal production research 50
9.2 Research and demonstration of legume establishment methods 50
9.3 Land condition 51
9.4 Carbon emissions accounting 51
9.5 Economic analysis - additional modelling 51
9.6 Extension recommendations 51
10 References 53
11 Appendix 1 56

List of tables

Table 1: Key investment results compiled from section 4.3 vi
Table 2: Description of QLD agro-climatic classes. 4
Table 3: Description of baseline pastures. 9
Table 4: Scenario descriptions. 10
Table 5: Fallowing, paddock preparation & planting legumes, failure rates & time to full production. 14
Table 6: Grass areas maintained and planted (% of paddock) 15
Table 7: Phosphorus (P) fertiliser assumptions for +P scenarios. 16
Table 8: Cattle prices (steers) in $/kg (liveweight), inflation adjusted and averaged over 10 years 17
Table 9: Machinery costs – contractor rates ($/ha) 18
Table 10: Seed costs ($/kg). 18
Table 11: Fertiliser and chemical costs ($/kg or L). 18

Table 12: Establishment timeline and carrying capacity during implementation (% of full capacity).... 21
Table 13: Pasture establishment operations and total costs across 500 ha. 22
Table 14: Additional expenses over 30 years. 24
Table 15: Quantities of biomass produced and utilised. 25
Table 16: Carrying capacity and liveweight gains. 26
Table 17: Proportion of annual liveweight gains in each month. 27
Table 18: Weaner intake, grazing duration, dry matter intake, steer sales and sale weights. 29
Table 19: Net cattle sales, variable costs and gross margins. 30
Table 20: Investment performance – high productivity land types. 31
Table 21: Investment performance – moderate productivity land types. 32
Table 22: Investment performance – arable low productivity land types. 32
Table 23: Investment performance – non-arable low productivity land types. 33
Table 24: Investment performance of establishment methods – arable land & Des/Stylo only. 33
Table 25: Investment performance range of each land productivity type. 34
Table 26: Change in investment performance from applying P fertiliser. 35
Table 27: Sensitivity of annualised net present value ($/year) to the cattle price premium (c/kg). 37
Table 28: Sensitivity of annualised net present value ($/year) to the life of the legumes (years). 38
Table 29: Sensitivity of annualised net present value ($/year) to “low-cost” establishment failure. 39
Table 30: Sensitivity of annualised net present value ($/year) to the frequency of pruning leucaena. 40
Table 31: Pasture and cattle production, and gross margin improvements – Leucaena. 41
Table 32: Pasture and cattle production, and gross margin improvements – Desmanthus/ Stylo. 42
Table 33: Pasture and cattle production, and gross margin improvements – Medic. 42
Table 34: Investment performance of each legume species–high & moderate productivity land only. 44
Table 35: Top two performing legume establishment options on high productivity land. 45
Table 36: Top two performing legume establishment options on medium productivity land. 46
Table 37: Top two performing legume establishment options on low productivity land (arable and non-arable). 46
Table 38: Pasture scenario assumptions for high productivity land. 56
Table 39: Pasture scenario assumptions for medium productivity land. 57
Table 40: Pasture scenario assumptions for low and low non-arable productivity land. 58

List of figures

Figure 1: Map of Queensland’s agro-climatic classes – modified from Hutchinson et al. (2005). 3

1 Introduction

Building pasture resilience across northern Australia is vital for the productivity and sustainability of grazing businesses. The Brigalow Belt agro-climatic zone produces 39% of Queensland's gross value of agricultural production from beef (Queensland Government, 2024) but faces challenges due to declining productivity from pasture rundown (caused by reduced nitrogen availability from tie-up in soil organic matter), deteriorated land condition and pasture dieback (Queensland Government, 2023).

The integration of legumes into grass dominated pastures can improve productivity and returns, reduce the impacts of pasture rundown and pasture dieback, and assist in improving land condition. Well adapted legumes have been shown to significantly increase pasture productivity and therefore carrying capacity; protein and digestibility and subsequently liveweight gain. The improved liveweight gains from incorporating legumes allow cattle to reach target market weights earlier, which can generate price premiums. Legumes can biologically fix nitrogen from the atmosphere which increases total pasture production by reducing the nitrogen deficiency to plant growth and increases protein levels in the plant which improves the diet quality of grazing animals. The improved nitrogen supply to the pasture has additional benefits, for example increase soil organic matter content, benefit soil fertility and health, and lead to more resilient pastures. Legumes can contribute to wider environmental benefits such as lower carbon emissions intensity and more resilient pastures reducing downstream sediment and nutrient levels. Despite the benefits from legumes, the extent of successful legume establishment is limited across the Brigalow Belt which highlights the opportunity presently available to increase the productivity and resilience of grazing businesses in the Brigalow Belt (Peck et al. 2011, Bowen et al. 2018).

Past economic analyses have shown that integrating legumes into pastures can improve farm profitability in the Brigalow Belt (Peck et al. 2011, Bowen et al. 2018). This report builds on this research by evaluating the economic implications from establishing leucaena, desmanthus/stylo or medics on paddocks in the Brigalow Belt but extends the analysis to examine several land productivity types (low, moderate and high productivity) using a range of establishment methods (lower to high cost) with resulting differences in reliability (i.e. rates of establishment failure). The analysis utilises recent research results on legume establishment (Peck et al. 2017; Peck et al. 2022) and incorporates updated costs and beef prices and additional modelling features.

The objective of this study is to compare the profitability of a range of legume systems and establishment options to help guide management recommendations and inform future investment decisions. This economic analysis is part of a broader activity to quantify the legume opportunity in Queensland as part of the Queensland Pasture Resilience Program that is being conducted in partnership between the Department of Primary Industries, Meat & Livestock Australia and the Australian Government through the MLA Donor Company.

There are four components to quantifying the legume opportunity in Qld:

1. Paddock scale economic analysis (this report).
2. Spatial analysis to improve the estimate of the area suited to key legume species.
3. Spatial survey to estimate the area established with legumes.
4. Spatial and economic analysis to quantify the impact of increased rates of legume adoption.

This report describes the paddock scale economic analysis (i.e. component 1). Companion reports will be prepared to describe the other components of the legume opportunity analysis (i.e. components 2, 3 and 4).

2 Background

2.1 Climate zone

Queensland has a diverse range of climates including arid, semi-arid, monsoonal, moderate rainfall sub-tropics, high rainfall tropical and subtropical environments. Climate has a large impact on legume suitability, reliable establishment methods, productivity and cattle growth rates. Pasture legumes are suitable to many, but not all of the climate zones of Queensland. Therefore, economic analysis needs to be regionalised to reflect the climatic influence on the production and economic returns from establishing legumes across Queensland.

The agro-climatic classification of Hutchinson *et al.* (1992) was used to regionalise Queensland for the economic analysis because it is closely aligned with legume suitability and grazing productivity across the state. The agro-climatic classes are also closely aligned with the bioregional classification of Australia (Hutchinson *et al.* 2005). The agro-climatic classes of Queensland are shown in Figure 1 with a description of classes in Table 2.

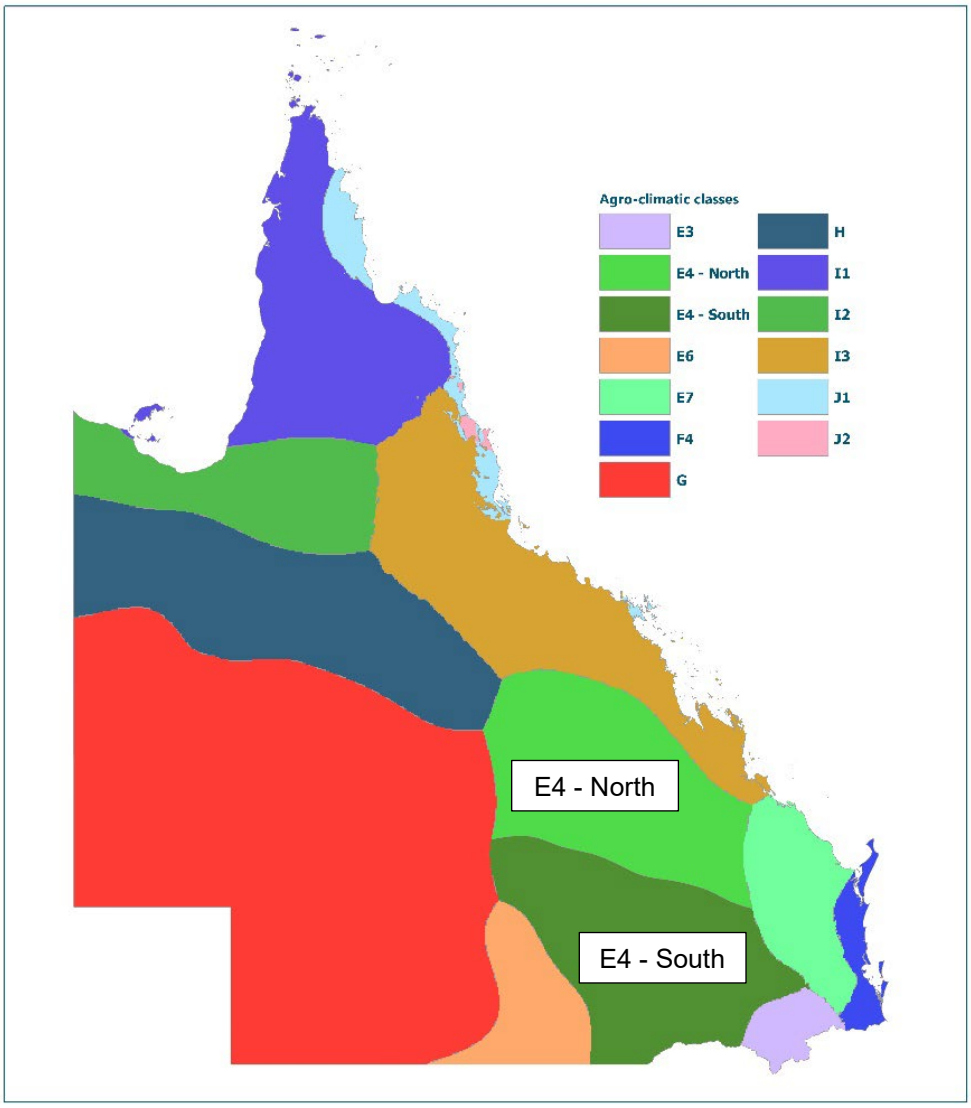


Figure 1: Map of Queensland's agro-climatic classes – modified from Hutchinson et al. (2005).

Agro-climatic class E4 has been separated into north and south based on 20 potential frost days (Bureau of Meteorology mapping).

Table 2: Description of QLD agro-climatic classes.

Class[A]	Description	% of Queensland Cattle herd[B]
E3	Most plant growth in summer, although summers are moisture limiting. Temperature limits growth in winter.	3%
E4 north	**Growth is limited by moisture rather than temperature and the winters are mild. Growth is relatively even throughout the year. This climate zone aligns with the Brigalow Belt bioregion, with <20 potential frost days per year.**	**21%**
E4 south	**As above, but with >20 potential frost days per year.**	**17%**
E6	Semi-arid climate that is too dry to support field crops. Soil moisture tends to be greatest in winter.	2%
E7	Moisture is the main limit on crop growth. Growth index lowest in spring. Southeast Queensland climate zone.	8%
F4	Warm and wet sub-tropics. High rainfall sub-tropics.	1%
G	Desert, supporting very little plant growth due to water limitation.	12%
H	Semi-arid, with some growth in the warm season but too dry for cropping. These climate zone forms a transition between the monsoonal zone (I) and the arid zone (G).	11%
I1	Strongly developed wet and dry seasons with plant growth determined by moisture availability. 5-6 month growing season.	3%
I2	Temperature and moisture are more seasonal than for I1 and the growing season is shorter (4-5 months).	5%
I3	This has cooler winters than I1 and I2 with a growing season lasting at least six months.	16%
J1	Wet-tropics. Moisture and temperature regime supports growth for 8-9 months of the year, with a 3 -4 month dry season.	1%
J2	As for J1 but with a shorter dry season.	0.05%
	Total Queensland beef herd	10.6M

[A] *Classes derived and modified from Hutchinson et al. (1992); Hutchinson et al. (2005)*

[B] *Australian Bureau of Statistics (2022).*

The agro-climatic zone covered by this report is E4, which is closely aligned with the Brigalow Belt bioregion (Thackway and Cresswell 1995; Hutchinson *et al.* 2005). The E4 climate zone has been split into north and south based on 20 potential frost days per year (Bureau of Meteorology mapping) due to the adaptation of shrubby stylo and annual medics which are important legume species used in the Brigalow belt. Shrubby stylo has been a useful pasture legume across E4 north, but has not been persistent in southern Queensland. Annual medics are persistent and provide useful forage during winter in E4 south but are not persistent or productive in E4 north.

The total areas of E4 North and South are around 16.1 million hectares (ha) each with the division between the two stretching approximately from Tambo through to Taroom. Both E4 north and south have a wide range of soil types with differing productivity. This report therefore evaluates the

economic implications from establishing legumes using different methods across various land types in the Brigalow belt climate zone.

The Brigalow Belt is characterized by a mosaic of vegetation types, with large areas associated with the Brigalow tree (*Acacia harpophylla*) in forests and woodlands. Most of the Brigalow associated vegetation communities were cleared of native vegetation to develop agricultural enterprises for grain, cattle and sheep production (Department of Environment and Science, 2018). The region is now one of Australia's most productive grazing areas, supporting extensive beef cattle operations. Grazing businesses in the Brigalow Belt typically include large-scale properties, often exceeding 5,000 hectares (and larger in the lower rainfall areas to the west), with varying soil types including black clay soils, red-brown earths, and alluvial plains. Stocking rates vary significantly depending on soil fertility, pasture quality, and rainfall, with an average of 1 head per 8 hectares over the entire zone (Australian Bureau of Statistics, 2022), and this report examined stocking rates from 1.1 Ha/Adult Equivalent (AE) to 11 Ha/AE.

The target markets for beef producers in the Brigalow Belt include domestic and export markets including Japan, Korea, and the United States. However, many producers initially aim to grow their cattle up to around 450kg liveweight on grass before selling them to feedlotters who will grow out to slaughter weights (often termed “feeder steers”). The economic analysis bases the target steer sale weights and pricing assumptions for all strategies on a producer purchasing weaner steers and supplying the feeder steer market.

2.2 Benefits of establishing legumes

The subtropical climate is characterised by summer-dominant rainfall averaging between 500 and 800 mm annually. Pasture production in this climate zone is constrained by nitrogen availability and beef production is constrained by protein deficits. A range of management options are available to address these constraints, however previous studies have concluded that establishing legumes into grass dominant pastures is the best long-term option for improving productivity (Peck *et al.* 2011).

The establishment of legumes in grazing systems within the Brigalow Belt offers numerous agronomic, animal production and environmental benefits. Nitrogen fixation from legumes improves soil health by increasing organic matter content and soil fertility, leading to more resilient pasture systems that can better withstand climatic variability. Rundown pastures that have locked-up nitrogen can benefit from the improved nitrogen availability (Peck et al. 2017). The integration of legumes, such as Leucaena (*Leucaena leucocephala*), *Desmanthus spp*. and *Stylosanthes spp. into grass pasture systems*, have been shown to significantly increase pasture productivity and carrying capacity. For instance, research by Peck et al. (2017) demonstrated that incorporating legumes into pastures can improve biomass production by up to 50-100%, enhance pasture utilisation, and increase digestibility, leading to improved liveweight gains in cattle. Pasture legumes maintain feed quality for longer into the dry season, providing an additional protein food source, allowing cattle to reach a target market weight earlier than cattle grazed on unimproved pastures, and this can result in a price premium.

While more productive than much of Queensland’s grazing areas, the Brigalow Belt's soils are often low in phosphorus (P), which can also limit pasture productivity and animal performance (Peck *et al.* 2015; Thornton and Shrestha 2020). Dry season protein supplementation is commonly used in the region; however, P supplementation or fertiliser is not commonly used.

2.3 Extent of legume establishment in the Brigalow Belt

Pasture legumes have been deliberately sown as well as naturalising through natural seed dispersal (e.g. via grazing animals) and un-intentional spread (e.g. slashing equipment spreading seed along roadsides). The extent of legume pasture adoption across the Brigalow Belt is difficult to estimate due to limited industry data on successful establishment or natural spread.

Leucaena has been one of the popular legumes in the Brigalow Belt due to its high biomass production and livestock production when sown on suitable soils (i.e. high fertility and high water holding capacity), but it has been successfully established on only a small percentage of the land area where it is considered suitable. Beutel et al. (2018) used high resolution imagery to estimate that there was 123,500 hectares of leucaena in Queensland, mostly in the Brigalow Belt, which indicates that previous estimates overstated the area established to leucaena.

The areas of other introduced legumes are difficult to estimate over large areas because they cannot be reliably identified from satellite imagery, due to lower growth habits which blends in with the grass. Stylos are by far the most widely sown group of legumes in Queensland (Walker et al. 2022). In the last decade, desmanthus has become the most popular legume for new plantings in the Brigalow Belt (Peck *et al.* 2022).

The area of land in Queensland that has legumes successfully established is a key knowledge gap. This gap in knowledge is being addressed in a project activity linked to this bioeconomic modelling, through conducting a georeferenced roadside survey to quantify the existing land area already established with legumes.

2.4 Methods of legume establishment

Despite impressive results in trials and some commercial plantings, graziers often report poor performance from pasture legumes in the Brigalow Belt. Focus group discussions with grazier groups across southern and central Queensland identified poor establishment as the most common reason for failure of legume adoption in the Brigalow Belt bioregion; however, a contributing factor is that graziers routinely use, and have been recommended to use low cost, low reliability establishment techniques (Peck *et al.* 2011).

The most commonly used and recommended legume establishment techniques are to broadcast seed into existing grass pasture with either no or minimal (e.g. a fire) preparation; or one pass cultivation and spreading of seed (e.g. with a chisel plough or deep ripper) (Peck *et al.* 2011). These establishment techniques result in failure in most years in the Brigalow Belt and failed in all six legume establishment trials initiated as part of the “Improving productivity of rundown sown grass pastures project” (B.NBP. 0639) (3 districts, 2 soil types, with different districts being sown in 2 different years) (Peck *et al.* 2017). These establishment techniques are more successful in other climate zones, for example stylo establishment in native pastures in the seasonally dry tropics (i.e. monsoonal areas) has been considered adequate with little or no disturbance to the existing pasture (e.g. heavy grazing, fire) or one-pass cultivation and seeding operations (e.g. band seeders, crocodiles, blade ploughs, discs, chisel ploughs) (Partridge *et al.* 1996).

Fallowing to store soil moisture and control competition from the existing grass pasture dramatically improves establishment reliability and early growth of legumes (i.e. five years post planting). Greater control of competition through the use of post-emergence herbicides can improve seedling survival and therefore establishment success (Peck *et al.* 2017).

This analysis improves on past economic analyses (Sanderson *et al.* 2013, Bowen *et al.* 2018, Bowen & Chudleigh 2020) by accounting for the reliability of legume establishment from using different methods. Cheaper establishment methods that result in higher failure rates (when averaged over multiple years) are accounted for by higher failure rates and longer time periods to achieve animal production improvements. To account for establishment failure we have used long term average results - it is analogous to using the establishment technique each year over the long term where 15 successful years in 100 is described as an 85% failure rate, rather than the same result every year of only 15% of the land area being successfully established with legumes. Legume establishment methods that involve fallow improve reliability through storing soil moisture (thereby reducing reliance on follow up rainfall) and reducing competition from the existing grass pasture and weeds; but they also increase costs.

2.5 Economic analyses and adoption of pasture legumes

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures in the Brigalow Belt bioregion (Peck et al. 2011; Peck et al. 2022). Some examples of the measured benefits of legumes include:

- On-farm research studies in central Queensland (Wandoan to Capella) reported a 60–160% increase in liveweight gain per hectare and a doubling of gross margins with legumes (leucaena or butterfly pea) compared to grass only pastures (Bowen et al. 2015)
- On-farm research sites in buffel grass pastures recorded a 40-100% increase in annual pasture production (dry matter per hectare) with legumes (Caatinga stylo near Moura; desmanthus near Wandoan) compared to grass only pastures approximately 15 years after establishment on low P soils (Peck *et al.* 2013). These grass-legume pastures also responded strongly to P fertiliser application with an additional 50% increase in kilograms of dry matter per hectare over the growing season.
- 10–30% increases in pasture production were reported in native pastures augmented with legumes (McIvor and Gardener 1995). Establishing stylos in native pastures increased live weight by 30–60kg per head per year (Hall et al. 2004).

Past economic analyses have consistently shown that the establishment of legumes in Brigalow Belt grazing systems can offer significant financial returns, despite the initial establishment costs (Sanderson 2013). A study by Bowen & Chudleigh (2019) highlighted that the introduction of legumes like leucaena can increase gross margins by up to 121% per hectare, primarily through enhanced cattle productivity and reduced feed costs. However, these benefits are contingent on successful establishment and ongoing management, including appropriate grazing pressure and fertilisation (Peck et al. 2011). These analyses indicate that the initial costs of legume establishment, including seed purchase, soil preparation, and planting, are outweighed by the long-term benefits. Improved cattle performance, reduced feed costs, and enhanced pasture sustainability contribute to positive economic returns. Additionally, the potential for carbon credits from reduced emissions and improved soil carbon sequestration further enhances the economic viability of legumes.

Nevertheless, the adoption of legume pastures in the Brigalow Belt remains very low. For example, leucaena is the most widely grown legume pasture species but is currently only being grown on <2% of the suitable area in Queensland (Beutel *et al.* 2018). These low adoption rates, together with the productivity and profitability improvements demonstrated in trials, economic analyses and on

commercial pastures highlight the opportunity available to increase the adoption of legume pastures (FutureBeef, 2018).

3 Methodology

This economic analysis was undertaken by DPI staff with specialist skills in pasture agronomy, economics and beef husbandry. The objective was to evaluate the profitability implications of establishing legumes on a theoretical 500-ha production paddock across a range of land types and establishment scenarios. The beef production business model used was to buy in weaner steers weighing 200 kg in June each year, grow them out on the pasture and sell once they hit the target paddock weight for feedlot entry of 495kg. A steer growing enterprise was chosen over a breeding operation as it was simpler to model and trial production data was available that covered most aspects of the analysis.

A discounted cashflow analysis was undertaken for multiple land productivity types. This compares the net present value of 30 years of cashflows from a base scenario of beef produced on a grass only system against the cashflows from a scenario that involves transitioning to one based on beef produced from a pasture that has legumes (and in some cases new grasses) planted into it. Pasture and animal production assumptions were based on average production, not a dynamic model that considered seasonal variability. The model therefore is about interpreting the “average” results from establishing legumes the same way over 100 year period, rather than specific seasonal conditions or years.

The evaluation was completed by defining scenarios that best represent the legume establishment options currently available to producers along with the underlying parameters needed for the analysis. Key parameters included the process and costs associated with pasture establishment, additional ongoing expenses and impacts on pasture and cattle production. These parameters are outlined in the following sections along with the parameters used for the investment analysis.

3.1 Baseline pasture scenarios

The baseline pasture scenarios describe the four land productivity groupings used in the study (see Table 3). The base scenario for the low productivity, non-arable land scenarios represent native grass pastures, while the base scenarios for the other land types represent old buffel pastures. These baseline scenarios were designed to cover the range of land types and productivity levels that occur across the Brigalow belt.

Each land productivity type was assumed to have a different weight gain potential for growing steers, as represented by a long-term average, measured in kg/head/year, based off research trials and commercial results. In all scenarios, mortality was assumed to be constant at 1.25% annually.

The three productivity zones used were based on pasture production levels, which were in turn determined by soil fertility and water holding capacity of the soil. Plant available P in the soil is a key indicator of soil fertility. It was assumed that in all cases the Phosphorus Buffering Index (PBI) was low (50-100), and that the high, moderate and low productivity land types had Colwell-P levels of 30, 10 and 5 mg P/kg in the top 10 cm, respectively.

Table 3: Description of baseline pastures.

Land productivity	DM produced (kg/ha/yr)	Arable land	Colwell P (mg P/kg)	Water holding capacity	Dominant grass species	Liveweight gain (kg/hd/yr)
High	5,000	Yes	30	High	Sown buffel	160
Moderate	3,750	Yes	10	Moderate	Sown buffel	145
Low	2,500	Yes	5	Low	Sown buffel	130
Low non-arable	2,000	No	5	Low	Native grass	115

3.2 Legume establishment scenarios

The legume establishment scenarios were a combination of land productivity level (i.e. the baseline pasture), legume species sown and establishment method. A range of legume establishment scenarios were chosen to best represent reliable options currently available to producers in the Brigalow Belt region. The scenarios and assumptions were based on commercial experience (from graziers involved in previous RD&E projects) and establishment field trial results (Peck et al. 2011; Peck et al. 2017; Peck et al. 2022). Each legume type, establishment method and fallow length was chosen to suit four land productivity types – high, moderate, low and non-arable.

The key attributes of each legume scenario include the type of legume planted, establishment method and expected rate of establishment failure along with an abbreviation for each scenario, which is used to identify each one throughout the report, are outlined in Table 4 and Appendix 1 for easy access to detailed pasture assumptions. Information relating to legume species, establishment methods and P fertiliser is outlined in the following subsections (specific methods for legume establishment, failure rates and time to full production time are covered in Section 3.2.2., and P fertiliser in 3.2.4., while establishment costs are outlined in section 3.5 (Establishment costs)).

The following abbreviations were used to identify the different scenarios:

- *Hi, Mid, Lo* and *LoNA* refer to land productivity classes: high, moderate, low or low non-arable.
- *Leucaena, Des/Stylo* and *Medic* refer to the legume species planted: leucaena, desmanthus and/or stylo (depending on soil / climate) or medic.
- *Hi$, Lo$* and *Strip* refer to the establishment method: high-cost whole-paddock establishment, low-cost whole-paddock establishment using a single pass, or strip planting.
- *LngFal, MidFal* and *NoFal* refer to fallow period before planting: long fallow (9 months), medium fallow (6 month) or no fallow (0 months). These abbreviations were only used where fallow period was shorter than assumed best practice, which is defined as 9 months for summer-planted crops, and 4 months for autumn-planted medics, or in the case of *LngFal,* where there was potential confusion with a similar scenario.
- *+P* indicates that additional P fertiliser was applied.

Where a scenario code consists only of the first two abbreviations, it indicates that the results are consistent across all establishment styles and fallow durations within that broader land and species category.

Table 4: Scenario descriptions.

Land productivity	Legume types[A]	Establishment method	Fallow period (months)	Cost[B]	Failure rate	P applied	Abbreviation
High	Leucaena	Strips-10m centres	9	High	10%	No	Hi Leucaena Strip
	Des/Stylo	Whole paddock	None	Low	85%	No	Hi Des/Stylo Lo$ NoFal
	Des/Stylo	Whole paddock	6	High	20%	No	Hi Des/Stylo Hi$ MidFal
	Des/Stylo	Whole paddock	9	High	10%	No	Hi Des/Stylo Hi$ LngFal
	Des/Stylo	Strips-15m centres	9	Mid	5%	No	Hi Des/Stylo Strip
	Medics	Whole paddock	None	Low	75%	No	Hi Medic Lo$ NoFal
	Medics	Strips-15m centres	4	High	5%	No	Hi Medic Strip
Moderate	Leucaena	Strips-10m centres	9	High	10%	No	Mid Leucaena
	Leucaena	Strips-10m centres	9	High	10%	Yes	Mid Leucaena +P
	Des/Stylo	Whole paddock	None	Low	85%	No	Mid Des/Stylo Lo$ NoFal
	Des/Stylo	Whole paddock	6	High	20%	No	Mid Des/Stylo Hi$ MidFal
	Des/Stylo	Whole paddock	9	High	10%	No	Mid Des/Stylo Hi$ LngFal
	Des/Stylo	Whole paddock	9	High	10%	Yes	Mid Des/Stylo Hi$ LngFal +P
	Des/Stylo	Strips-15m centres	9	Mid	5%	No	Mid Des/Stylo Strip
	Des/Stylo	Strips-15m centres	9	Mid	5%	Yes	Mid Des/Stylo Strip +P
	Medics	Whole paddock	None	Low	75%	No	Mid Medic Lo$ NoFal
	Medics	Whole paddock	None	Low	75%	Yes	Mid Medic Lo$ NoFal +P
	Medics	Strips-15m centres	4	High	5%	No	Mid Medic Strip
	Medics	Strips-15m centres	4	High	5%	Yes	Mid Medic Strip +P
Low arable	Des/Stylo	Whole paddock	None	Low	85%	No	Low Des/Stylo Lo$ NoFal
	Des/Stylo	Whole paddock	6	High	20%	No	Low Des/Stylo Hi$ MidFal
	Des/Stylo	Whole paddock	6	High	20%	Yes	Low Des/Stylo Hi$ MidFal +P
	Des/Stylo	Strips-15m centres	9	Mid	5%	No	Low Des/Stylo Strip
	Des/Stylo	Strips-15m centres	9	Mid	5%	Yes	Low Des/Stylo Strip +P
Non-arable	Stylo	Whole paddock	None	Low	85%	No	LoNA Stylo Lo$ NoFal
	Stylo	Strips-20m centres	6	Low	20%	No	LoNA Stylo Strip MidFal

[A] *"Des/Stylo" refers to desmanthus or stylo, while "Medics" denote annual medic from multiple species (e.g. Barrel, Burr and Button).*

[B] *Cost relates to the amount of money spent on establishing legumes including land preparation, weed control, planting seed and any foregone income from reduced stocking during a fallow period.*

3.2.1 Legume species

The legume establishment scenarios used species that are suitable for long-term pastures because most cattle in the Brigalow Belt graze permanent pastures. Also, previous analysis showed that short-

term fodder crops that are sown annually provide poor returns over long investment periods (Bowen and Chudleigh 2018). The three legume types[1] included in the analysis were:

- Leucaena (*Leucaena leucocephala* cv. 'Wondergraze')
- Desmanthus or stylo (abbreviated as Des/Stylo) refers to planting either desmanthus (*Desmanthus spp*) or stylos (*Stylosanthes spp*) depending on the species best suited to the soil type. Desmanthus is suited to clay soils in the Brigalow belt. Caatinga, shrubby and Caribbean stylo are all suited to parts of the Brigalow Belt.
- Medic (*Medicago spp*). Medic refers to annual medics from multiple species including barrel, burr and button medics. Medics are temperate, winter growing annual legumes which are only suited to southern parts of the Brigalow belt bioregion.

Leucaena is suited to being planted on higher productivity land types that have fertile soils with high water holding capacity. Consequently, leucaena was considered suited to the high and moderate productivity land types but unsuitable for low productivity land types. Leucaena is commonly planted into cultivated strips when established into an existing pasture in good land condition where graziers prefer to keep the existing grass species rather than replanting with a different grass with a risk of poor establishment of the grass.

Shrubby legumes such as stylos and desmanthus are considered suitable for a wide range of land types, therefore they were examined across all land productivity groupings. Given their versatility, desmanthus and stylo were modelled using various establishment methods and fallow lengths to assess the sensitivity of their strengths (e.g. low cost) and weaknesses (e.g. high failure rate) within the economic analysis.

The costings for the analysis were based on the seed price of desmanthus for the high, medium and low productivity land types and a mix of Caatinga, shrubby and Caribbean stylo for the non-arable land type (Table 10). In practice the choice of legume would be based on soil type because the different legumes are suited to different soil types. Desmanthus is suited to clay soils, while Caatinga stylo is suited to a wide range of soils from clays to sandy loams. Shrubby and Caribbean are only suited to loamy and sandy soils; therefore, they were only used in the analysis for the non-arable land type.

Medics were also included in the analysis given their applicability to southern areas of the Brigalow Belt region. Medics can be productive in southern inland Queensland (Clarkson *et al.* 1987), however caution should be applied to the results presented for medic due to less research data being available from grazing experiments to confirm animal production parameters for the analysis.

3.2.2 Legume establishment methods

Table 5 outlines assumptions for each legume establishment scenario including the fallow period prior to planting, the operations involved in preparing the paddock and planting legumes, the establishment failure rates and the amount of time needed to reach full production capacity after planting.

Fallow periods, where existing pasture growth is terminated via tillage and/or herbicides, help to increase soil moisture and reduce the seed populations of weed or pasture species competing for valuable inputs such as water and nutrients. While medium (6 months) and long fallows (9 months) require reduced stocking rates before planting, they offer an opportunity to reduce the risk of

[1] For detailed information, refer to: https://tropicalforages.info/text/intro/index.html.

establishment failure. Establishment costs are dependent on the amount of tillage, weed control and fertiliser applied along with the proportion of the paddock being established and the type, quantity and quality of seed and machinery used for planting (see section 3.5 for establishment costs).

The type and amount of cultivation and weed control, planting operation and fallow length used for each legume establishment scenario were informed by the Rundown project (Peck *et al.* 2017). Legumes established in strips were planted inside cultivated strips 5m wide, with varying amounts of uncultivated area between the cultivated strips. Leucaena was planted in two rows 1m apart, with 10m between strip centres, while desmanthus, stylo or 'medics' were planted across the width of the cultivated strip, with 15m centres on arable land types and 20m centres on non-arable land.

Low-cost establishment denotes cultivating the whole paddock in one pass while planting. Higher cost methods place more emphasis on good land preparation, fallow period and planting techniques along with effective weed control to improve the likelihood of successful establishment.

Legume establishment failure rates and the amount of time needed to reach full production capacity after planting were based on field trial results and commercial experience (Peck et al. 2017; Peck et al. 2022). They are influenced by legume type, fallow period, land preparation, planting technique, weed control, and nutrient accessibility. Fallowing kills the existing pasture, reduces the quantity of seed in the soil and stores soil-moisture. This results in more moisture being available at planting and more of the available soil moisture and following rainfall being used for growing legume (as opposed to weeds or grass). Fallowing therefore dramatically improves legume establishment in the Brigalow belt climate (Peck et al. 2017), and legume establishment scenarios that used medium or long fallows dramatically reduced failure rates. Scenarios without fallows had higher failure rates due to not storing soil moisture and having greater competition from the existing pasture.

Herbicide-based weed control[2] was used to improve legume establishment in existing grass pastures. Prior to sowing, a fallow period combined with a broad-spectrum knockdown herbicide such as glyphosate was used to reduce competition from existing grasses and broadleaf weeds, creating a cleaner seedbed and improving soil moisture availability for establishing legumes. In addition, for longer fallow periods in strip plantings, a broadleaf herbicide (2,4-D) was also used to control a broader range of weeds.

Following sowing, selective post-planting herbicides can be used to protect establishing legumes from weed competition. Products containing imazethapyr (for example, Spinnaker®) were assumed to be applied in the strip plantings (where registered and appropriate for the target legume species) to suppress susceptible grass and broadleaf weeds while allowing the legume to establish. In addition, a post-emergent grass herbicide containing fluazifop-P (e.g. Fusilade) was applied to the cultivated strips of leucaena for longer term grass control. As whole paddock plantings contained grasses and legumes, no post planting herbicides were applied in these scenarios.

An integrated approach combining fallow management, pre-sowing weed control and selective post-emergent herbicides was followed to minimise competition during the critical establishment phase and maximise the likelihood of successful legume recruitment into grass pastures.

Several different establishment strategies were compared for desmanthus/stylo on arable land types:

[2] Herbicide selection and timing should be based on the legume species, weed spectrum, pasture composition and product label directions.

- A low-cost strategy cultivating the whole paddock in one pass while planting, which incurs a high expected failure rate.
- A high-cost strategy that implements a medium or long fallow with effective land preparation, weed control and planting across the whole paddock, which has a low failure rate and quickly reaches full production.
- A cost-effective strategy that involves planting in strips across one-third of the area (implementing a long fallow, weed control and good land preparation and planting), which has a low failure rate but takes time to spread across the whole paddock so reaches full production relatively slowly.

Planting leucaena in strips on productive land types after a long fallow and good land preparation and weed control has a low expected failure rate and reaches full production capacity relatively quickly. Two strategies were examined for medics including a low-cost strategy, or a moderate cost strategy of planting in strips across one-third of the area. Similarly to desmanthus/stylo, the low-cost strategy incurs a high expected failure rate and slowly reaches full production, while planting in strips has low failure rates but takes time to disperse medics across the full area and reach full production.

Options for the non-arable, native grass scenarios were more limited due to challenges with land accessibility and soil properties. Consequently, one option examined burning the paddock and then spreading stylo seed from a plane, which incurs a high expected failure rate, due to unreliable follow-up rainfall and competition from the existing pasture. The second option examines preparing, fallowing and planting strips of stylo seed across a quarter of the area (we have assumed an area of arable land within the generally “non-arable” landscape), which has a lower expected failure rate, as the seed is sown into a prepared seedbed with stored soil moisture and reduced competition from the existing pasture.

Table 5: Fallowing, paddock preparation & planting legumes, failure rates & time to full production.

Land product-ivity	Legume	Establish-ment method	Fallow period	Land prep, weed control & planting operations	Establish-ment failure (%)	Time to full production post-planting
High & Mid	Leucaena	5m strips, 10m centres	9 months	4 cultivations, 5 weed sprays, leucaena planter	10%	1.5 years
High, Mid & Low	Des/Stylo	Low-cost, whole paddock	None	1 cultivation/drum seed	85%	2.5 years
		High-cost, whole paddock	6 or 9 months	3 or 5 cultivations, 1 or 2 weed sprays, airseeder	10-20%	1 years
		5m strips, 15m centres	9 months	4 cultivations, 3 weed sprays, airseeder	5%	2.5 years
High & Mid	Medic	Low-cost, whole paddock	None	Zero-till planter	75%	3 years
		5m strips, 15m centres	4 months	4 cultivations, 3 weed sprays, airseeder	5%	3 years
Non-arable	Stylo	Low-cost, whole paddock	None	Burn pasture, apply seed via plane	85%	20 years
		5m strips, 20m centres	6 months	2 weed sprays, 1 cultivation/ drum seed	20%	14 years

3.2.3 Maintaining or re-planting grass

Table 6 outlines the proportions of grass areas maintained and planted for each legume scenario. These assumptions were informed by Report 4 in the Rundown project series (Peck *et al.* 2017). The baseline (grass-only) scenarios on the high, medium and low productivity land types (arable land) were all assumed to have buffel grass pastures. Different legume establishment scenarios have different impacts on the amount of grass plants that are retained and how much of the grass seed that would remain viable in the soil.

Establishing legumes in strips did not need grass seed sown because grass would re-establish from seed from the remaining grass strip. Legume scenarios using the low-cost establishment method (one-pass cultivation and seeding) did not require grass seed sown because there would be minimal impact on the soil seed bank and some grass plants would remain. For scenarios with the high-cost establishment method, there would be some recruitment from the soil seed bank (particularly the shorter fallow scenarios); however, buffel grass seed was also assumed to be sown at 4.5 kg/ha as back-up in case the seed bank reduced too much.

Table 6: Grass areas maintained and planted (% of paddock).

Land productivity	Legume type	Establishment method	Fallow period	Grass area maintained (%)	Grass area planted (%)
High & Mid	Leucaena	Strips	9 months	50%	0%
High, Mid & Low	Des/Stylo/Medic	Low-cost	None	0-100%	0%
High, Mid & Low	Des/Stylo/Medic	High-cost	6/9 months	0%	100%
High, Mid & Low	Des/Stylo/Medic	Strips	9 months	67%	0%
Non-arable	Stylo	Low-cost	None	100%	0%
Non-arable	Stylo	Strips	6 months	88%	0%

3.2.4 Phosphorus (P) fertiliser

Plant available P in the soil is a key indicator of soil fertility and a major constraint to legume productivity. The high productivity land type has assumed Colwell-P levels of 30 and has no need for additional P fertiliser to keep legumes producing at their optimal yield potential. The moderate productivity land type was assumed to have a Colwell-P level of 10 mg P/kg, raised to a target of 20 mg P/kg for leucaena and medic plantings using added P fertiliser, and 15 mg P/kg for desmanthus and stylo. The low productivity zones were assumed to have a range of limiting factors, including a Colwell-P level of 5 mg P/kg, which was raised to a target of 10 mg P/kg for desmanthus/stylo through addition of P fertiliser.

Based on the Five Easy Steps guide, approximately 2.7 kg P/ha is required to raise the level of Colwell-P by one unit (Simpson et al. 2022). This analysis assumes that di-ammonium phosphate (DAP) fertiliser was applied to meet P requirements. Given DAP contains approximately 20% P, the fertiliser rate requirement in kg/ha was calculated by dividing the quantity (kg) of P required by 20% (e.g. 1 kg P requires 5 kg DAP to be applied).

Table 7 outlines the assumptions used for the scenarios that have P fertiliser applied to improve legume productivity. For leucaena on the moderate productivity land type, Colwell P needs to be raised by 10 mg/kg, which is the difference between the amount of available P in the soil (baseline = 10 mg/kg) and the critical Colwell P value for leucaena. Therefore, approximately 27 kg/ha of P is required (10 x 2.7), which can be achieved by applying DAP fertiliser at 135 kg/ha. The same amount of DAP is needed for medics on the moderate productivity land type, while desmanthus or stylo needs half the amount (67.5 kg/ha DAP) on both the land types.

The amount of maintenance P fertiliser needed to maintain adequate P levels in the soil was calculated based on requiring 7 kg P/AE/ha/year, which was based off recommendations in the Five Easy Steps decision support tool[3] (Simpson *et al.* 2009) assuming a medium soil loss factor, low animal loss factor and 600mm of rain. DAP fertiliser was assumed to be applied using a fertiliser spreader in five year intervals. Despite some legumes being planted in strips, maintenance fertiliser was assumed to be spread across the whole paddock, as the legumes would spread into the grass strips over time.

As mentioned above, the amount of DAP needed to maintain Colwell P to the critical level is dependent on the number of cattle being stocked. The stocking rate for the leucaena scenario on moderate productivity land is 1.2 AE/ha so 8.4 kg P/ha is required annually, which can be achieved by

[3] 0.83 kg P/DSE/ha/year multiplied by 8.4 to adjust to an AE.

applying DAP fertiliser at 209 kg/ha every five years. In comparison, desmanthus/stylo and medics require 177 and 173 kg/ha of DAP every five years, while desmanthus/stylo on low productivity land needs 108 kg/ha.

Table 7: Phosphorus (P) fertiliser assumptions for +P scenarios.

Land product-ivity	Legume	Colwell P (mg/kg): Critical P - Baseline P = *Required*	Planting fertiliser		Maintenance fertiliser		
			P required (kg P/ha)	DAP applied (kg)	AE/ ha	P required annually (kg P/ha)	DAP applied (kg/5 yrs)
Mid	Leucaena	20 - 10 = ***10***	27	135	1.2	8.4	209
Mid	Des/Stylo	15 - 10 = ***5***	13.5	67.5	1.01	7.1	177
Mid	Medic	20 - 10 = ***10***	27	135	0.99	6.9	173
Low	Des/Stylo	10 - 5 = ***5***	13.5	67.5	0.62	4.3	108

3.3 Investment analysis

Investment analyses were undertaken by completing discounted cashflow analyses to determine key measures of investment performance including net present value (NPV), internal rate of return (IRR), payback period and peak deficit. The NPV is the sum of all discounted cash flows over an investment period, which in this case was assumed to be 30 years. If positive, the investment is considered acceptable as it provides a return on investment greater than the assumed cost of capital (Keat *et al.* 2013). The IRR is the expected annual rate of return over the investment period that results in an NPV of zero. The payback period is the year that the cumulative discounted cash flow becomes positive (breaks even), which is relevant when future cash flows are uncertain, and is measured from the commencement of year 1, not from first or final planting. Instead of using discounted cash flows, the peak deficit uses cumulative future cash flows to identify the peak cash flow deficit that the investor will need to sustain over the investment period. Awareness of this measure is crucial to ensure competing future cash flow demands can be met, and the business remains viable.

Each discounted cashflow analysis was completed by calculating the marginal differences in cash flow between the base scenarios and the legume establishment scenarios over the investment period and discounting them to present value (today's dollars). Marginal differences in cash flow were calculated by subtracting the gross margins of the base scenario from the legume establishment scenarios along with any capital expenditures (establishment costs). All scenarios were assumed to have the same fixed costs. A discount rate of 5% and an investment period of 30 years was used for all the analyses. All remaining cattle were assumed to be sold at the end of the 30-year period to account for the different herd sizes.

Gross margins were calculated by subtracting variable costs from gross revenue (cattle sales). Gross revenues were calculated from the numbers of cattle sold and their sale weights (see section 4.1) along with their corresponding cattle prices. Variable costs include weaner steer purchase costs and transport, husbandry costs, selling costs and additional expenses to maintain legumes (see section 3.5). Cattle price and variable cost parameters are presented in the following subsections.

3.3.1 Cattle prices

The analysis assumed the producer was targeting the feed-on market via a 495 kg steer turnoff weight in the paddock (sale weight of 470 kg after 5% weight loss in transit to market). Cattle prices vary over

time, according to weight, age, body condition, availability, market and other factors. To best reflect the potential relative differences, cattle prices for the various weight bands for Roma and Gracemere CQLX saleyards were extracted from the Meat & Livestock Australia (MLA) prices and markets statistics database (2024). These were chosen partly due to their central position within the Brigalow Belt, but also as they have the highest volume of auction cattle sales in Queensland which means the relative pricing between different categories is less likely to be distorted by low volume outliers.

Prices were averaged over a 10-year period from July 2014 (Roma) and October 2014 (Gracemere's first MLA grown steer records) to June 2024 and converted into 2024 prices by adjusting via the relative quarterly Australian Consumer Price Index (CPI) figure. The respective weight categories were chosen from the MLA database, and included the 200kg or less band for the purchased weaners, an average of the 201kg to 280kg and 281kg to 330kg bands for the lighter steers sold in the transition phase, the 331kg to 400kg band for the heavier transition steers, and the 400+kg band for the steers that weighed over 400kg (the bulk of the feed-on steers), as shown in Table 8. In addition, seasonal price variability was investigated by dividing the prices into the 4 quarters (Q) of the year (January to March, April to June, etc.). The weaner steers were assumed to be bought in June which coincides with good availability, and the Q2 price was used for this ($4.06/kg).

For growing steers, one of the key benefits of legumes is the ability for stock to keep growing when those fed on grass-only pastures tend to struggle due to reduced feed quality, palatability and availability. The outcome is the potential for sales at a time of year when those other cattle do not yet have sufficient weight or body condition, and at a younger age, which can result in a double premium. Firstly, most grass fattened cattle put on weight over summer and autumn with growth slowing over the dry season, so increased quantities of cattle are sold between April and September as this growth slows. Consequently, when prices were analysed over the 4 quarters of the year, it was found that there was a premium for those cattle sold in Q1 and Q4, which is when most of the legume fattened cattle attained the target weight. Secondly, there is a premium paid for cattle reaching the target weight at an earlier age. MLA records this by differentiating the prices of younger 'yearling' steers (generally younger than 2-tooth) in the 400-500kg band, while older 'grown' steers are recorded in the 400+kg band.

The inflation adjusted 10-year average price for the grown steers (400+) sold in the middle of the year (Q2 and Q3) was $3.46/kg, while the yearling steers (400-500kg) sold in Q1 and Q4 averaged $3.92/kg. This is a premium of $0.46/kg, but to be conservative, half that figure was used as the premium for these faster growing legume-fed steers, as in Table 8 below.

Table 8: Cattle prices (steers) in $/kg (liveweight), inflation adjusted and averaged over 10 years.

Weight band	200kg or less	201-330kg	331-400kg	400+kg	Premium
Price ($/kg liveweight)	$4.05	$3.91	$3.90	$3.46	$0.23

3.3.2 Variable costs

Weaner steer purchases were made in June of each year, and costs were calculated based on the numbers of weaners, a purchase weight of 200 kg/head and a price of $4.05/kg. Transport costs assumed a travel distance of 350km, 40 weaner steers transported per deck and charges of $2.30/deck/km. Husbandry costs were calculated assuming induction costs of $2/head, buffalo fly and Cydectin Platinum treatment costs of $11/head and botulism and NLIS tag replacement costs of $1.20/head (one-off). Selling costs were calculated based on 4% sales commission and $22/head for

levies and yard fees. Transport costs for sale steers also assumed a travel distance of 350 km and charges of $2.30/deck/km but assumed a deck could transport 24-28 steers weighing 400-500 kg (paddock weight). Feed supplementation with urea, phosphate and/or other minerals has been assumed not to occur and therefore has been excluded from the analysis.

To calculate establishment costs and additional ongoing annual costs, input prices were sourced from local suppliers and machinery operations were costed based on estimated contractor rates considering machinery purchase costs, work rates and fuel use. Machinery cost estimates included labour ($35/hour), diesel ($1.20/litre excluding GST and rebate), repairs and maintenance, depreciation, interest, insurance, storage costs, travel and profit margin. Table 9 outlines the machinery costs used for the analysis, while Table 10 and Table 11 shows the input costs.

Table 9: Machinery costs – contractor rates ($/ha)

Offset discing	Tyne cultivating	Fertiliser spreading	Planter / Air seeder	Boom spraying	Pruning (leucaena)	No till seeder
$82.96	$51.28	$20.30	$39.53	$22.59	$100	$39.96

Table 10: Seed costs ($/kg).

Species	Leucaena [A]	Desman-thus[A]	Stylo[A]			Medic[B]	Buffel grass[B]
Variety examples	Wonder-graze	Progardes	Primar/ Unica	Seca/ Siran	Verano/ Amiga	Annual	Gayndah
Type	Improved	Blend of species	Caatinga	Shrubby	Caribbean	Multiple[C]	Grass
Price ($/kg)	$60	$33.50	$35	$20	$20	$8	$15
Proportion	100%	100%	40%	40%	20%	100%	100%
Price ($/kg)	$60	$33.50	$26			$8	$15

[A] *Un-coated seed.* [B] *Coated seed.* [C] *Annual medics from multiple species.*

Table 11: Fertiliser and chemical costs ($/kg or L).

DAP fertiliser	Glyphosate	Imazethapyr	2,4-D	Fluazifop-P	Rhizobium
$1.10	$9.90	$106.50	$6.83	$69.27	$128

3.4 Carrying capacity during establishment

The combinations of legume type, establishment method and fallow length influence the time required for site preparation and planting, and carrying capacity during the implementation period until full establishment is realised. Table 12 describes the legume establishment timeline for each scenario along with carrying capacity during the implementation period. For the base buffel grass scenarios, carrying capacity is assumed to remain at 100% over the 30 years and describes average production rather than modelling seasonal variability between years. The time required to reach the long-term carrying capacity of the improved legume-based pasture varied for the different legume establishment scenarios (Table 7). The quickest to reach full carrying capacity was the high-cost desmanthus/stylo scenario (whole paddock planting after a medium length fallow) which reached full capacity in year 3. The slowest was the non-arable land type scenarios which reached 100% carrying capacity in years 16 and 21.

As legumes were assumed to be planted over several years, for the period prior to planting, carrying capacity was based on the buffel baseline. It was then changed to legume pasture potential after planting, except on the non-arable land type (which incorporated a longer transitional period due to a slower assumed legume spread). Carrying capacity has been modelled above the long-term average for some legume scenarios in the early years to account for an increase in pasture production caused by nitrogen release during cultivation of the relevant treatments, and also the positive effect of the legumes. The magnitude of the increase is dependent on the legume type, quality of land preparation, planting method and proportion of paddock area initially established.

Legumes planted in strips

In all scenarios with strips, carrying capacity during the fallow is proportional to the width of the strip and distance between strips, as well as the length of time grazed. For example, a leucaena strip width of 5m with strip centres 10m apart, would have 50% left uncultivated for grazing, which if grazed for half the time would result in 25% carrying capacity for that season (Table 12 displays the progressive seasonal changes). Similarly, a 5m wide desmanthus/stylo strip with 15m centres that has the uncultivated portion grazed 100% of the time would have 67% carrying capacity. In the whole paddock fallow scenarios, and all scenarios after planting, time is the only factor considered – a 50% carrying capacity indicates the paddock is grazed for half the time.

Leucaena

The ideal planting window for leucaena and other shrubby legumes is generally between December and February, while April is generally ideal for Medics. For leucaena, the paddocks are partially destocked from March of year 1 and strips of land are prepared and fallowed for 9 months until around Christmas when planting occurs. While the timeline shows this option as planted in year 2, this is purely to capture cashflows from destocking in the year prior to planting, and the start of the year is defined in the timeline as beginning in May. Strips of leucaena are not grazed over the following wet and dry season in the year of planting to promote establishment until the paddocks are partially stocked in December of year 3, while full establishment and carrying capacity are realised in year 4.

Desmanthus/Stylo scenarios

For the low-cost method of planting desmanthus or stylo, the paddocks are not fallowed and can be planted around Christmas in year 1. The paddocks are then partially stocked in year 2 after the wet season with full carrying capacity achieved in year 4. In contrast, the high-cost method of planting desmanthus or stylo destocks cattle six to nine months prior to planting (medium fallow) but reaches full carrying capacity faster than the low-cost option and benefits from the renovation effect. In these scenarios the pasture renovation effect was assumed to increase pasture production in cultivated areas due to mineralisation of soil organic matter resulting in high nitrogen availability and higher initial grass growth over one (strips) to three (whole paddock) years.

Another scenario (e.g. Low Des/Stylo Strip) was to plant desmanthus or stylo in strips, which assumes the partial destocking of cattle nine-months prior to planting and has a relatively slower pathway than the high cost scenarios (Low Des/Stylo Hi$ MidFal) to full carrying capacity.

Medic scenarios

For the low-cost medic scenarios, grass is assumed to be grazed heavily prior to planting around April. The paddock is then lightly stocked through winter to allow establishment, with stocking gradually increased until full carrying capacity is reached in year 5. The strip planted method to establish medics models the same gradual increase in carrying capacity but factors in partial

destocking (medium fallow) six-months prior to planting to prepare and fallow the strips of land. The medic scenarios on moderate productivity land assume similar gradual increases in carrying capacity but take more time to establish in the initial years. Applying P generates higher carrying capacity once full production is reached so the initial years after planting have relatively lower proportions of the full production levels.

Non-arable land scenarios

The low-cost, non-arable scenario factors in burning and spreading seed by plane before the wet season (around Christmas) and then partially stocking the paddocks in the dry season. The paddocks then go through several years of full stocking in the dry season and partial destocking in the wet season to encourage seed set. Carrying capacity for the non-arable scenarios is assumed equal to native pasture potential until year 15 for establishing legumes in strips (over 25% of the paddock), and year 20 for the low-cost method, with carrying capacity converting to the higher legume potential each year after.

Table 12: Establishment timeline and carrying capacity during implementation (% of full capacity).

Note: Prior to planting, carrying capacities are described as a percentage of the baseline grass-only pasture. Post planting, carrying capacities are described as a percentage of the fully established legume and grass pasture. Each scenario may have a different carrying capacity (these are shown in Table 16 and Appendix 1).

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
Scenario	***Period 1***	***Period 2***	***May-Dec***	***Dec-May***	***M- D***	***D- M***	***M- D***	***D- M***	***M- D***	***D- M***	***M- D***	***D- M***
Leucaena Strip	*May-Mar* 100	*Mar-May* 50	50	0[#]	0	50	100	110	110	100	100	100
Des/Stylo Lo$ NoFal[a]	*May-Dec* 100	Dec-May 0	50	50	75	75	100	100	100	100	100	100
Des/Stylo Hi$ MidFal[b]	*May-May* 100		0	0	50	110	110	120	120	110	110	100
Des/Stylo Hi$ LngFal[c]	*May-Mar* 100	*Mar-May* 0	0	0	50	110	120	120	120	110	110	100
Des/Stylo Strip[d]	*May-Mar* 100	*Mar-May* 67	67	0	50	50	75	75	100	100	100	100
Hi Medics Lo$ NoFal	*May-Apr* 100*	*Apr-May* 0	29	29	43	57	75	75	100	100	100	100
Hi Medics Strip	*May-Dec* 100	*Dec-Apr* 50* *Apr-May* 0	29	29	43	57	75	75	100	100	100	100
Mid Medic Lo$ NoFal	*May-Apr* 100*	*Apr-May* 0	23	23	35	46	75	75	100	100	100	100
+P			18	18	27	36	75	75	100	100	100	100
Mid Medic Strip	*May-Dec* 100	*Dec-Apr* 50* *Apr-May* 0	23	23	35	46	75	75	100	100	100	100
+P			18	18	27	36	75	75	100	100	100	100
LoNA Lo$ NoFal	*May-Dec* 100	*Dec-May* 0	50	50	100	50	100	50	100	50	100	100
LoNA Strip	*May-May* 100		75	0	50	50	100	50	100	50	100	50

* *In these medic scenarios, heavy grazing prior to planting improved turnoff weights in April to be equivalent to grazing normally up until May.*

[#] *The yellow shaded areas show the period when planting occurs, and the stocking rate transitions from grass only to legume.*

[a] *Desmanthus or stylo planted using the low-cost method includes scenarios on high, moderate and low productivity land.*

[b] *Desmanthus or stylo planted using the high-cost, medium fallow method includes scenarios on high, moderate and low productivity land and with and without P on the low productivity land.*

[c] *Desmanthus or stylo planted using the high-cost, long fallow method includes scenarios on high and moderate productivity land and with and without P on the moderate productivity land.*

[d] *Desmanthus or stylo scenarios planted in strips method includes scenarios on high, moderate and low productivity land and with and without P on the moderate and low productivity land.*

3.5 Establishment costs

Table 13 details the costs involved with tillage, weed control, planting, fertilising and pest control for each scenario. All scenarios examine establishing legumes on a 500-hectare steer production paddock with planting staggered over 4 years (125-ha each year) except for the low-cost methods, which plant over two years (250-ha each year). Costs involved with replanting areas that suffer establishment failure are shown in the table with replanting taking place in the year after initial plantings have finished. Replanting costs were from the expected failure rates[4] outlined for each scenario in Table 4.

[4] Although replanting may be impractical in many situations, it is important to factor in the cost to balance out the assumption of full productivity after planting.

All scenarios were assumed to be replanted upon failure except for the low-cost methods given their high risk of failure ('Hi Des/Stylo Lo$ NoFal', etc.). For management scenarios that were not replanted, the unestablished area for these scenarios is assumed to have the same production as the base scenario.

Leucaena was planted into a buffel grass paddock in 5m cultivated strips at 10m centres with the remaining grass left undisturbed (i.e. 50% of the paddock remains as grass pasture). The desmanthus/stylo scenarios used the desmanthus seed cost (see Table 10) for the high, moderate and low productivity land types. The non-arable land type scenarios used a stylo seed mix (see Table 10). The low-cost desmanthus or stylo scenarios are established in one pass across the whole paddock and reflect the most common industry practice. The high-cost method establishes both legumes and buffel grass across the whole paddock and places much more emphasis on fallowing (6 or 9 months), good land preparation and planting techniques along with effective weed control to improve the likelihood of successful establishment. The strip planted method established legumes in 5m strips at 15m centres with all operations occurring on the strips only.

Establishment costs across the 500-ha paddocks were $76,200 for the low-cost desmanthus/stylo method and $269,500-$319,300 for the high-cost method, while planting in strips was relatively cost-effective at $85,600. Establishment costs for leucaena were just below those of the high-cost method at $238,900, while establishing medics was $30,300 for the low-cost method and $77,300 for the strip planted method. Applying P increased these costs further depending on the land type and whether they were established in strips or across the whole paddock.

Table 13: Pasture establishment operations and total costs across 500 ha.

Scenario and total cost	**Operations and costs assumptions**
Leucaena – planted in strips: **$238,900**	Strips fallowed for 9-months. Offset disc and tyne cultivate the strip area twice ($67,100). Boom spray the strips twice with glyphosate (x2) and 2,4-D ($19,600). Inoculate and sow leucaena seed at 2 kg/ha in strips ($80,100), spray with imazethapyr ($3,700) and apply beetle bait ($3,500). Spray strips with glyphosate and then Fluazifop-P ($41,000). Replant ~10% of the crop due to establishment failure ($23,900).
+P: **$279,900**	As above plus 135 kg/ha of DAP fertiliser at planting ($37,000) and additional replanting ($4,100).
Desmanthus/Stylo low-cost: **$76,300**	Offset disc and drum seed the whole paddock area in one pass ($41,500) applying 2 kg/ha of inoculated desmanthus seed ($34,800) (or stylo dependent on soil type and landholder preference).
Desmanthus/Stylo whole paddock, medium fallow: **$269,500**	Whole paddock fallowed for 6-months. Offset disc the whole paddock area twice and then tyne cultivate ($108,600). Boom spray with glyphosate ($18,700). Inoculate and air seed desmanthus and grass seed at 2 kg/ha (bare seed) and 4.5 kg/ha (coated seed) respectively ($88,300). Replant ~20% of the area due to establishment failure ($53,900).
+P: **$315,700**	As above plus apply DAP fertiliser at 68 kg/ha ($37,000) and added replanting ($9,200).

Desmanthus/Stylo whole paddock, long fallow: **$319,300**	Whole paddock fallowed for 9-months. Offset disc and tyne cultivate the whole paddock area twice ($134,200). Boom spray the area twice with glyphosate (x2) and 2,4-D ($39,200). Inoculate and air seed desmanthus and grass seed at 2 kg/ha (bare seed) and 4.5 kg/ha (coated seed) respectively ($88,300) and tyne cultivate ($25,600). Replant ~10% of the area due to establishment failure ($31,900).
+P: **$360,300**	As above plus apply DAP fertiliser at 68 kg/ha ($36,900) and added replanting ($4,100).
Desmanthus/Stylo planted in strips: **$85,600**	Strips fallowed for 9-months. Offset disc and tyne cultivate the strip area twice ($44,700). Boom spray the strips twice with glyphosate (x2) and 2,4-D ($12,900). Inoculate and air seed desmanthus in strips at 2 kg/ha ($18,200) and spray with imazethapyr ($5,500). Replant ~5% of the area due to failure ($4,300).
+P: **$98,800**	As above plus apply DAP fertiliser at 68 kg/ha ($12,300) & added replanting ($700).
Medics – low-cost: **$30,300**	Plant inoculated medics seed at 2.25 kg/ha across the whole paddock with zero till planter.
+P: **$104,200**	As above plus apply DAP fertiliser at 135 kg/ha across the whole paddock ($73,900).
Medics – planted in strips: **$77,300**	Strips fallowed for 4-months. Offset disc and tyne cultivate twice in strips across the paddock ($44,700). Boom spray the strips twice with glyphosate (x2) and 2,4-D ($13,100). Inoculate and air seed medics seed at 2.25 kg/ha in strips ($10,100) and boom spray with imazethapyr ($5,500). Replant ~5% of the area due to establishment failure ($3,900).
+P: **$103,200**	As above plus apply DAP fertiliser at 135 kg/ha in strips ($24,600) & added replanting ($1,300).
Non-arable land – plane: **$52,000**	Create fire breaks and burn the pasture ($5,000) then apply stylo seed mix at 2 kg/ha via plane ($47,000).
Non-arable land – planted in strips: **$16,700**	Strips fallowed for 6-months. Boom spray glyphosate (x2) and 2,4-D in strips across 1/8 of the paddock ($4,900). Offset disc and drum seed in one pass applying 2 kg/ha of stylo seed mix in the strips ($8,400). Replant ~20% of the strip area due to establishment failure ($3,300.

* *Replanting costs are based on the establishment failure rates described in Table 4. Given their high establishment failure rates, the low-cost scenarios are not replanted after failure.*

3.6 Additional expenses

Growing legume pastures can require additional expenses over time in addition to upfront establishment costs. For example, leucaena requires pruning and cattle can perform better if they receive rumen inoculant on entry to leucaena paddocks. Also, less productive land types may need P fertiliser to keep legumes producing at their optimal yield potential.

Table 14 shows a breakdown of the additional expenses for each scenario. Leucaena had the most additional expenses over 30 years. On highly productive land, additional expenses totalled $348,800, while moderately productive land with and without P totalled $971,100 and $332,500 respectively. Desmanthus or stylo had no additional expenses unless P was applied. If P was applied on moderate or low productivity land, additional expenses amounted to $534,400 or $345,300 respectively.

Additional expenses for medics ranged between $47,700 and $71,800 depending on the carrying capacity of the scenario, while applying P increased these expenses to $596,700. Bloat can be an issue for cattle grazing medics at certain times of the year and can have a serious impact on mortality rates. Early detection and prophylactic treatment can reduce severity. Therefore, an allowance was made in the husbandry costs for anti-bloat oil to help treat the symptoms.

Table 14: Additional expenses over 30 years.

Scenario and additional costs over 30 years	**Additional expenses**
Leucaena: Hi = **$348,800**	Mechanically prune leucaena (~$50,000 every five years from year 5). Administer leucaena rumen inoculant[5] to one in ten steers to enable detoxification of mimosine (~$1,700/year).
Mid = **$332,500**	Mechanically prune leucaena (~$50,000 every five years from year 5). Administer leucaena rumen inoculant to one in ten steers to enable detoxification of mimosine (~$1,200/year).
Mid +P = **$971,100**	Spread DAP fertiliser at 209 kg/ha across the whole paddock (~$124,500 every five years from year 6). Mechanically prune leucaena ($50,000 every five years from year 5). Administer leucaena rumen inoculant to one in ten steers to enable detoxification of mimosine (~$1,700/year).
Desmanthus/Stylo: No P = **$0**	None.
Mid +P = **$534,400**	Spread DAP fertiliser at 177 kg/ha across the whole paddock (~$106,900 every five years from year 6).
Low +P = **$345,300**	Spread DAP fertiliser at 108 kg/ha across the whole paddock (~$69,100 every five years from year 6).
Medics = **$47,700-$71,800**	Treat cattle with anti-bloat oil[6] ($1,700 to $2,600 per year).
Mid +P = **~$596,700**	Spread DAP fertiliser at 173 kg/ha across the whole paddock (~$105,100 every five years from year 6).

3.7 Pasture production

Pasture production and quality attributes were estimated for each scenario (Table 15). Estimates of annual herbage yields for each baseline scenario and intervention were based on data obtained from published reports, field trials and on-farm data, supplied by graziers. The results from 40 grazing trials that compared grass-only pastures to grass with legume pastures were also reviewed, with trials grouped by legume species. Baseline herbage yields were reviewed by pasture agronomists and beef husbandry advisors to ensure representative pasture and animal production assumptions were derived for the legume establishment scenarios.

[5] Leucaena rumen inoculant was costed at $51.10 for every tenth weaner steer on entry to the leucaena paddocks, which is the recommended population frequency(2023) Leucaena inoculum for cattle. In 'FutureBeef'. Available at https://futurebeef.com.au/resources/leucaena-inoculum/ [Verified August/29/2024].
[6] Anti bloat oil was assumed to be needed one year in 5, applied through the drinking water at 420ml per 15 litres of water, with a steer drinking 40 litres per day for 45 days.

Compared to the base buffel grass scenario, establishing leucaena on high productivity land types increased the quantity of dry matter produced by 1,800 kg/ha/yr. From this, 20%[7] of the total was considered lost to spoilage and detachment and 80% available for utilisation by cattle to maintain a similar level of residual biomass at the end of the dry season. Consequently, the amount of dry matter available for consumption doubled to 3,030 kg/ha/yr (+1,530 kg/ha/yr) and dry matter digestibility increased by 6% mostly due to the addition of leucaena to the diet of steers (50% of diet). Comparatively, establishing desmanthus/stylo increased the amount of dry matter available by 1,175 kg/ha/yr (78% increase) and digestibility by 4%, with medics generating a similar improvement.

Establishing leucaena on moderate productivity land increased the quantity of dry matter available by 1,190 kg/ha/yr (+127%) and digestibility by 6%. Applying sufficient P fertiliser to reach yield potential added another 903 kg/ha/yr (+96%) of available dry matter to be 2,093 kg/ha/yr (+223%) higher. In comparison, establishing desmanthus/stylo on grass pastures in moderately productive land increased available dry matter by 728 kg/ha/yr (+78%) and digestibility by 4%, while also supplying sufficient P increased available DM by 1,738 kg/ha/yr (+185%). On low productivity land, desmanthus/stylo increased available DM by 395 kg/ha/yr (+79%) and 1,165 kg/ha/yr (+233%) with sufficient P, and on non-arable land by 235 kg/ha/yr (+78%).

Table 15: Quantities of biomass produced and utilised.

Scenario	DM produced (kg/ha/yr)	Utilis-ation (%)	DM available (kg/ha/yr)	Spoilage & detach-ment* (kg/ha/yr)	End of dry residual (kg/ha/yr)	Legume in diet (%)	DM digest-ibility (%)
Hi Base	5,000	30%	1,500	1,000	2,500	0%	55%
Hi Leucaena	6,800	45%	3,030	1,360	2,410	50%	61%
Hi Des/Stylo	6,500	41%	2,675	1,300	2,525	25%	59%
Hi Medics	6,500	40%	2,625	1,300	2,575	43%	59%
Mid Base	3,750	25%	938	563	2,250	0%	54%
Mid Leucaena	5,150	41%	2,128	1,030	1,993	56%	60%
+P	6,800	45%	3,030	1,360	2,410	50%	61%
Mid Des/Stylo	4,950	34%	1,665	990	2,295	32%	58%
+P	6,500	41%	2,675	1,300	2,525	25%	59%
Mid Medics	4,950	37%	1,838	990	2,123	49%	58%
+P	6,500	40%	2,625	1,300	2,575	43%	59%
Low Base	2,500	20%	500	375	1,625	0%	54%
Low Des/Stylo	3,100	29%	895	465	1,740	30%	56%
+P	4,950	34%	1,665	990	2,295	32%	58%
Non-arable Base	2,000	15%	300	300	1,400	0%	54%
Non-arable Stylo	2,300	23%	535	345	1,420	25%	56%

** 15-25% of the dry matter was considered lost to spoilage and detachment depending on the amount produced.*

[7] Following the Rundown Review (Peck et al. 2011), if the total annual biomass produced was more than 7,500 kg of Dry Matter (DM) per year, it was assumed 25% was lost to spoilage and detachment, if it was under 4,500 kg DM/year 15% was assumed lost, and between the two, 20% lost.

3.8 Carrying capacity and liveweight gains

Past research has identified that the introduction of leucaena to the diet of steers can increase liveweight gains by 75 kg/year, while increases of 50 kg can be achieved with stylos or desmanthus (see section 2.5). Applying sufficient P fertiliser to achieve pasture biomass yield potential was assumed to increase steer liveweight gains to the next highest land productivity level for that legume type. This only applies to paddocks where P is the major limiting factor (rather than soil water holding capacity, for example).

Grazing trial results (i.e. directly measured animal performance) were not available for annual medics in tropical grass pastures compared to grass-only pastures. There were however multiple plot trials conducted in southern Queensland. Medics provide high quality forage during winter and nitrogen to companion grasses during summer. Based on these trial results and commercial experience, it was decided to assume the same annual liveweight gain benefit from medics in southern Queensland as for the desmanthus and stylo based pastures.

Table 16 outlines the carrying capacity and steer liveweight gains for each scenario. Carrying capacity was calculated by dividing the amount of 'dry matter available' by the 'dry matter intake' of an adult equivalent (AE[8]). Dry matter intake for each scenario and age group was calculated using QuikIntake (McLennan and Poppi 2016) by entering the associated pasture digestibility and average steer age, liveweight and liveweight change[9].

Table 16: Carrying capacity and liveweight gains.

Scenario	Carrying capacity (ha/AE)	Liveweight gain (kg/hd/year)
Hi Base	1.92	160
Hi Leucaena	0.83	235
Hi Desmanthus/Stylo	0.99	210
Hi Medics	1.01	210
Mid Base	3.15	145
Mid Leucaena	1.21	220
+P	0.83	235
Mid Desmanthus/Stylo	1.62	195
+P	0.99	210
Mid Medics	1.47	195
+P	1.01	210
Low Base	5.9	130
Low Desmanthus/Stylo	3.15	180
+P	1.62	195
Non-arable Base	9.83	115
Non-arable Stylo	5.27	165

[8] Assumed to be a 450 kg, 2 ¼ year old, bos taurus steer at maintenance with dry matter intake calculated using QuikIntake (McLean & Blakely, 2014).
[9] Each scenario assumed the steers were 50% Bos indicus and walked 7 km/day on level 1 terrain (Bowen & Chudleigh, 2018)Bowen MK, Chudleigh F (2018) Fitzroy beef production systems: Preparing for, responding to, and recovering from drought. Department of Agriculture and Fisheries, Queensland.

Table 17 shows the modelled liveweight gains over each month of the year. These changes in liveweight gain across the year influence the steer growth paths, the duration of grazing until steers reach their target turnoff weights and the date of turnoff. The monthly liveweight gain ratios for buffel grass, leucaena and desmanthus/stylo were derived from Bowen and Chudleigh (2018). The ratios for medics were estimated by DPI pasture agronomists from southern Queensland based on feed quality trial results from laboratory analysis (i.e. medic has very high feed value at a time of year when tropical grasses have very low nutritive value) and commercial experience.

Table 17: Proportion of annual liveweight gains in each month.

Legume	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	Total
None	6%	6%	6%	2%	2%	2%	13%	14%	14%	11%	13%	12%	**100%**
Leucaena	6%	6%	6%	6%	6%	6%	13%	13%	13%	9%	10%	6%	**100%**
Des/Stylo	7%	6%	7%	7%	5%	6%	13%	13%	13%	8%	9%	6%	**100%**
Medics	9%	9%	9%	5%	1%	1%	11%	12%	12%	10%	11%	10%	**100%**

4 Results

The effects of the various legume development scenarios on cattle performance, gross margins and long-term profitability are outlined in the following sections.

4.1 Cattle production

Table 18 shows the intake of weaners per year, grazing duration and total DM intake from weaning until turnoff, annual steer sales and delivered sale weights[10] once the paddocks reach full carrying capacity.

Establishing leucaena on high productivity land types doubled carrying capacity and increased liveweight gain by 75 kg/hd/year. These improvements increased the intake of weaners into the 500-ha production paddock by 216 head/year (175%), enabled steers to be turned off 6 months faster than the base scenario, decreased total dry matter intake until turnoff by 1,643 kg/head (-27%) and increased steer sales by 213 head/year (175%). Comparatively, establishing desmanthus/stylo reduced time to turnoff by 4 months and total DM intake by 1,049 kg/head (-17%) and increased sales by 140 head/year (115%), whilst medics generated similar improvements.

Establishing leucaena on moderately productive land reduced turnoff time by 7 months and total DM intake by 1,894 kg/head (-29%) and increased steers sales by 153 head/year (221%). Applying sufficient P fertiliser reduced turnoff time by a further month and intake by 256 kg/head and increased steer sales by another 112 head/year (162%). In comparison, establishing desmanthus/stylo reduced the time to turnoff by 5 months and total DM intake by 1,297 kg/head (-20%) and increased steer sales by 85 head/year (123%). Supplying sufficient P reduced turnoff time by another month and intake by 256 kg/head, and increased steer sales by another 106 head/year (153%).

On low productivity land, desmanthus/stylo reduced turnoff time by 10 months and total DM intake by 2,428 kg/head (-30%) and increased steer sales by 47 head/year (156%). Applying sufficient P reduced turnoff time by an additional month, reduced intake by 404 kg/head and increased steer sales by an additional 77 head/year (256%). On non-arable land, stylo reduced turnoff time by 11 months and total DM intake by 2,531 kg/head (-31%) and increased steer sales by 28 head/year (158%).

[10] Scenarios had different sale weights as some paddock weights exceeded 495 kg. Transport incurred 5% loss.

Table 18: Weaner intake, grazing duration, dry matter intake, steer sales and sale weights.

Scenario	Weaner intake (hd/yr)	Duration of grazing until turnoff (months)	Total DM intake until turnoff (kg/hd)	Steer sales (hd/yr)	Sale weights[A] (kg)
Hi Base	123	23	6,133	122	476
Hi Leucaena	339	17	4,489	335	480
Hi Des/Stylo	265	19	5,084	261	489
Hi Medics	260	19	5,069	257	481
Mid Base	71	25	6,640	69	474
Mid Leucaena	225	18	4,745	222	474
+*P*	339	17	4,489	335	480
Mid Des/Stylo	157	20	5,342	155	492
+*P*	265	19	5,084	261	489
Mid Medics	174	20	5,321	172	482
+*P*	260	19	5,069	257	481
Low Base	31	31	8,174	30	482
Low Des/Stylo	78	21	5,747	77	491
+*P*	157	20	5,342	155	492
Non-arable Base	18	33	8,277	18	478
Non-arable Stylo	47	22	5,746	46	479

[A] *Some paddock weights exceeded 495 kg as the full month's growth was calculated, and then 5% was reduced to account for transport loss. Consequently, each scenario has slightly different sale weights.*

4.2 Revenues, costs and gross margins

Table 19 displays the net value of cattle sales (revenue minus selling costs), weaner purchases and husbandry costs, legume maintenance costs (annual average) and gross margins once the paddocks reach full carrying capacity. Compared to the base buffel grass scenario, establishing leucaena on high productivity land types increased weaner purchases and husbandry costs by $184,600/year. It also had average legume maintenance costs of $11,700/year. However, net cattle sales increased by $365,400/year ($550,900 minus $185,500) , which had the net effect of making the gross margin higher by $169,100/year than the base buffel grass scenario. In comparison, establishing desmanthus/stylo increased the gross margin by $131,700, while medics had positive though slightly lower results than the other legumes.

Establishing leucaena (without P) on moderately productive land increased net cattle sales by $256,200/year, costs by $142,200/year and the gross margin by $114,100/year. Applying adequate P fertiliser increased the gross margin further by $66,400/year due to additional pasture yield. Comparatively, establishing desmanthus/stylo increased the gross margin by $83,300/year, while applying sufficient P fertiliser increased the gross margin further by $63,300/year.

On low productivity land, desmanthus/stylo increased net cattle sales by $83,700/year, costs by $40,200/year and the gross margin by $43,500/year, plus an additional $50,000 in gross margin with adequate P. And finally on non-arable land stylo increased the gross margin by $24,300.

Table 19: Net cattle sales, variable costs and gross margins.

Scenarios	Net cattle sales ($/year)	Weaner purchases & husbandry costs ($/year)	Legume maintenance costs ($/year)	Gross margin ($/year)
Hi Base	$185,495	$105,321	$0	$80,175
Hi Leucaena	$550,850	$289,875	$11,732	$249,243
Hi Des/Stylo	$438,117	$226,225	$0	$211,892
Hi Medics	$423,467	$222,645	$2,608	$198,213
Mid Base	$105,561	$61,633	$0	$43,927
Mid Leucaena	$361,807	$192,668	$11,151	$157,988
+P	$550,850	$289,875	$36,625	$224,350
Mid Des/Stylo	$261,264	$134,065	$0	$127,200
+P	$438,117	$226,225	$21,376	$190,516
Mid Medics	$283,168	$148,545	$1,740	$132,882
+P	$423,467	$222,645	$23,623	$177,199
Low Base	$46,685	$26,807	$0	$19,878
Low Des/Stylo	$130,397	$67,020	$0	$63,377
+P	$261,264	$134,065	$13,811	$113,389
Non-arable Base	$27,478	$15,900	$0	$11,578
Non-arable Stylo	$75,996	$40,077	$0	$35,919

4.3 Investment analysis

4.3.1 High productivity land types

Table 20 presents key measures of investment performance for each legume establishment scenario on high productivity land types. Every legume establishment option had a positive NPV, indicating that all options provide a return on investment greater than the cost of capital. Leucaena generated the largest NPV of $1.49 million, which is equivalent to increasing profitability each year by $91,800 (annualised NPV) relative to retaining a buffel grass pasture. The investment was expected to pay back in 10 years (year 10), which is five years after the last section of leucaena was planted. On the other hand, it had the second lowest IRR at 25% and the highest peak cash flow deficit of $415,500 in year 6 that an investor would need to be able to finance. Leucaena's high peak deficit was due to having a relatively long fallow, high upfront costs to purchase stock (high stocking rate) and a later return to sales.

Comparing the desmanthus/stylo scenarios, the strip planted option had a much better annual rate of return (62% vs 21-29%) and more sustainable peak deficit ($116,100 vs $289,100-$407,300) than the high-cost (whole paddock sown) option despite having a similar NPV and payback period. The low-cost 'other legume' option had the lowest return and one of the longest payback periods. For the medic scenarios, the strip planted option provided a much higher increase in profitability each year compared to the low-cost scenario ($69,000 vs $19,000), while they had a similar annual rate of return (35% vs 39%) and payback period (9 vs 8 years). The low-cost option had the lowest peak deficit, which may resonate with some producers who have limited cash flow.

Table 20: Investment performance – high productivity land types.

Scenarios	Net present value ($)	Annualised net present value ($/year)	Internal rate of return (%)	Payback period* (years)	Peak deficit ($)	Years to peak deficit
Leucaena Strip	$1,486,445	$91,800	25%	10	-$415,488	6
Des/Stylo Lo$ NoFal	$160,953	$10,322	16%	10	-$100,558	3
Des/Stylo Hi$ MidFal	$1,228,805	$75,885	29%	9	-$289,101	6
Des/Stylo Hi$ LngFal	$1,181,953	$72,992	21%	10	-$407,340	5
Des/Stylo Strip	$1,291,094	$79,732	62%	8	-$116,058	6
Medic Lo$ NoFal	$295,626	$18,959	39%	8	-$49,430	4
Medic Strip	$1,116,989	$68,980	35%	9	-$172,846	5

***** *An 8-year payback indicates the investment is paid back 3 years after planting finishes in year 5 (except Lo$ NoFal)*.

4.3.2 Moderate productivity land types

Table 21 outlines investment performance on moderate productivity land types. The internal rate of return was not able to be calculated due to computational limitations for several scenarios that had positive cash flows in the first few years of the investment (e.g. from destocking cattle in years 1 and 2 to free up area to plant legumes). Therefore the internal rate of return for these scenarios was estimated by reducing negative cash flows in later years (e.g. years 3 and 4) by the equivalent amounts (adjusted by the discount rate).

Similar to the high productivity land type results, every legume establishment option had a positive NPV indicating they are acceptable investments. Compared to not applying P, applying P to leucaena was found to generate a larger increase to profitability ($103,400 vs $62,400/year) and provide a similar annual rate of return (IRR) and payback period. However, it also had a higher peak cash flow deficit of ($326,000 vs $246,900) in year 6 that a producer would need to be able to endure.

For the desmanthus/stylo scenarios, the low-cost option had the lowest NPV and longest payback period. For scenarios where P was not added, the strip planted option performed the best out of the desmanthus/stylo scenarios, generating the largest increase to profitability ($53,000/year) and shortest payback period (6 years) with a very low peak deficit (-$2,900). The very low peak cash flow deficit was due to relatively low establishment costs and these costs being offset in the initial years by selling cattle prior to planting paddocks (freeing up cash flow). The planted paddocks then have a higher carrying capacity so by the time the last paddocks are planted, cattle sales have already increased on the planted blocks. Applying P to the strip planted option increased profitability even more ($95,100/year).

Among the medic scenarios, the strip planted option provided a much higher increase in profitability each year particularly when P was applied, while the rate of return was also much higher and the payback period and peak deficit were relatively low.

Table 21: Investment performance – moderate productivity land types.

Scenarios	Net present value ($)	Annualised net present value ($/year)	Internal rate of return (%)	Payback period^ (years)	Peak deficit ($)	Years to peak deficit
Leucaena Strip	$1,010,594	$62,410	28%	9	-$246,908	6
+P	$1,674,773	$103,426	31%	9	-$325,999	6
Des/Stylo Lo$ NoFal	$87,475	$5,610	13%	12	-$75,690	3
Des/Stylo Hi$ MidFal	$760,001	$46,934	33%	9	-$175,537	6
Des/Stylo Hi$ LngFal	$711,346	$43,930	20%	10	-$278,929	5
+P	$1,419,455	$87,659	26%	9	-$317,350	5
Des/Stylo Strip	$858,178	$52,997	513% (est*)	6	-$2,868	5
+P	$1,539,882	$95,096	337% (est*)	6	-$3,947	5
Medic Lo$ NoFal	$236,102	$15,142	63% (est*)	6	-$15,151	4
+P	$292,482	$18,757	23%	9	-$98,372	5
Medic Strip	$909,727	$56,181	159% (est*)	7	-$19,840	5
+P	$1,349,906	$83,364	85% (est*)	7	-$50,232	5

* *The internal rate of return has been estimated for some scenarios due to issues with the IRR formula in Excel. These unusually high IRRs arise because establishment costs were largely offset by cattle sales during implementation, resulting in very small net capital outlays.*

^ *An 8-year payback indicates the investment is paid back 3 years after planting finishes in year 5 (except Lo$ NoFal).*

4.3.3 Arable low productivity land types

Table 22 shows investment performance on arable and low productivity land types. Every desmanthus/stylo scenario had a positive NPV indicating they are all acceptable investments. Strip planting was found to perform the best out of all the options producing the largest increase in profitability ($58,400/year with P, or $25,300/year without P) and annual rate of return (38-50%) and providing a relatively short payback period (8 years) and low peak cash flow deficit (-$57,500 to -$68,500). The worst performing scenario was the low-cost option, which had the smallest increase in profitability ($700/year) and rate of return (6%), and had the longest payback period (25 years). The high-cost options had the highest peak deficits (-$254,100 to -$292,500), which may be a barrier for some producers who have constrained cash flows.

Table 22: Investment performance – arable low productivity land types.

Scenarios	Net present value ($)	Annualised net present value ($/year)	Internal rate of return (%)	Payback period (years)	Peak deficit ($)	Years to peak deficit
Des/Stylo Lo$ NoFal	$10,771	$691	6%	25	-$80,521	4
Des/Stylo Hi$ MidFal	$277,111	$17,113	14%	14	-$254,105	6
+P	$811,400	$50,108	22%	10	-$292,479	6
Des/Stylo Strip	$409,076	$25,263	38%	8	-$57,510	5
+P	$945,737	$58,404	50%	8	-$68,499	5

***** *An 8-year payback indicates the investment is paid back 3 years after planting finishes in year 5 (except Lo$ NoFal where planting finished in year 3).*

4.3.4 Non-arable, low productivity land types

Table 23 presents investment performance on non-arable low productivity land types. The low-cost stylo option was found to decrease profitability. Only the strip planted option had a positive NPV. This option increased profitability by $5,600/year and had an annual rate of return of 15%. The investment was found to take 19 years to payback and a producer would need to sustain a peak cash flow deficit of -$58,400 in year 12.

Table 23: Investment performance – non-arable low productivity land types.

Scenarios	Net present value ($)	Annualised net present value ($/year)	Internal rate of return (%)	Payback period (years)	Peak deficit ($)	Years to peak deficit
Stylo Lo$ NoFal	-$39,325	-$2,522	No return	No payback	-$178,457	31
Stylo Strip	$91,029	$5,622	15%	19	-$58,387	12

4.4 Establishment method

Three different establishment methods were examined with desmanthus/stylo on high, moderate and low productivity land types[11]. Table 24 outlines the investment performance of each establishment method for desmanthus/stylo. Comparing the methods, establishing strips produced slightly higher net present value results ($0.4-$1.5 million) than establishing a whole paddock using the high-cost option ($0.3-$1.4 million). However, establishing strips generated much higher rates of return (38-513%), paid back much faster (6-8 years) and had a much lower peak deficit (-$0M to -$0.1M) than both the other establishment methods. Establishing desmanthus/stylo across the whole paddock using the high-cost option had the next best returns and payback period, while the whole paddock low-cost option had the lowest returns and longest payback period.

Table 24: Investment performance of establishment methods – arable land & Des/Stylo only.

Establishment method	Establish-ment costs ($M)	Fallow period (months)	Net present value ($M)	Internal rate of return (%)	Payback period (years)	Peak deficit ($M)
Whole paddock (Hi$)	0.27-0.36[A]	6 or 9	0.3-1.4	14-33%	9-14	-0.18 to -0.41
Whole paddock (Lo$ NoFal)	0.08[B]	0 (none)	0-0.2	6-16%	10-25	-0.08 to -0.1
Strips	0.09-0.1[A]	9	0.4-1.5	38-513%	6-8	-0 to -0.1

[A] *Including replanting costs after establishment failure along with any upfront P application costs.*

[B] *Assuming no replanting, or replanting costs, after establishment failure.*

4.5 Land type

Table 25 summarises the investment performance range for each land productivity type (all legume species and establishment methods). Comparatively, the high and moderate productivity land types generated relatively stronger returns and faster payback periods followed by the arable, low productivity land type. The low, non-arable land type had the weakest performance with one option

[11] Leucaena was planted in strips only, while medics were not examined on low productivity land.

that generated a positive return (strip planted option) and one that was negative (low-cost option). These results suggest that establishing legumes on high and moderate productivity land types should be prioritised before low arable land types, and low non-arable land types last (strips).

Table 25: Investment performance range of each land productivity type.

Land productivity type	Net present value ($M)	Internal rate of return (%)	Payback period (years)	Peak deficit ($M)
High	0.2-1.5	16-62%	8-10	-0.05 to -0.42
Moderate	0.1-1.7	13-513%	6-12	-0 to -0.33
Low, arable	0-0.9	6-50%	8-25	-0.06 to -0.29
Low, non-arable	-0-0.1	No return-15%	19-no payback	-0.06 to -0.18

4.6 Phosphorus (P) fertiliser

Applying P fertiliser before planting and maintaining phosphorus levels over the life of the legumes was found to improve the total profitability generated by each of the legume establishment methods (see Table 26). On moderate productivity land for leucaena, applying P fertiliser increased profitability by $0.66 million and the rate of return by 3% but also increased the peak deficit by -$80,000.

For high-cost desmanthus/stylo, applying P increased profitability by $0.7 million and the rate of return from 20% to 26%, while reducing the payback period from 10 to 9 years. For desmanthus/stylo in strips, it increased profitability by $0.68 million but reduced the rate of return from 513% to 337% given larger outlays on fertiliser early on.

For the low-cost medic scenario, applying P fertiliser only increased profitability by $60,000 and reduced the rate of return from 63% to 23%, while increasing the payback period by 3 years. For the strip planted medic scenario, applying P increased profitability by $0.44 million and had a similar payback period but reduced the rate of return from 159% to 85%.

Applying P fertiliser provided good returns in both desmanthus/stylo scenarios on low productivity land. For the high-cost establishment method, it increased profitability by $530,000 and the rate of return from 14% to 22%, while reducing the payback period from 14 to 10 years. For the strip planted method, it increased profitability by $540,000 and the rate of return from 38% to 50%.

Overall, applying P fertiliser:

- Provided little benefit when using the low-cost establishment method.
- Improved profitability for all legume species when establishing legumes in strips or using the high-cost method across the whole paddock.
- Provided better rates of return and shorter payback periods on low productivity land where P deficiency was a constraining factor on productivity.

Table 26: Change in investment performance from applying P fertiliser.

Land productivity	Legume	Establishment method	Net present value ($M)	Internal rate of return (%)	Payback period (years)	Peak deficit ($M)
Mid	Leucaena	Strips	$0.66	3%	0	-0.08
Mid	Des/Stylo	High-cost	$0.71	6%	-1	-0.04
Mid	Des/Stylo	Strips	$0.68	-176%	0	0
Mid	Medic	Low-cost	$0.06	-41%	+3	-0.08
Mid	Medic	Strips	$0.44	-73%	0	-0.03
Low	Des/Stylo	High-cost	$0.53	8%	-4	-0.04
Low	Des/Stylo	Strips	$0.54	12%	0	-0.01

5 Sensitivity Analysis

Sensitivity analyses were completed for four key variables including the cattle price premium, the productive life of legumes, the expected establishment failure rate for low-cost options and the pruning frequency of leucaena.

5.1 Cattle price premium

Legume pastures enable steers to keep growing in the dry season and be sold at younger ages and at earlier times of the year with sufficient weight and body condition for premium markets compared to cattle on grass-only pastures. While an average premium of 45.6 c/kg was identified for yearling steers sold between October and March (Section 3.3.1), to be conservative only half of the price premium was factored in for the baseline legume scenarios presented earlier (22.8 c/kg). This sensitivity analysis explores a wider range of prices from receiving no premium up to the full premium; i.e. the cattle price premiums used were 0 c/kg (no premium), 22.8 c/kg (50%, base), and 45.6 c/kg (full premium). Table 27 outlines the sensitivity of the annualised net present value results to the price premium received for cattle grazing pastures with legumes. In addition, the premium required for the scenarios to break even with the grass-only scenario (i.e. where the net present value result equals zero) is shown in the right hand side column.

The results indicate that price premiums influenced profitability noticeably more in scenarios that previously demonstrated large increases in profitability from establishing legumes (due to large productivity gains), while establishment options that previously had smaller increases in profitability were less affected. For example, obtaining no cattle price premium when establishing leucaena on high productivity land types increased profitability by $66,800/year, while obtaining a 45.6 c/kg price premium increased profitability by $50,000/year more ($116,800/year). In contrast, when establishing stylo on non-arable land types using the low-cost method, the difference in profitability was only $440/year between receiving no premium and 45.6 c/kg.

Even with no price premium, all the legume establishment options increased profitability except for establishing desmanthus or stylo using the low-cost method on low productivity land types (both arable and non-arable), which needed premiums of 8 c/kg and 285 c/kg to breakeven. All other scenarios could sustain a price discount of between 39 c/kg and 92 c/kg before they became less profitable than the base (grass-only) scenario.

Table 27: Sensitivity of annualised net present value ($/year) to the cattle price premium (c/kg).

Cattle price premium *Proportion of premium (%)*			**0 c/kg** *0% (no premium)*	**22.8 c/kg** *50% (base)*	**45.6 c/kg** *100% (full premium)*	**Breakeven price premium or discount (c/kg)**
Hi	Leucaena	-	$66,784	$91,796	$116,809	-61
	Desmanthus/ Stylo	Lo$ NoFal	$6,853	$10,322	$13,792	-45
		Hi$ MidFal	$55,535	$75,885	$96,236	-62
		Hi$ LngFal	$52,400	$72,992	$93,585	-58
		Strip	$60,490	$79,732	$98,974	-72
	Medics	Lo$ NoFal	$13,838	$18,959	$24,081	-62
		Strip	$50,280	$68,980	$87,680	-61
Mid	Leucaena	-	$46,248	$62,410	$78,571	-65
		+P	$78,414	$103,426	$128,439	-71
	Desmanthus/ Stylo	Lo$ NoFal	$3,533	$5,610	$7,687	-39
		Hi$ MidFal	$34,639	$46,934	$59,230	-64
		Hi$ LngFal	$31,488	$43,930	$56,371	-58
		+P	$67,067	$87,659	$108,252	-74
		Strip	$41,367	$52,997	$64,627	-81
		+P	$75,854	$95,096	$114,338	-90
	Medics	Lo$ NoFal	$11,717	$15,142	$18,566	-78
		+P	$13,711	$18,757	$23,804	-62
		Strip	$43,677	$56,181	$68,684	-80
		+P	$64,936	$83,364	$101,792	-80
Low	Desmanthus/ Stylo	Lo$ NoFal	-$347	$691	$1,729	8
		Hi$ MidFal	$10,930	$17,113	$23,296	-40
		+P	$37,813	$50,108	$62,404	-70
		Strip	$19,411	$25,263	$31,114	-76
		+P	$46,775	$58,404	$70,034	-92
Non-arable	Stylo	Lo$ NoFal	-$2,742	-$2,522	-$2,302	285
		Strip	$3,673	$5,622	$7,571	-43

5.2 Productive life of legumes

While well-established legumes commonly persist for 30 years, pasture lifespan can be shortened by a range of natural and management processes. Table 28 shows the sensitivity of the annualised net present values from shorter legume lifespans including 10, 15, 20 and 25 year lives (from the year of planting).

Similarly to price premium, the results indicate that reducing productive pasture lifespans have relatively larger impacts on profitability where there were large increases in profitability from establishing legumes (again due to large productivity gains) in the previous analyses, while options

that previously had smaller increases in profitability were less affected. Unsurprisingly, the shorter the life of the legumes, the larger the reduction in profitability. For example, when establishing leucaena on high productivity land types a 25-year life was $5,600/year less profitable than a 30-year life, while a 10-year life was $23,800/year less profitable than a 15-year life (i.e. over 4 times larger reduction in NPV for a 5 year period than reducing life span from 30 to 25 years). In comparison, decreases in profitability were less in absolute terms when establishing stylo on non-arable land types using the low-cost method but the relative trends were similar, with less than one third the profitability for 10/15 years than 25/30. These results highlight that scenarios with higher establishment costs have relatively greater risks from reduced productive pasture lifespan (e.g. desmanthus/stylo Hi$ versus Lo$ NoFal).

Even with halving the common productive life of legumes to 15 years, all legume establishment options increased profitability, with the exception of establishing stylo on non-arable land or using the low-cost method on low productivity land. Note that the payback periods (shown in Table 20 to Table 23) effectively denote the lifespan of the legumes required for each scenario to breakeven.

Table 28: Sensitivity of annualised net present value ($/year) to the life of the legumes (years).

Productive life of legumes			**10 years**	**15 years**	**20 years**	**25 years**	**30 years** (base)
Hi	Leucaena	Strip	$40,746	$64,509	$77,866	$86,219	$91,796
	Desmanthus/ Stylo	Lo$ NoFal	$3,082	$6,701	$8,538	$9,623	$10,322
		Hi$ MidFal	$39,237	$56,296	$65,885	$71,882	$75,885
		Hi$ LngFal	$33,494	$51,880	$62,214	$68,677	$72,992
		Strip	$44,015	$60,641	$69,986	$75,830	$79,732
	Medics	Lo$ NoFal	$11,441	$15,199	$17,106	$18,233	$18,959
		Strip	$36,002	$51,353	$59,981	$65,377	$68,980
Mid	Leucaena	Strip	$25,094	$42,464	$52,227	$58,333	$62,410
		Strip *+P*	$52,157	$76,022	$89,436	$97,825	$103,426
	Desmanthus/ Stylo	Lo$ NoFal	-$545	$2,531	$4,093	$5,016	$5,610
		Hi$ MidFal	$19,069	$32,040	$39,330	$43,890	$46,934
		Hi$ LngFal	$13,468	$27,647	$35,617	$40,602	$43,930
		Hi$ LngFal *+P*	$47,123	$65,992	$76,598	$83,230	$87,659
		Strip	$27,958	$39,613	$46,165	$50,262	$52,997
		Strip *+P*	$58,723	$75,654	$85,171	$91,122	$95,096
	Medics	Lo$ NoFal	$8,942	$12,041	$13,614	$14,543	$15,142
		Lo$ NoFal *+P*	$7,697	$13,225	$16,032	$17,689	$18,757
		Strip	$29,912	$42,139	$49,012	$53,311	$56,181
		Strip *+P*	$48,822	$64,901	$73,938	$79,590	$83,364
Low	Desmanthus/ Stylo	Lo$ NoFal	-$4,408	-$1,860	-$566	$198	$691
		Hi$ MidFal	-$1,730	$7,041	$11,971	$15,055	$17,113
		Hi$ MidFal *+P*	$21,900	$35,031	$42,411	$47,027	$50,108
		Strip	$11,072	$17,677	$21,390	$23,712	$25,263

		+P	$34,400	$45,574	$51,854	$55,782	$58,404
Non-arable	Stylos	Lo$ NoFal	-$6,266	-$4,632	-$3,821	-$3,043	-$2,522
		Strip	-$2,277	-$1,077	$2,073	$4,201	$5,622

5.3 Failure rate for low-cost options

As outlined in section 3.2.2 (Legume establishment) expected failure rates were based on field trial results and commercial experience, and are heavily influenced by good fallow management which kills existing pasture (which helps retain moisture to be available at planting) and reduces weed seed populations – thus dramatically improving the likelihood of legume establishment. Given the low-cost legume establishment options had no fallow, their failure rates are high due to not storing soil moisture and having greater competition from the existing pasture – 85% failure for desmanthus/stylo and 75% for medics. These rates reflect long-term averages, and it is important to note that the success of legume establishment varies year to year depending on the climatic conditions and other variables. Therefore, it is informative to understand the impacts on profitability if failure rates turn out to be better than the long-term average.

Table 29 shows the sensitivity of the annualised net present value results, to better legume establishment failure rates for the low-cost legume establishment options, with the investigated failure rates being 15%, 30%, 45%, 60% and 75%. The results show that the profitability of the low-cost legume establishment options increases with lower failure rates, with the magnitude of the increases much greater on higher productivity land types (due to larger productivity gains). Consequently, timing the establishment of legumes to years where the likelihood of establishment success is greater will increase profitability.

Comparing the results for replanting versus not replanting after failure indicates that replanting after establishment failure further increases profitability for most options where establishing legumes is profitable. Only non-arable land decreased profitability when replanting after establishment failure (except at a low 15% failure rate). How practical replanting is to achieve in the paddock depends on the nature and distribution of the establishment failure, which reinforces the advantage of pursuing a lower risk strategy from the outset.

Table 29: Sensitivity of annualised net present value ($/year) to "low-cost" establishment failure.

Scenario		**Replant after failure**	**Establishment failure rate**					
			15%	**30%**	**45%**	**60%**	**75%**	**85%**
Hi	Desmanthus / Stylo	No	$79,712	$64,843	$49,974	$35,104	$20,235	$10,322
		Yes	$91,550	$89,460	$85,026	$78,708	$65,629	$47,173
	Medics	No	$68,585	$56,178	$43,772	$31,366	$18,959	$10,688
		Yes	$78,770	$77,506	$74,475	$70,326	$61,490	$48,845
Mid	Desmanthus / Stylo	No	$53,009	$42,852	$32,695	$22,538	$12,381	$5,610
		Yes	$60,881	$59,120	$55,628	$50,533	$40,156	$25,638
	Medics	No	$55,606	$45,490	$35,374	$25,258	$15,142	$8,398
		Yes	$63,864	$62,759	$60,186	$56,631	$49,109	$38,378
	+P	No	$77,972	$63,169	$48,365	$33,561	$18,757	$8,888
		Yes	$89,552	$87,150	$82,289	$75,248	$60,836	$40,620

Low	Desmanthus / Stylo	No	$25,133	$19,896	$14,658	$9,420	$4,183	$691
		Yes	$28,866	$27,449	$24,939	$21,121	$13,565	$3,157
Non-arable	Stylo	No	$178	-$401	-$979	-$1,558	-$2,136	-$2,522
		Yes	$204	-$553	-$1,666	-$3,493	-$6,929	-$11,526

5.4 Pruning frequency

Leucaena must be pruned to promote leaf growth in areas that are easily accessible to foraging cattle. Increased pruning frequency increases operational costs (mechanical pruning was costed at $50,000 across 500 hectares). The analysis assumed that pruning occurred every 5 years (on average) but in some cases leucaena may need to be pruned more often. Due to the lack of research on the effects of pruning on biomass, utilisation and digestibility, the only variable considered was the additional cost of pruning.

Table 30 outlines the effect of pruning frequency on annualised net present value by pruning every 1, 2, 3, 4 or 5 years. The impact on profitability was the same for each leucaena scenario. Compared to pruning leucaena every 5 years, profitability changed by -$1,400/year when pruning frequency increased to every 4 years, -$4,100/year pruning every 3 years, -$9,300/year pruning every 2 years, and -$25,700/year when pruning every year. These results demonstrate the importance of producers using grazing management strategies that reduce the need to prune leucaena while ensuring grass productivity is maintained.

Table 30: Sensitivity of annualised net present value ($/year) to the frequency of pruning leucaena.

	Phosphorus applied	**Leucaena pruning frequency**				
		Every year	*Every 2 years*	*Every 3 years*	*Every 4 years*	*Every 5 years*
Hi	No	$66,103	$82,491	$87,731	$90,347	$91,796
Mid	No	$36,717	$53,105	$58,344	$60,961	$62,410
	Yes	$77,733	$94,122	$99,361	$101,978	$103,426

6 Discussion

6.1 Legume species

6.1.1 Leucaena

The investment performance results for the different legume establishment options put into perspective where the biggest opportunities lie across several land productivity types. Leucaena is best suited to moderate to high productivity land as the crop requires high fertility soils with good water holding capacity to produce high yields and persist in the long-term. Table 31 shows the changes in productivity compared to a grass pasture, such as improved beef production per ha from higher stocking weights and faster weight gains. These all contributed to the improvement in gross margins

Table 31: Pasture and cattle production, and gross margin improvements – Leucaena.

Land productivity type / P application	**Hi**	**Mid**	**+P**
Available DM ▲ (kg/ha)	1,530	1,190	2,093
Carrying capacity ▲ (%)	130%	159%	277%
Liveweight gain ▲ (kg/yr)	75	75	90
Turnoff time ▼ (months)	-6	-7	-8
DM intake ▼ (kg/hd)	-1,643	-1,894	-2,150
Steer sales ▲ (hd/yr)	213	153	265
Gross margin ▲ ($/yr)	$169,068	$114,061	$180,423

6.1.2 Other tropical legumes (desmanthus and stylo)

Desmanthus and stylo are suited to a broader range of land productivity types than leucaena as they have lower soil fertility requirements and can persist on soils with lower water holding capacity.

The gains in pasture and cattle production, and increase in gross margin, from establishing desmanthus/stylo were considerable (Table 32). On high productivity land types, the amount of available DM increased by 1,175 kg/ha, carrying capacity by 95% and liveweight gains by 50 kg/yr, while the time to turnoff steers reduced by 4 months and total DM intake decreased by 1,049 kg/hd. These improvements increased steer sales by 140 hd/yr and the gross margin by $131,700.

Less productive land types without P application produced similar proportional improvements in pasture and cattle production but had larger decreases in total dry matter intake (-1,300 to -2,400 kg/hd) and the time required to turnoff steers (-5 to -10 months). Steer sales were found to increase by 85, 47 and 28 hd/yr on moderate, low and non-arable land types, while gross margins increased by $83,300, $43,500 and $24,300/year respectively. Applying adequate maintenance P fertiliser grew steer sales by another 106 and 77 hd/yr on moderate and low productivity land, while gross margins increased by another $63,300 and $50,000/year.

Table 32: Pasture and cattle production, and gross margin improvements – Desmanthus/ Stylo.

Land productivity type / P application	Hi	Mid	+P	Low	+P	Low non-arable
Available DM ▲ (kg/ha)	1,175	728	1,738	395	1,165	235
Carrying capacity ▲ (%)	95%	94%	219%	87%	264%	87%
Liveweight gain ▲ (kg/yr)	50	50	65	50	65	50
Turnoff time ▼ (months)	-4	-5	-6	-10	-11	-11
DM intake ▼ (kg/hd)	-1,049	-1,297	-1,556	-2,428	-2,832	-2,531
Steer sales ▲ (hd/yr)	140	85	192	47	125	28
Gross margin ▲ ($/yr)	$131,718	$83,272	$146,588	$43,499	$93,511	$24,341

6.1.3 Medics

Medics grow in winter and are only suited to southern parts of the Brigalow Belt (refer to E4(S) in Figure 1). The authors of this report did not find animal performance data for medic augmented pastures from research trials in Queensland. Animal performance assumptions were based on dry matter production studies, feed quality analysis, seasonality of growth (relative to the companion tropical grass) and commercial experience. Therefore, results from the analysis should be considered exploratory and would be improved by conducting field measurements of livestock productivity from medic based pastures.

Medic pastures perform best when the initial planting coincides with good winter rains, and are sown in higher productivity land (with additional P if required). Table 33 shows the changes in parameters relating to cattle performance which contribute to improved gross margins for medics, assuming a modest establishment failure rate of 10 % or less.

Table 33: Pasture and cattle production, and gross margin improvements – Medic.

Land productivity type / P application	Hi	Mid	+P
Available DM ▲ (kg/ha)	1,125	900	1,688
Carrying capacity ▲ (%)	91%	114%	213%
Liveweight gain ▲ (kg/yr)	50	50	65
Turnoff time ▼ (months)	4	5	6
DM intake ▼ (kg/hd)	1,063	1,319	1,571
Steer sales ▲ (hd/yr)	135	102	188
Gross margin ▲ ($/yr)	$118,039	$88,955	$137,022

Two establishment methods were considered including (1) a low-cost option ($30,300) applying seed using a zero till planter, and (2) a higher cost option ($77,300) planting in strips with land preparation and weed control. Additional ongoing expenses included treating cattle with anti-bloat oil ($47,700-$71,800) along with applying maintenance P fertiliser on moderately productive land types (+$549,000 including additional anti-bloat oil costs). Like desmanthus/stylo, the pasture and cattle production benefits from establishing medics were large. Compared to unimproved buffel grass pastures, medics increased available dry matter by 900-1,125 kg/ha, carrying capacity by 91-114% and liveweight gains

by 50 kg/yr. Steers could be turned off 4-5 months faster, total DM intake reduced by 1,063-1,319 kg/head and steer sales increased by 102-135 head/year (111-147%). Once medics were fully established, net cattle sales expanded along with costs to increase annual gross margins by $89,000-$118,000/year. Applying adequate P fertiliser grew steer sales by another 86 hd/yr, while gross margins increased by another $48,067/year.

The investment analysis revealed that establishing medics increased profitability (NPV) in all land type scenarios. Strip planting medics performed better than the low-cost option. It increased profitability by $56,200-$69,000/year and had a 35-159% rate of return, peak deficit of -$19,800 to -$172,800 and paid back in 7-9 years (one to three years after planting finished). Comparatively, the low-cost option increased profitability by much less ($15,100-$19,000/year), had relatively lower rates of return (39-63%) and a similar payback (6-8 years) but had a lower peak deficit (-$15,200 to -$49,400).

6.2 Which option is "best"?

There is no single "best' solution. Available land types, climate, attitude to risk, financial position and management capabilities all contribute to the choices made by one grazier over another. While whole-paddock renovation offers a more uniform increase in productivity, the data shows that strip planting provides a more robust economic buffer, particularly by lowering the peak cash flow deficit, which is critical for producers with capital constraints. Leucaena offers the highest peak profitability on high-fertility country, but its reliance on specific soil types and higher management requirements limits its application. Conversely, desmanthus and stylo exhibit greater resilience across lower fertility classes, making them more suitable for risk-averse, lower input management. The one stand-out in terms of choices was that the application of P fertiliser (where needed) resulted in a better outcome in every scenario examined.

All three groups of legume species were evaluated on high and moderate productivity land types (leucaena, desmanthus/stylo and medics), while just one legume species was examined on low productivity land – arable (desmanthus/stylo) and non-arable (stylo). Consequently, Table 34 compares the investment performance of the three legume species on high and moderate productivity land only. As the legume species had different establishment methods, land types and fertiliser requirements with varying performance, it is not possible to identify a single legume option that maximises profitability in all situations, and this is compounded when considering that risk appetite and financial resources various between individual businesses. Desmanthus/Stylo had ranges both higher and lower than leucaena and medics in terms of the rate of return and payback period. While establishing desmanthus/stylo in strips generated strong returns and quick payback, establishing the same species across the whole paddock using the low-cost option had low returns and a long payback.

Key findings include:

- A leucaena scenario generated the highest net present value.
- A desmanthus/stylo scenario produced the highest rate of return, lowest peak deficit and had one of the fastest payback periods.
- Investing in reliable establishment methods is worthwhile for desmanthus, stylo and medic. Cheaper establishment methods that had higher failure rates produced poorer returns when accounting for establishment failure.

More discussion about the best performing scenarios is covered in section 6.4 (Recommendations for producers).

Table 34: Investment performance of each legume species–high & moderate productivity land only.

Legume species	Net present value ($M)	Internal rate of return (%)	Payback period (years)	Peak deficit ($M)
Leucaena	1-1.7	25-31%	9-10	-0.25 to -0.42
Desmanthus/Stylo	0.1-1.5	13-513%	6-12	-0 to -0.41
Medic	0.2-1.3	23-159%	6-9	-0.02 to -0.17

6.3 Sensitivity Analysis

Analyses were completed to examine the sensitivity of the annualised net present value results to the cattle price premium, productive life of legumes, establishment failure rate for low-cost options and the pruning frequency of leucaena. The findings identified that:

- Even with no cattle price premium, all legume options increased profitability except for establishing desmanthus/stylo using the low-cost method on low productivity land types.
- Even when halving the common productive life of legumes to 15 years, all legume options still increased profitability except for establishing stylo on non-arable land and using the low-cost method on low productivity land.
- The profitability of the low-cost establishment options increases with lower failure rates with the magnitude of increases greater on higher productivity land, which highlights potential benefits from timing the establishment of legumes to years where the likelihood of establishment success is greater (i.e. wetter years or years when high rainfall occurs early in the growing season to provide significant stored soil moisture during the planting window).
- Pruning leucaena every two years, instead of every five, reduced the increase in profitability by $9,300/year, which could be offset by the potential benefits of pruning (e.g. greater utilisation and digestibility).

6.4 Recommendations for producers

Discounted cashflow analysis is a powerful tool for comparing alternatives against a base scenario over an extended period. To achieve this, all scenarios contain many assumptions, almost none of which will be exactly the same as occurring on an individual property, so the recommendations should not be interpreted as financial advice. Regardless, the assumptions made were based off the experience and research conducted by pasture agronomists and beef extension officers using conservative estimates, so while theoretical, the numbers provide a guide as to the relative potential of each option.

Recommendations are based on each of the four land productivity types. From an economic perspective, key factors that strongly influence producer decision making include what legume establishment options provide the:

- Largest increase to profitability = largest net present value.
- Highest rate of return per dollar invested = highest internal rate of return.

- Fastest payback = lowest payback period.
- Lowest cash flow deficit = lowest peak cash flow deficit requirement.

Different producers value each of these measures differently depending on their situation. For example, producers that have the capital resources available may derive the greatest value from investing in a legume establishment option that generates the largest increase in profitability. Alternatively, these producers might consider alternative investments that generate similar rates of return to legumes if other options are available. Other producers may be more risk averse and be looking to recover their investment as soon as they can with the fastest payback option. Other producers may currently have limited access to capital and be looking for an option with the lowest cash flow deficit. However, a better option when access to capital is limited may be to establish legumes across a smaller area using an option that has a high return (machinery costings are based on using contractors so impacts are generally proportional). Practical considerations in terms of cost-effective access to contractors may be an issue for very small and/or remote plantings. In situations where one option performs the best across all measures, choosing the best option is straight-forward.

Table 35 to Table 37 show the two best performing legume establishment options for each of the four factors that influence investment decisions. For high productivity land types, establishing leucaena generated the largest increase in profitability. In comparison, establishing desmanthus/stylo in strips had the second largest increase in profitability along with the highest rate of return and fastest payback. Establishing medics on the same land using the low-cost option across the whole paddock had the second highest rate of return, a quick payback and a low cash flow deficit. However, given the lowest cash flow deficit options are the least profitable, producers may be better off establishing other legumes across a smaller area to start with using an option that generates higher profitability, but this needs a detailed scenario analysis for verification.

For moderate productivity land types, establishing desmanthus/stylo in strips with or without P performed well across all investment performance measures. Establishing leucaena generated the largest increase in profitability but did not rank as well in the other measures. On arable low productivity land types, establishing desmanthus/stylo in strips with P performed well across all performance metrics. Establishing desmanthus/stylo across the whole paddock using good land preparation, planting and weed control (high-cost option) generated the second largest increase in profitability but ranked lower in the other measures. Establishing desmanthus/stylo in strips without P performed well in all measures but only had a moderate increase in profitability. On non-arable low productivity land types, establishing stylo in strips (without P) performed the best across all performance measures.

Table 35: Top two performing legume establishment options on high productivity land.

Financial metric	**Top performing scenario**		**2nd best scenario**	
Largest increase in profitability ($M)	Leucaena	1.5	Des/Stylo Strip	1.3
Highest rate of return per $ invested (%)	Des/Stylo Strip	62%	Medic Lo$ NoFal	39%
Fastest payback (years)	Des/Stylo Strip	8	Medic Lo$ NoFal	8
Lowest cash flow deficit ($)	Medic Lo$ NoFal	-0.05	Des/Stylo Lo$ NoFal	-0.1

Table 36: Top two performing legume establishment options on medium productivity land.

Financial metric	Top performing scenario		2nd best scenario	
Largest increase in profitability ($M)	Leucaena +P	1.7	Des/Stylo Strip +P	1.5
Highest rate of return per $ invested (%)	Des/Stylo Strip	513%	Des/Stylo Strip +P	337%
Fastest payback (years)	Des/Stylo Strip	6	Des/Stylo Strip +P	6
Lowest cash flow deficit ($)	Des/Stylo Strip	-0	Des/Stylo Strip +P	-0

Table 37: Top two performing legume establishment options on low productivity land (arable and non-arable).

Financial metric	Top performing scenario		2nd best scenario	
Largest increase in profitability ($M)	Des/Stylo Strip +P	0.9	Des/Stylo Hi$ MidFal +P	0.8
Highest rate of return per $ invested (%)	Des/Stylo Strip +P	50%	Des/Stylo Strip	38%
Fastest payback (years)	Des/Stylo Strip +P	8	Des/Stylo Strip	8
Lowest cash flow deficit ($)	Des/Stylo Strip	-0.06	LoNA Stylo Strip +P	-0.07

Key findings:

- The better the soil type, the more options available and the greater the profitability.
- Where P deficiency is a constraining factor on productivity, the application of P fertilisers increased profitability when using effective legume establishment methods.
- Especially if the existing grass pasture was in reasonable condition, planting in strips provided the best returns.
- Successful first-time establishment to a 30-year investment is key to reducing risk of replanting and maximising profitability. This involves planning and preparation up to a year before planting.
- Planting legumes can increase profitability but can also increase short-term financial risk and management requirements, so may not be the best option for every grazier.

6.5 Contribution of this report

The integration of legumes into grazing pastures is less likely to occur when there is limited information on potential returns and risks to production and business bottom lines. This study integrates the collective impacts of legume establishment on production and profitability, that will help inform industry and improve the wider adoption of legumes in the Brigalow Belt. This study has identified the optimum combinations of legume types and establishment methods for different land types. It has also established key investment performance measures to help producers identify options that best suit their business circumstances and financial situation to support their investment decisions.

7 Limitations

The limitations of the analysis largely relate to the simplifying assumptions made in the calculations and methodology to enable comparisons. The bioeconomic analysis has assumed long-term average seasonal conditions and does not account for inter-annual variation, for example a run of drought years or consecutive wet years. However, the advantage (and constraint) of a long-term average annual model is that while the timing of any catastrophe is ignored, its effect on long-term average results is not. Conceptually, it is the expected results from conducting the analyses over multiple paddocks on multiple properties for a hundred years. In effect frost, flood, drought, hail are taken into account in the average. Future studies are recommended to account for seasonal variation in more detail e.g. results from wet years versus dry etc., extended wet or dry periods (i.e. consecutive wet or dry years), rather than just average, perhaps using a biophysical modelling approach.

The lifespan and medium-term productivity of both legumes and run-down grass pastures is likely to vary considerably according to soil-type, climate and biological interactions. Notably, the inter annual variation and seasonal conditions at planting have a large impact on individual plantings. Additional analysis could try and account for seasonal variation and its impact on returns (e.g. establishing legumes during a run of wet years compared to a run of below average rainfall years).

Establishment failure is a key variable, which can depend on seed quality, weed seedbanks, rainfall timing and intensity, soil tilth and human factors (management, timeliness, attention-to-detail). For example, productivity zones have been split largely according to climate zones, average annual rainfall and P levels, but there are many other factors that impact on establishment and growth such as soil moisture infiltration and drainage rates, salinity, sodicity, rockiness, lack of uniformity, tree cover, etc.). To complicate matters, there may be compensatory pasture growth depending on the extent and distribution of any establishment failure. While steps have been taken to account for differences in establishment failure in the analysis (along with a sensitivity analysis), failure rates on individual farms will vary from the estimates presented herein.

There may be other practical limitations, such as the accessibility of trucks during wet season for cattle going to market, consistent availability of uniform replacement weaners, and variable stocking and replenishment rates depending on pasture growth. However, the modelling is a dynamic process that combines data, theory, and computational techniques to explore the potential outcomes of different variable combinations over the long term. It allows for the exploration of complex systems, providing valuable insights that can guide strategic planning and decision-making.

8 Conclusion

The Brigalow Belt is a major cattle producing region in Queensland but faces challenges from declining productivity due to pasture rundown, deteriorating land condition and pasture dieback. Building pasture resilience by expanding the integration of legumes into grazing pastures provides substantial benefits for pasture productivity and utilisation, carrying capacity and liveweight gain, which can generate access to premium markets. Despite these benefits, the extent of successful legume adoption is relatively low, indicating a large opportunity for the beef industry to improve production and returns.

Past work has shown that integrating legumes into grazing pastures can improve farm profitability. This report extended on this work by evaluating the economic implications from establishing legumes across several land productivity types using a range of establishment methods.

8.1 Legume species findings

The results highlight where the biggest opportunities and trade-offs lie for different legume species across land types. Leucaena had high upfront establishment costs and ongoing maintenance expenses but delivered substantial production gains. Planting leucaena also increased profitability by $62,400-$103,400/year, with an annual rate of return of 25-31% and a 9-10 year payback, albeit with a large peak cash flow deficit that producers would need to be able to sustain.

The desmanthus/stylo scenarios had low to high establishment costs depending on the method and P application; establishing these legumes increased profitability in all arable land scenarios, with strip planting consistently outperformed other options through higher profitability, strong rates of return, relatively short payback periods and moderate peak deficits.

Medics had relatively low establishment costs and, despite reliance on inferred animal performance, also produced large pasture and cattle production benefits, with strip planting again outperforming the low cost option on profitability and rate of return, though with higher peak deficits.

Across species, most legume methods were profitable, but there was no “best” species in all circumstances because performance depended on establishment method, land type and fertiliser use. Leucaena scenarios generated the highest net present value, while desmanthus/stylo scenarios achieved the highest rates of return, lowest peak deficits and some of the fastest payback periods.

8.2 Establishment method, land type and fertiliser findings

Comparing establishment methods for desmanthus/stylo showed that strips planting generated slightly higher profitability than high-cost whole-paddock renovation, but much higher rates of return, faster payback and lower peak deficits, while the low-cost whole-paddock option produced the lowest returns and longest payback.

High and moderate productivity land types generated stronger returns and faster payback periods than low productivity land; arable low productivity land next, with non-arable land having the weakest performance. These results suggest that legumes should be prioritised on higher productivity land before lower productivity, and non-arable land last.

Applying P fertiliser to increase legume yields improved profitability for all legume species when using effective establishment methods and particularly strong gains in rate of return and payback on low productivity land where P deficiency constrained production.

8.3 Key grazier recommendations

Recommendations differ by land type and by which investment performance measures producers prioritise.

On high productivity land, establishing leucaena generated the largest increase in profitability, while desmanthus/stylo strips delivered the second largest profitability gain along with the highest rate of return and one of the fastest payback periods. Medic low-cost options offered high rates of return and low peak deficits but were among the least profitable overall. Consequently, producers may be better off starting with a smaller area of a higher-return legume option.

On moderate productivity land, desmanthus/stylo strips performed well across all measures (especially when P was applied), whereas leucaena generated the largest increase in profitability but ranked lower in other metrics.

On arable low productivity land, desmanthus/stylo in strips with P performed well across all performance metrics, the high-cost whole-paddock option generated the second largest increase in profitability but weaker results in other measures, and strips without P performed consistently but with moderate profitability gains. On non-arable, low productivity land, stylo strips performed the best across all performance measures.

Overall, producers with strong capital positions may prioritise options that maximise profitability, while more risk averse or capital constrained producers may focus on shorter payback or lower peak deficits, potentially by using high return methods over smaller areas.

8.4 Usefulness for industry

The integration of legumes into grazing pastures is less likely to be widely implemented when there is limited information or perceived risks to production and business bottom lines. This project has created information to assist producers with considering the ‘value proposition’ of adopting legumes under a range of scenarios. Factors examined include identifying (1) what pasture combinations and establishment methods work well, and not so well, on different land types, and (2) key investment performance measures that can help producers identify options that best suit their business circumstances and financial situation to support their investment decisions. These findings will facilitate the development of recommendations and extension-friendly resources to help guide and shape future investment decisions.

9 Future Recommendations

The opportunities to introduce leucaena or desmanthus/stylo into grazing systems are potentially large. For this to be done successfully, it is important that these opportunities (as well as the pitfalls that may befall them) are examined in detail. To better understand and quantify the effects of introducing legume pastures, this can be divided into areas that interact with animal functions, economic responses and investment requirements.

9.1 Animal production research

Most of the weight gain trials completed to date have not examined the interaction with feed supplementation (especially in low productivity zones), which like pastures, can supply protein, P and other minerals. This would be a useful research area to help graziers understand the optimal economic combination. Connected to this is the implication for methane reductions from differing feedstocks. While the productivity zones attempted to differentiate between different soil-types, there is still a wide variety of soil constraints, pasture composition and climatic conditions. More work is needed to understand the best economic options over a wider range of constraints.

This study focuses on steer weight gain and cattle numbers as the primary outputs. However, improved diets from legume rich pastures are also likely to have an impact on breeder productivity. For breeding operations considering establishing legumes, it would be relevant to extend the analysis to consider the wider economic implications for a breeding operation.

There has not been grazing trials that have directly measured cattle liveweight gain from tropical grasses (i.e. C4 grasses) with temperate legumes. Medic is the main temperate annual legume used with tropical grasses in the Queensland Brigalow Belt, however other legumes are used in NSW. Grazing trials that directly measure the impact that temperate legumes have on cattle liveweight gains would improve confidence in the economic results.

9.2 Research and demonstration of legume establishment methods

Results from the analysis indicate that establishing legumes in strips reduces establishment costs, risk of failure and provides good economic returns. However, there have been few grazed paddock examples of legumes established in strips and the assumptions for this analysis were extrapolated from results of plot trials that recorded 4-5 times higher legume yield from a long fallow with post emergence weed control compared to a medium length fallow (Peck et al., 2017). Key knowledge gaps include:

- Rate of spread out of the legume strips into surrounding grass (to achieve full production of legume across the whole paddock).
- Grazing behaviour impact on seed set and rate of spread. For example, do cattle selectively graze along the strip and severely retard seed set and therefore rate of spread of the legume.
- Animal performance assumptions. The analysis assumed liveweight gain improvements in through improved diet quality immediately after planting (at lower stocking rates); however, if selective grazing and seed set issues (described above) inhibit grazing management then live weight gains will likely be lower.

Furthermore, to achieve widespread adoption of legume establishment in strips, management recommendations are needed around grazing and promoting recruitment of legumes.

9.3 Land condition

The baseline grass-only scenarios for the different land types were assumed to have good land condition (e.g. A or B). Though, establishing legumes and sown grass can also have a role in rehabilitating degraded land condition. Therefore, it would be useful to evaluate the economic implications from rehabilitating degraded land condition:

- Especially rehabilitating C condition land due to the dominance of less desirable grasses such as Indian couch, African lovegrass, other weedy lovegrasses, pitted bluegrass dominant pastures etc – where the soil is still in good condition.
- Rehabilitating land in poor condition where soil condition has deteriorated (loss of topsoil) and rehabilitation will not achieve the production levels preceding the land condition decline.

9.4 Carbon emissions accounting

There is an increasing emphasis on reducing carbon emissions (e.g. methane) in grazing systems and achieving wider emissions reduction targets. Given legume establishment can substantially improve cattle liveweight gains and reduce cattle growth periods, it is also likely to reduce carbon emissions per kg of liveweight gain. Thus, it would be useful to measure how much the different legume establishment scenarios reduce carbon emissions by and if there are certain strategies that generate relatively larger reductions than the alternatives.

9.5 Economic analysis - additional modelling

There are large areas of uncertainty that need to be explored including medics, cool climate legumes, and matching varieties specific to soil and location. While much work has been done on leucaena, there are opportunities to vary the frequency of pruning to optimise utilisation and digestibility within the constraint of maintenance costs.

Leucaena can die out in less suitable locations (e.g. drier interior, southerly and frosty, lower water holding capacity and fertility soils). It would be useful to model a scenario with deteriorating production from a relatively early age (e.g. years 5-10) until it is completely gone by about year 15-20.

In regard to the constraint of using long term averages which ignore the timing of variable establishment conditions, it would add to the understanding of risk by modelling seasonal variability. What are the returns like if established during a run of wet years, compared to a run of dry years. This may confirm why some producers who encounter favourable establishment conditions at the start go from strength to strength, while others who follow the same practices but under adverse conditions experience a financial loss.

9.6 Extension recommendations

There are a wide range of options and considerations when deciding how to establish legumes into existing grass pastures. Graziers need to decide which options suit their situation considering their soil types, climate, suitable legume species, existing pasture, productivity levels, financial situation and the impact on their production system. This bio-economic analysis can help graziers and their advisors consider their options and decide where and how to invest their time and money.

This report quantifies the economic impact of a range of legume establishment methods on different land types which can assist graziers to decide which options suit their situation, however it is written as a technical report. Developing a range of extension products and messages based on the information in this report would make it accessible to a wider audience. It is recommended that extension publications and delivery packages should be developed (e.g. fact sheets, webpages, presentations, option analysis) which are distributed, discussed and presented at extension events and through on-line formats.

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11 Appendix 1

Table 38, Table 39 and Table 40 show the pasture production parameters for all scenarios and their associated abbreviated code.

The following abbreviations were used to identify the different scenarios:

- *Hi, Mid, Lo* and *LoNA* refer to land productivity classes: high, moderate, low or low non-arable.
- *Leucaena, Des/Stylo* and *Medic* refer to the legume species planted: leucaena, desmanthus and/or stylo (depending on soil / climate) or medic.
- *Hi$, Lo$* and *Strip* refer to the establishment method: high-cost whole-paddock establishment, low-cost whole-paddock establishment using a single pass, or strip planting.
- *LngFal, MidFal* and *NoFal* refer to fallow period before planting: long fallow (9 months), medium fallow (6 month) or no fallow (0 months). These abbreviations were only used where fallow period was shorter than assumed best practice, which is defined as 9 months for summer-planted crops, and 4 months for autumn-planted medics, or in the case of *LngFal,* where there was potential confusion with a similar scenario.

Table 38: Pasture scenario assumptions for high productivity land.

Land product-ivity	Legume	Establish-ment method	Failure rate	Phos. applied	Abbreviation	Dry matter produced (kg/ha)	Utilis-ation (%)	Dry matter available (kg/ha)	End of dry residual (kg/ha)	Legume in diet (%)	Dry matter digest-ibility (%)	Carrying capacity (ha/AE)	LWT gain (kg/year)
High	-	-	-	-	Hi Base	5,000	30%	1,500	2,500	0%	55%	1.9	160
High	Leucaena	Strips	10%	No	Hi Leucaena Strip	6,800	45%	3,030	2,410	50%	61%	0.8	235
High	Des/Stylo	Whole paddock	85%	No	Hi Des/Stylo Lo$ NoFal	6,500	41%	2,675	2,525	25%	59%	1.0	210
High	Des/Stylo	Whole paddock	20%	No	Hi Des/Stylo Hi$ MidFal	6,500	41%	2,675	2,525	25%	59%	1.0	210
High	Des/Stylo	Whole paddock	10%	No	Hi Des/Stylo Hi$ LngFal	6,500	41%	2,675	2,525	25%	59%	1.0	210
High	Des/Stylo	Strips	5%	No	Hi Des/Stylo Strip	6,500	41%	2,675	2,525	25%	59%	1.0	210
High	Medic	Whole paddock	75%	No	Hi Medic Lo$ NoFal	6,500	40%	2,625	2,575	43%	59%	1.3	210
High	Medic	Strips	5%	No	Hi Medic Strip	6,500	40%	2,625	2,575	43%	59%	1.3	210

Table 39: Pasture scenario assumptions for medium productivity land.

Land product-ivity	Legume	Establish-ment method	Failure rate	Phos. applied	Abbreviation[A]	Dry matter produced (kg/ha)	Utilis-ation (%)	Dry matter available (kg/ha)	End of dry residual (kg/ha)	Legume in diet (%)	Dry matter digest-ibility (%)	Carrying capacity (ha/AE)	LWT gain (kg/year)
Moderate	-	-	-	-	Mid Base	3,750	25%	938	2,250	0%	54%	3.1	145
Moderate	Leucaena	Strips	10%	No	Mid Leucaena	5,150	41%	2,128	1,993	56%	60%	1.2	220
Moderate	Leucaena	Strips	10%	Yes	Mid Leucaena +P	6,800	45%	3,030	2,410	50%	61%	0.8	235
Moderate	Des/Stylo	Whole paddock	85%	No	Mid Des/Stylo Lo$ NoFal	4,950	34%	1,665	2,295	32%	58%	1.6	195
Moderate	Des/Stylo	Whole paddock	20%	No	Mid Des/Stylo Hi$ MidFal	4,950	34%	1,665	2,295	32%	58%	1.6	195
Moderate	Des/Stylo	Whole paddock	10%	No	Mid Des/Stylo Hi$ LngFal	4,950	34%	1,665	2,295	32%	58%	1.6	195
Moderate	Des/Stylo	Whole paddock	10%	Yes	Mid Des/Stylo Hi$ LngFal +P	6,500	41%	2,675	2,525	25%	58%	1.0	210
Moderate	Des/Stylo	Strips	5%	No	Mid Des/Stylo Strip	4,950	34%	1,665	2,295	32%	58%	1.6	195
Moderate	Des/Stylo	Strips	5%	Yes	Mid Des/Stylo Strip +P	6,500	41%	2,675	2,525	25%	59%	1.0	210
Moderate	Medic	Whole paddock	75%	No	Mid Medic Lo$ NoFal	4,950	37%	1,838	2,123	49%	58%	1.8	195
Moderate	Medic	Whole paddock	75%	Yes	Mid Medic Lo$ NoFal +P	6,500	40%	2,625	2,575	43%	59%	1.3	210
Moderate	Medic	Strips	5%	No	Mid Medic Strip	4,950	37%	1,838	2,123	49%	58%	1.8	195
Moderate	Medic	Strips	5%	Yes	Mid Medic Strip +P	6,500	40%	2,625	2,575	43%	59%	1.3	210

[A] *Abbreviations such as +P indicates that additional P fertiliser was applied.*

Table 40: Pasture scenario assumptions for low and low non-arable productivity land.

Land product-ivity	Legume	Establish-ment method	Failure rate	Phos. applied	Abbreviation	Dry matter produced (kg/ha)	Utilis-ation (%)	Dry matter available (kg/ha)	End of dry residual (kg/ha)	Legume in diet (%)	Dry matter digest-ibility (%)	Carrying capacity (ha/AE)	LWT gain (kg/year)
Low arable	-	-	-	-	Low Base	2,500	20%	500	1,625	0%	54%	5.9	130
Low arable	Des/Stylo	Whole paddock	85%	No	Low Des/Stylo Lo$ NoFal	3,100	29%	895	1,740	30%	56%	3.1	180
Low arable	Des/Stylo	Whole paddock	20%	No	Low Des/Stylo Hi$ MidFal	3,100	29%	895	1,740	30%	56%	3.1	180
Low arable	Des/Stylo	Whole paddock	20%	Yes	Low Des/Stylo Hi$ MidFal +P	4,950	34%	1,665	2,295	32%	58%	1.6	195
Low arable	Des/Stylo	Strips	5%	No	Low Des/Stylo Strip	3,100	29%	895	1,740	30%	56%	3.1	180
Low arable	Des/Stylo	Strips	5%	Yes	Low Des/Stylo Strip +P	4,950	34%	1,665	2,295	32%	58%	1.6	195
Low non-arable	-	-	-	-	LoNA Base	2,000	15%	300	1,400	0%	54%	9.8	115
Low non-arable	Des/Stylo	Whole paddock	85%	No	LoNA Stylo Lo$ NoFal	2,300	23%	535	1,420	25%	56%	5.3	165
Low non-arable	Des/Stylo	Strips	20%	No	LoNA Stylo Strip MidFal	2,300	23%	535	1,420	25%	56%	5.3	165