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Use of phosphorus fertiliser for increased productivity of legume-based sown pastures in the Brigalow Belt region – a review

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Abstract

The Brigalow Belt bioregion of southern and central Queensland supports a large percentage of northern Australia's sown pastures and beef herd. The Brigalow soils were widely thought to have adequate phosphorus (P) for cropping, sown pastures and grazing animals, which has led to almost no use of P fertiliser on sown pastures. The majority of pastures established in the region were sown with tropical grasses only (i.e. no legumes were sown). Under grass-only pastures, nitrogen (N) mineralisation rates decline with time since establishment as N is 'tied-up' in soil organic matter. This process leads to a significant decline in pasture and animal productivity and is commonly called 'pasture rundown'. Incorporating pasture legumes has been identified as the best long-term solution to improve the productivity of rundown sown grass pastures. Pasture legumes require adequate P to grow well and fix large amounts of N to increase the productivity of rundown sown grass pastures.

Producers and farm advisors have traditionally thought that P fertiliser is not cost-effective for legume-based improved pastures growing on inland areas of Queensland despite there being little, if any, data on production responses or their economic outcomes. Recent studies show large and increasing areas of low plant available soil P and large responses by pasture legumes to P fertiliser on Brigalow soils.

The economic analysis in this scoping study indicates potential returns of 9–15% on extra funds invested from the application of P fertiliser, when establishing legumes into grass pastures on low P soils (i.e. lower than the critical P requirement of the legume grown). Higher returns of 12–24% may be possible when adding P fertiliser to already established grass/legume pastures on such soils.

As these results suggest potential for significant returns from applying P fertiliser on legume pastures, it is recommended that research be conducted to better quantify the impacts of P fertiliser on productivity and profit. Research priorities include: quantifying the animal production and economic impact of fertilising legume-based pastures in the sub-tropics for currently used legumes; quantifying the comparative P requirements and responses of available legume varieties; understanding clay soil responses to applied P fertiliser; testing the P status of herds grazing in the Brigalow Belt; and quantifying the extent of other nutrient deficiencies (e.g. sulphur and potassium) for legume based pastures. Development and extension activities are required to demonstrate the commercial impacts of applying P fertiliser to legume based pastures.

Executive Summary

Background:

The Brigalow Belt bioregion is an important part of the northern Australian beef industry as it carries a high proportion of the herd and supports relatively high stocking rates and growth rates. The Brigalow Belt carries approximately 30% of the northern Australian beef herd on 15% of the grazed land area. This high productivity is largely due to sown grass pastures growing on relatively fertile soils in a moderate rainfall zone.

Although these sown grass pastures are highly productive compared to most of northern Australia, their productivity has declined dramatically since they were first established, due to ‘pasture rundown’. ‘Pasture rundown’ is the decline in grass growth due to a decline in available nitrogen in the soil with increasing age of the pasture stand. Improving the productivity of rundown sown grass pastures in the Brigalow Belt bio-region has the potential to have a large impact on the beef industry, due to the large percentage of the herd that it carries, and relatively high value of animals produced.

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from rundown sown grass pastures, through their ability to biologically fix atmospheric nitrogen. Nitrogen fixation by legumes results in higher quality forage for a longer period of the year than grass-only pastures, and additional nitrogen cycling to companion grasses, which leads to better grass growth. However, for legumes to grow well and fix large amounts of nitrogen they need good nutrition. Phosphorus (P) is the most commonly limiting nutrient for pasture legume growth.

Soil P levels in Brigalow soils have been widely thought to be adequate for both grazing animals and sown pastures, which has resulted in very low use of P fertiliser on pastures. Unfortunately, there is increasing evidence that suggests this widely accepted belief is inaccurate and that graziers need to consider using P fertiliser to improve productivity.

Project objectives:

Legumes are recognised as being the best option to improve the productivity of rundown sown grass pastures; however, the results of introducing legumes into larger paddocks under commercial conditions have been mixed. The nutrition of pastures, especially phosphorus nutrition of legumes, is likely to be one of the contributing factors to mixed commercial results. There have been few trials on phosphorus nutrition of pastures in the Brigalow Belt. The aims of this review and scoping study were to:

- review what is known about P nutrition of pastures in the Brigalow Belt
- conduct bio-economic modelling to indicate where and when application of P fertiliser may improve returns
- identify research, development and extension (RD&E) priorities for industry.

Major conclusions:

Past studies on P in the Brigalow Belt show that:

- Low plant available P levels are common in Brigalow Belt soils.
- Long histories of cropping and export of P in grain and via erosion has led to reductions in soil P levels (and other nutrients). When these cropping soils are abandoned or sown to pastures, the resulting pasture productivity is often constrained by low nutrient levels.
- Even where plant available P is adequate when pastures are first established, P availability is expected to decline with time and could lead to P deficiency for pasture legumes.
- Pasture legumes, either those commonly used or those showing promise as permanent pastures, respond strongly to applied fertiliser P on low P soils.
- Cattle in two current grazing trials on Brigalow clay soils have low or marginal P levels, suggesting P deficiency of stock could be more widespread than previously thought and not currently recognised by industry as a problem.

Bio-economic modelling was used to evaluate the likely returns at the paddock scale from applying P fertiliser to low P soils, with either an existing grass/legume pasture or when establishing a legume into a grass-only pasture. The analysis assumed that pastures were growing on Brigalow soils where P deficiency is the main constraint to pasture legume growth. Broadly speaking the scenarios analysed were:

- 3 soil fertilities – very low, low and moderate soil P levels (Colwell P of 4, 8 and 12 mg/kg respectively)
- 3 levels of legume P responsiveness – critical soil P requirements that were either low, moderate or high (Colwell P of 10, 15 and 25 mg/kg respectively)
- 2 fertiliser strategies – applying P fertiliser to achieve either maximum legume yield or 75% of maximum
- 4 pasture situations:
    - establishing legumes into grass-only pasture
    - legume-based pasture where legume has low P requirement
    - legume-based pasture where legume has moderate P requirement
    - legume-based pasture where legume has high P requirement
- With and without P supplements when soil Colwell P was <10mg/kg. Without P supplements when Colwell P was >10mg/kg.

The bio-economic modelling suggests that:

- Applying P fertiliser to existing grass-legume pastures on P deficient soils is likely to be profitable. Returns of 12–24% on the extra inputs appear achievable.
- Returns from establishing legumes with P fertiliser into existing sown grass pastures on deficient soils are often likely to be positive. Returns on the extra input costs of 9-15% seem achievable.
- Returns for establishing legumes into existing grass pastures (with P fertiliser application on deficient soils) will generally be higher on soils with higher starting P levels (i.e. very low P<low P<moderate P<adequate P). This implies soils with adequate P levels should be the first to be improved. Establishing legumes into soils with adequate P can provide returns of 15-30% on the extra inputs.
- Returns from P fertiliser application to existing grass-legume pastures on deficient soils were generally positive for all legume types.
- In the absence of P fertiliser, returns from P deficient soils are likely to be greater with low P-requiring legumes.
- Supplementing stock with P when grazing unfertilised grass or grass-legume pastures on soils with very low levels of P will generally increase profit.

- Fertiliser rates that were adequate to meet the needs of legumes will generally avoid the need to feed P supplement.

Recommendations:
Pasture legumes are the most promising option for improving the productivity of rundown sown grass pastures in the Brigalow Belt. For legumes to realise their potential, they must become more reliably productive on commercial properties. Improving the nutrition of pasture legumes is likely to play a significant role in improving their reliability. The potential economic returns from adoption of productive legumes into existing grass pastures to individual graziers and the industry, as a whole, provides a persuasive argument for significant RD&E investment.

RD&E priorities include:
1. Demonstrating the animal production response and economic impact of P fertiliser applied to legume-based pastures at the paddock scale in the sub-tropics, and developing recommendations for important legume species.
2. Pot trials to rapidly develop comparative response curves for adapted legumes to establish critical P requirements and rate of response to applied P for legumes.
3. Test the field responses of legumes to applied fertiliser (rate and application method). Key measures to be quantified include pasture yield, nitrogen fixation response and pasture composition changes.
4. Understand Brigalow clay soil responses to fertiliser P, i.e. how much fertiliser and how often does it need to be applied to achieve critical P levels.
5. Develop a better understanding of the extent and impact of P deficiency on animal production (i.e. screen herds for their P status).
6. Test the extent of other nutrient deficiencies (e.g. sulphur, potassium) for pasture legumes.

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1 Project background and objectives

The Brigalow belt is an important region for beef production in northern Australia as it carries a high proportion of the herd, supports high stocking rates and high animal performance (i.e. reproduction and growth rates). This high productivity is largely due to sown grass pastures growing on relatively fertile soils in a moderate rainfall climate. The region also supports a large percentage of Queensland's grain production with many 'mixed farms' that have both cropping and grazing enterprises.

Although sown grass pastures growing on Brigalow soils are highly productive compared to most of northern Australia, their productivity has declined dramatically since they were first established, due to 'pasture rundown'. 'Pasture rundown' is the decline in grass growth due to a decline in available nitrogen in the soil with increasing age of the pasture stand.

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from rundown sown grass pastures through their ability to biologically fix atmospheric nitrogen. However, for legumes to grow well and fix large amounts of nitrogen they need good nutrition. Phosphorus (P) is the most commonly limiting nutrient for pasture legume growth.

Phosphorus deficiency is widespread in northern Australia with 70% of soils being estimated to have P levels low enough to cause P deficiency in cattle (McCosker and Winks, 1994). Soil P levels in the Brigalow Belt have generally been thought to be high relative to most of northern Australia, however, there is increasing evidence that P deficiency is limiting pasture legume and animal production in the region.

This project, therefore, re-assessed the extent of P deficiency in the Brigalow belt bioregion and the role P fertiliser may play in improving productivity. The project objectives were to:

1. Review literature and other information relevant to sub-tropical pastures in the Brigalow Belt bioregion for:
    a. critical P requirements of pasture legumes
    b. responsiveness of legumes to applied P fertiliser
    c. effectiveness of fertiliser application methods
    d. likely effect on animal production.
2. Conduct economic analyses to indicate where and when application of P fertiliser will cost-effectively increase productivity.
3. Identify research, development and extension priorities for industry.

2 Introduction

2.1 Brigalow Belt bio-region

The Brigalow Belt bio-region occupies approximately 36 million hectares of Queensland and New South Wales, stretching from Dubbo in the south to Townsville in the north. Approximately 80% of the bioregion is in Queensland (Figure 1).

Figure 1: Queensland Brigalow Belt bioregion (© Environmental Protection Agency 2008)

The Brigalow Belt bioregion includes a range of land types (including eucalypt woodlands and grasslands), but is characterised by clay soils where the native vegetation was dominated or associated with Brigalow (*Acacia harpophylla*). The soils were initially very fertile for agriculture, which led to large areas being cleared for grain cropping and sown pastures. Tree clearing, combined with the inherent soil fertility and moderate rainfall environment, contribute to it being a highly productive region of northern Australia.

2.1.1 Beef production

The Queensland section of the Brigalow Belt bioregion supports a significant percentage of northern Australia's sown pastures and beef herd.

The Australian Bureau of Statistics (ABS), together with the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), survey beef producers in northern Australia on a regular basis. Summarised statistics from the 2010-11 ABS survey are provided as a guide to livestock numbers and sown pasture area. Figure 2 shows the zones used by ABARES to group the regional production and financial data collected during surveys. A large part of the Queensland section of the Brigalow Belt bioregion is covered by zone 322 plus parts of 314, 321, 332 and 331.

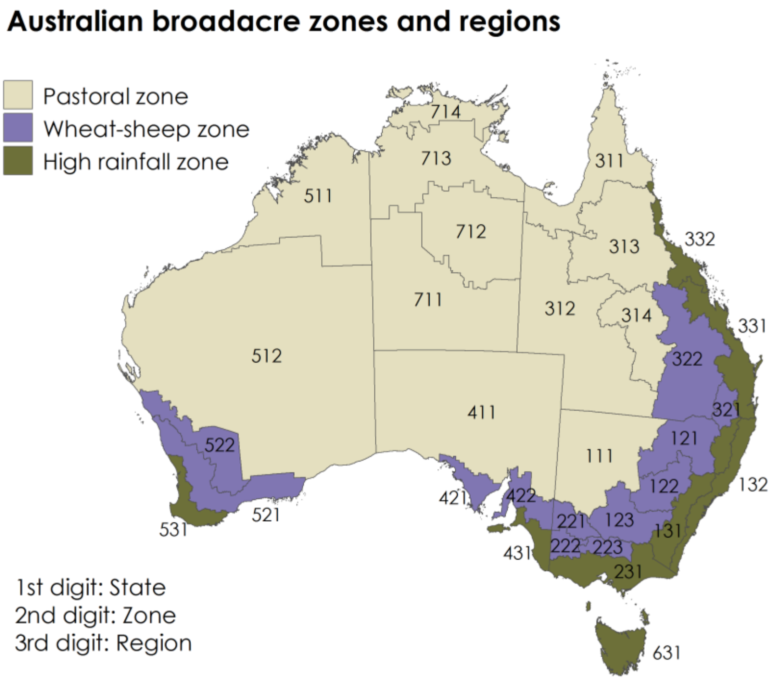

Figure 2: Australian broad acre zones and regions applied by ABARES

Table 1 summarises the data collected by the ABS during the 2010-2011 survey (ABS 2012) for specialist beef producers in northern Australia.

Table 1: Area of improved and other pasture, female breeder herd and total meat cattle northern Australia*.

Region	Grazing on improved pastures (ha)	Grazing on other land (ha)	Cows and heifers one year and over (no.)	Meat cattle (no.)	Stocking rate (grazed ha /head)
311	1,496,632	9,454,981	445,433	687,625	15.93
312	3,331,329	43,686,454	723,393	1,621,352	29
313	3,881,519	22,463,865	1,225,885	2,336,650	11.27
314	4,114,206	9,771,542	607,389	1,183,052	11.74
321	395,134	1,273,386	205,114	589,423	2.83
322	9,170,427	11,554,054	1,538,853	3,492,902	5.93
331	3,090,424	5,621,075	952,993	1,946,244	4.48
332	708,821	2,350,410	301,678	592,375	5.16
Subtotal	26,188,492	106,175,767	6,000,738	12,449,623	10.63
711	252,566	17,098,922	117,696	246,590	70.37
712	286,358	18,627,464	476,493	858,465	22.03
713	408,984	16,384,174	552,929	996,388	16.85
714	45,580	1,297,615	40,685	95,914	14
Subtotal	993,488	53,408,175	1,187,803	2,197,357	24.76
511	194,927	18,096,628	419,367	705,942	25.91
512 (part)**	5,421	28,057,703	173,074	284,136	98.77
Subtotal	200,348	46,154,331	592,441	990,078	46.82
Total	27,382,328	205,738,273	7,780,982	15,637,058	14.91

*Source: ABS 7121.0 - Agricultural Commodities, Australia, 2010-11 available at http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7121.02010-11

**Region 512 above latitude 26° comprises the shires of Ashburton, East Pilbara, Port Hedland, Roebourne, Exmouth, Upper Gascoyne, Meekatharra and Carnarvon and contains approximately 80% of the beef cattle in the total region.

Based on the figures in Table 1, the Queensland portion of the Brigalow Belt bioregion has more than 10 million hectares of improved pasture plus at least 2 million cows and heifers included in a total beef herd of approximately 5 million head. On this basis, 32% of the total beef cattle in northern Australia are carried by the Brigalow Belt bioregion on approximately 15% of the grazed land area. About 40% of the land area of the Brigalow Belt has been developed to improved pastures.

2.2 Sown pastures

Well adapted sown pastures enable higher productivity and profitability in grazing enterprises because they can produce more feed of a higher quality, for a longer period of the year than native pastures (Quirk and McIvor, 2005). They have been widely sown in northern Australia and continue to improve production and economic returns from grazing, especially the beef industry (Chudleigh and Bramwell, 1996; Walker and Weston, 1990). The largest areas of sown pasture development in Queensland has occurred on fertile soils that have been cleared of Brigalow and Gidgee woodlands and associated land types (Peck *et al.*, 2011).

Of the total area planted to sown pasture in northern Australia, 70% has been sown only with tropical grasses. Buffel grass (*Pennisetum ciliare*) is the most widely adapted and planted species comprising over 75% of the area sown to tropical grasses (Walker *et al.*, 1997; Walker and Weston, 1990). While the majority of sown pastures in the Brigalow Belt are dominated by buffel grass, there are also significant areas established with other species notably (Peck *et al.*, 2011):

- Bambatsi panic and purple pigeon grass on clay soils
- Rhodes grass, Green and Gatton panic (although many areas planted with these species subsequently converted to buffel grass)
- in more recent times, creeping bluegrass and digit grasses.

The better soils in the bioregion are also used for cropping activities, and some are being converted from cropping to grazing. Although many of these soils initially had adequate P levels for crop production, years of cropping with little or no P fertiliser being applied has now resulted in areas of P (and other nutrient) deficiency (Bell *et al.*, 2010). Most of these soils have also been depleted of soil organic matter (and hence nitrogen (N) and other nutrients) by the farming process (Radford *et al.*, 2007). When these soils can no longer reliably produce good crops, they are often converted to pasture, however, their degraded state often leads to relatively poor pasture and animal growth. Pasture and animal production on these depleted ex-cropping soils are destined to remain relatively low for the long-term unless nutrient deficiencies are addressed through the use of fertiliser.

2.2.1 Pasture 'rundown'

Sown pasture grasses are very productive when they are planted after clearing virgin Brigalow or softwood scrub forest or into fertile cropping soils. However, the productivity of these pastures typically declines with time, a phenomenon often described as "pasture rundown" (Myers and Robbins, 1991). The annual dry matter production from sown grass pastures can decline by 50–60% within five to ten years of establishment across a range of soils and seasons (Radford *et al.*, 2007; Graham *et al.*, 1981; Myers and Robbins, 1991). Animal production shows a similar trend with a linear decline of 20-70% in liveweight gains over the first five years of pastures when stocking rates are held constant (Radford *et al.*, 2007; Robbins *et al.*, 1987). However, individual animal performance may be maintained if stocking rates are reduced in line with the reduced pasture production (Radford *et al.*, 2007;

Burrows, 1991). The economic impact of pasture rundown to Queensland's grazing industry has been conservatively estimated at over $17B at the farm gate over the next 30 years (Peck *et al.*, 2011). Regaining some of the lost production from pasture rundown has the potential to dramatically increase beef production and economic returns across the Queensland beef industry.

The decline in pasture productivity with age is directly attributable to a lack of plant available N in the soil as the nitrogen and other nutrients become 'tied-up' in soil organic matter, roots and crowns of old grass plants (Robertson *et al.*, 1997). The majority of soil N is in organic forms, however, plants can only use mineral forms of N in the soil.

The large pasture yields produced initially when pasture grasses are established is a response to the high levels of available N and water that accumulate on fertile soils during a fallow prior to planting. However, dry matter production and subsequent animal performance decline as the available N reserves decline and become less available to pasture grasses (Graham *et al.*, 1981; Robbins *et al.*, 1987). The reduction in dry matter production can result in overgrazing if stocking rates are not adjusted accordingly, which in turn can lead to poor land condition and land degradation.

Given the time since land clearing and pasture establishment, and the low uptake of management options that mitigate the effects of pasture rundown, it is reasonable to assume that the vast majority of sown pastures in the Brigalow Belt are now 'rundown', i.e. productivity is severely reduced by N deficiency (Peck *et al.*, 2011).

2.2.2 Management options for rundown sown grass pastures

The reduction in productivity of sown grass pastures as they age is due to a reduction in the supply of available N in the soil. With age since sowing, more of the mineral N is incorporated into organic material, and its subsequent availability for plants each growing season is governed by the rate of mineralisation. Strategies for mitigating the impact of pasture productivity (Peck *et al.*, 2013), therefore, need to either:

- Accept the reduction in pasture productivity and adjust management of other aspects of the farm business to maintain animal, environmental and economic performance.
- Increase the rate of N cycling. Nitrogen is mineralised and made available to pasture plants through the decomposition of organic matter, therefore, those practices that increase the rate of decomposition increase the rate of N supply, e.g. mechanical renovation.
- Add additional N to the pasture sward through either N fertiliser or biological N fixation (i.e. legumes).

Legumes have been identified as the best long-term option for improving the productivity of rundown sown grass pastures (Peck *et al.*, 2012; Peck *et al.*, 2011; Myers and Robbins, 1991). Legumes can improve production of rundown grass pastures through biologically fixing atmospheric N, and thereby improving diet quality directly through providing higher quality forage, and indirectly by improving the growth and quality of companion grasses from increased N availability. However, commercial use of legumes has achieved mixed results with notable successes, but with many failures (Peck *et al.*, 2011). Many of the poor results from legumes can be attributed to poor establishment, which could be improved through the wider use of better agronomic practices.

Grass pasture growth is commonly limited, first by N, then by P or other nutrients. However, legumes can fix their own N from the atmosphere if they are well-nodulated with effective rhizobium. Consequently, P is more commonly a limitation for legumes rather than grass and has the potential to reduce legume productivity and persistence. Grass competition further restricts legume productivity and persistence on low P soils with some legumes not persisting or producing well in the absence of P fertiliser (Jones *et al.*, 1993; Shakhane *et al.*, 2013).

The production potential of many legumes recorded in research trials is often much higher than what is generally achieved commercially (Peck et al., 2011). Poor establishment is the most common reason for failure of legumes in commercial paddocks, which is often due to competition from the existing grass not being adequately controlled. Legume nutrition and grazing management are important for both establishment and long-term productivity of grass/legume pastures.

There is significant opportunity to improve commercial results from legumes using existing technologies; however, there is a need for targeted research to improve the reliability of establishment and productivity of legumes. Phosphorus and other nutrient deficiencies are contributing to poor commercial results with pasture legumes.

2.3 Phosphorus deficiency for cattle production in northern Australia

Phosphorus deficiency is common in cattle across northern Australia because most soils in northern Australia are very low in P, and cattle cannot get sufficient P from the pasture (Jackson *et al.*, 2012; McCosker and Winks, 1994). It has been estimated that 70% of soils in northern Australia have P levels low enough to cause P deficiency in cattle (Figure 3) (McCosker and Winks, 1994). The notable exceptions to the generally low P levels in northern Australia are the Brigalow Belt bioregion, Mitchell grass downs soils, the Channel Country in western Queensland and other alluvial soils elsewhere, and some areas along the coast of Queensland.

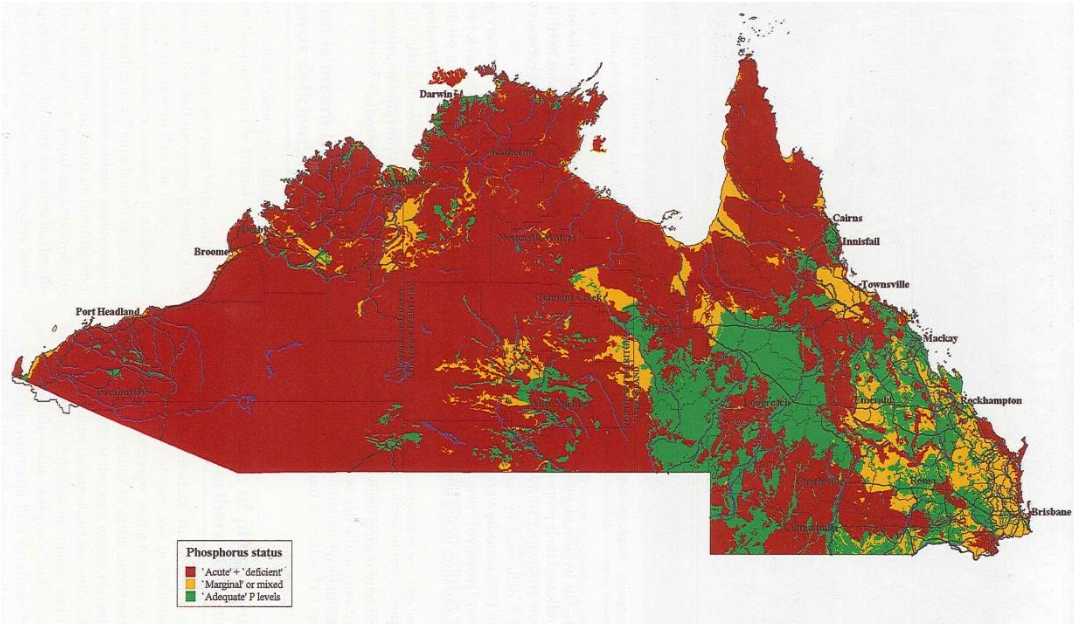

Figure 3: Map showing the phosphorus status of grazing lands in northern Australia as it relates to animal production (McCosker & Winks 1994)

Phosphorus availability in the soil is generally analysed using the Colwell extraction and expressed as milligrams of P per kg of soil (mg/kg) (Colwell, 1963). For beef cattle production, P deficiency in relation to soil Colwell P and supplementary feeding recommendations, have been summarised by Jackson *et al.* (2012) and previously by McCosker and Winks (1994) and is described in Table 2. The coloured shading in Table 2 relates to the colours on the map in Figure 3.

Table 2: Soil Colwell P levels (mg/kg) in relation to P deficiency in cattle (McCosker and Winks, 1994)

	Acute	Deficient	Marginal	Adequate
Soil phosphorus	<4	4-6	7–8	>8

The soil P levels shown in Figure 3, combined with the animal response to supplements (described in section 2.5) and paucity of fertiliser trial data with sown grass/legume pastures, has led to a paradigm for P where graziers and their advisors within the beef industry of northern Australia generally believe:

- Severe P deficiency in lower productivity environments in the west and north of Queensland, Western Australia and the Northern Territory is best addressed through directly supplementing stock.
- In high rainfall areas, predominantly along the Queensland coast, the higher pasture production potential means that fertilising pastures with P is economically worthwhile.
- In moderate rainfall environments such as the Brigalow Belt, fertilising with P is considered to not be economically viable.
- The clay soils of the Brigalow Belt have been considered to have adequate P for both cattle and pastures.

The generalised paradigm described above has led to very low (almost nil) use of P fertiliser on sown pastures in the Brigalow Belt (or elsewhere in northern Australia). Recent studies are showing that this paradigm needs to be re-evaluated for the Brigalow Belt. Briefly these studies show that:

- Low soil P levels are common within the Brigalow Belt (section 2.4).
- Pasture legumes either commonly used or showing promise as permanent pastures respond strongly to applied fertiliser P on low P soils (section 2.6 and 2.7).
- Cattle in current grazing trials have low or marginal P levels suggesting that P deficiency of stock is more widespread than previously thought (section 2.7).

2.4 Soil phosphorus levels in the Brigalow Belt

The map shown in Figure 3 shows that much of the Brigalow Belt has soil Colwell P levels >8 mg/kg and is therefore considered adequate for cattle. However, the mapping in Figure 3 is coarse, only considers the grazing animal, and most pasture legumes have critical P levels greater than 10 mg/kg (section 2.6).

Trial work comparing supplemented with un-supplemented stock on legume-based pastures, suggested animal liveweight gain approaches a maximum at a Colwell P of between 8-10 mg/kg (Kerridge *et al.*, 1990). Figure 7 (from the same trial work) shows a theoretical meeting of animal liveweight gains between supplemented and un-supplemented stock at a Colwell P of 13 mg/kg. The P nutrition manuals for the northern Australian beef industry both settled on describing >8 mg/kg Colwell P as being a level above, which the likelihood of getting good responses to P supplements reduces (McCosker and Winks, 1994; Jackson *et* *al.*, 2012). However, responses to supplements have been recorded up to 10 mg/kg (Ahern *et al.*, 1994). Ahern *et al.* (1994) reported difficulty in reaching a consensus between researchers and potential users of P mapping and supplement or fertiliser recommendations on what categories of Colwell P levels to use when describing P deficiency of pastures and cattle.

The relationship between soil Colwell P levels and pasture growth varies with species and soil type which has implications for the reliability of predicting animal responses from soil tests. There is also some variation in soil Colwell P levels with sampling method, laboratory technique, season and moisture status of the soil. Although there are limitations in linking soil test results to animal responses to P supplementation, it is still a useful tool for initial screening of potential P deficiency at the property and regional scale. For the purposes of this project the categorisation of Ahern et al. (1994) for describing P status was adopted and is described in Figure 4.

For the purposes of this review, legumes have been classified as having low (approximately <12 mg/kg), medium (approximately 12-20 mg/kg) or high (approximately >20 mg/kg) critical P requirements. Soil mapping and other data sources suggest that there are large areas with soil P levels where pasture legumes are likely to respond to applied P fertiliser. Specifically the other data sources or studies are:

- soils mapping of north-east Queensland (Ahern *et al.,* 1994)
- a departmental soils database (Lawrence *et al.* un-published data)
- Incitec soil test results and Queensland Government soil databases
- declining P availability under buffel grass pastures on Brigalow soils (Thornton *et al.*, 2010)
- long histories of cropping and export of P in grain has led to reductions in soil P levels (and other nutrients) (Bell *et al.,* 2010).

2.4.1 Phosphorus mapping

More detailed P mapping for the northern half of the Brigalow Belt is shown in Figure 4. This suggests that there are large areas where moderate (i.e. requiring approximately 12-20mg/kg) or high (i.e. requiring approximately >20mg/kg) P requiring legumes are likely to respond to applied P fertiliser.

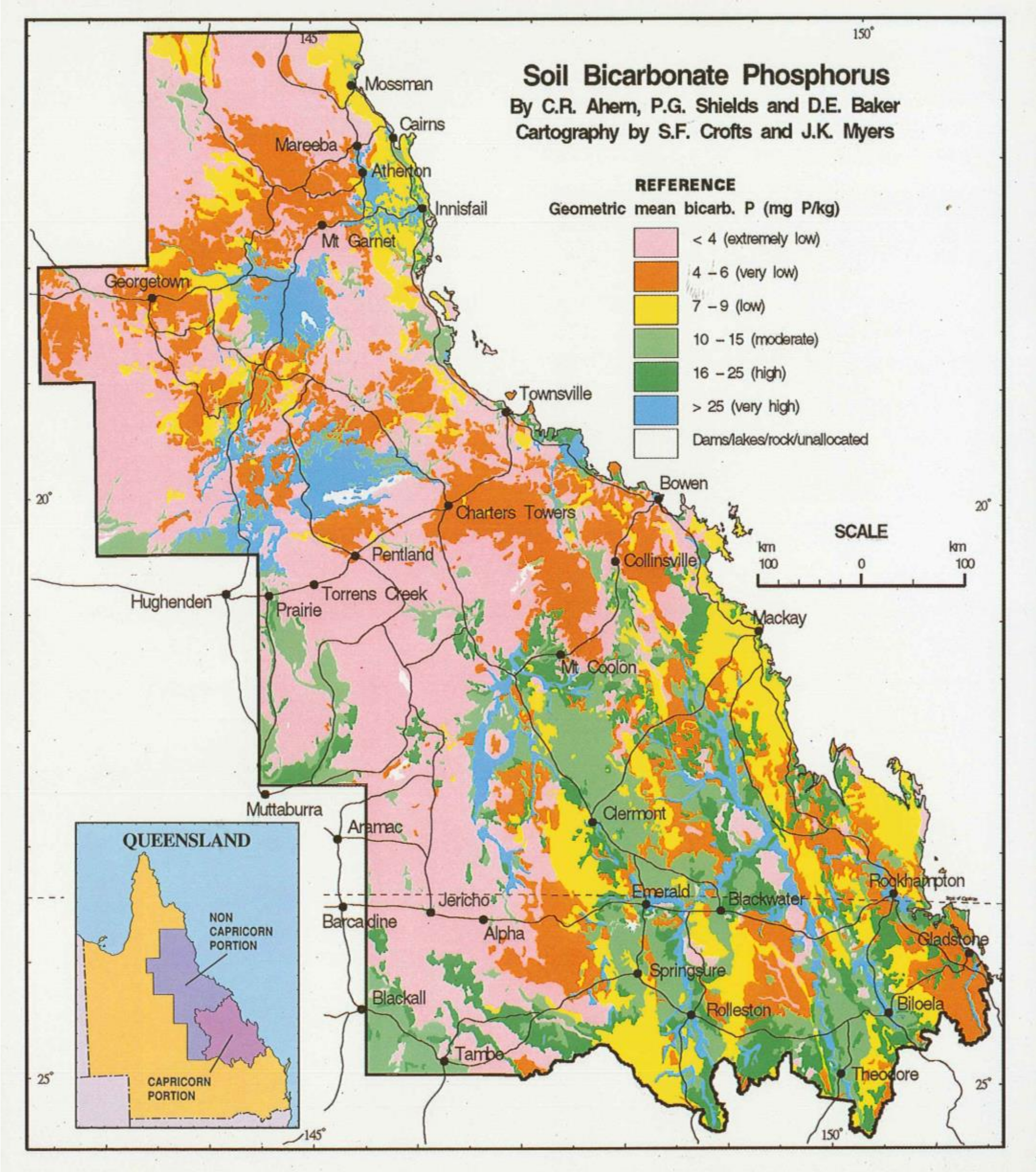

Figure 4: **Map showing soil Colwell P levels in north east Queensland (Ahern *et al.*, 1994)**

2.4.2 Soils databases

Table 3 and Table 4 show the soil Colwell P levels from an on-going collection of soil samples of more than 680 sites across southern and central Queensland (i.e. across the Brigalow Belt). Table 3 shows the number and percentage of soils within different Colwell P levels across all land types. Table 4 shows the number and percentage of soils within different Colwell P levels for samples collected from Brigalow/Belah/Softwood scrub land types. Soils have been collected since 2008 for paddock comparisons of soil organic matter and soil health assessments. Soil samples were subsequently analysed for P to help plan fertility strategies and pasture development where required. The data set contains (David Lawrence, November 2013):

- a range of soil types (Brigalow/Belah 51%; Downs/Coolibah 38%; Box/Sandalwood 8%; other 3%)
- 607 soil samples for Colwell bicarbonate P at 0-10 cm depth with a range of 1-280 mg/kg; mean 28 mg/kg

- 604 matching soils for BSES acid P at 0-10 cm depth with mean 131 mg/kg
- 390 matching soils for BSES P & Colwell P at 10-30 cm.

Table 3: Number and percentage of soil samples across all land types within Colwell P level ranges at 0-10cm depth with corresponding mean BSES P levels (Lawrence *et al.* un-published data)

P bicarbonate (0-10cm) mean 28 (1-280) mg/kg	**ALL SOILS**		
	No of samples	Percent of soils	P acid (Mean)
< 4 mg/kg	14	2%	6
4-6 mg/kg	53	9%	19
7-9 mg/kg	71	12%	13
10-15 mg/kg	134	22%	29
16-25 mg/kg	130	21%	57
>25 mg/kg	205	34%	325

Table 4: Number and percentage of soil samples from Brigalow/Belah/Softwood scrub land types within Colwell P level ranges at 0-10cm depth with corresponding mean BSES P levels (Lawrence *et al.* un-published data)

P bicarbonate (0-10cm) mean 25 (3-152) mg/kg	**Brigalow/Belah/Softwood scrub**		
	No of samples (255)	Percent of soils	P acid (Mean)
< 4 mg/kg	5	2%	7
4-6 mg/kg	28	10%	14
7-9 mg/kg	32	12%	14
10-15 mg/kg	59	21%	26
16-25 mg/kg	67	24%	94
>25 mg/kg	86	31%	103

Table 3 and Table 4 show that there are large areas of soils with Colwell P levels that are low enough for pasture legumes to respond to applied P fertiliser. Brigalow and associated clay soils had similar P levels to the average across all land types. Only 34% of soils tested had P levels high enough that high P requiring legumes are unlikely to respond to fertiliser (i.e. >25mg/kg). 23% of soils were less than 10 mg/kg, a level at which P deficiency of stock might occur and all legumes are likely to respond to P fertiliser.

Analysis of Queensland surface soil samples, de-identified and provided by Incitec Pivot Pty Ltd, collected from early 2012 to mid-2013, revealed very similar distributions to the unpublished Lawrence data. Of 227 surface samples, 31% had Colwell P values less than 10 mg/kg, 30% were between 11-25 mg/kg (11% were below 15 mg/kg), whilst 39% had >25 mg/kg Colwell P in the surface.

Of particular interest to legume nutrition was that soils that are low in P are normally also low in sulphur (S). Of the soils with low P levels that would be responsive to fertiliser for all legume types (i.e. Colwell <10 mg/kg), 85% had S (measured as MCP-S) values less than 5 mg/kg (Incitec Pivot Pty Ltd un-published data). Given that legumes also require higher S values to be productive, persistent and to fix large amounts of N, solutions to low P fertility also need to consider S nutrition.

Extracting just Vertosols and Dermosols (clay soils typical of the Brigalow Belt) from the Queensland Government soils database (12,555 samples) revealed a more disturbing picture of P status. 56% of 0-10 cm samples had Colwell P values less than 10 mg/kg, 18% between 11 and 25 mg/kg and just 26% were adequate for all legumes (i.e. >25 mg/kg).

2.4.3 Phosphorus cycling

Phosphorus availability for pasture growth depends on cycling within the soil. Biological decomposition of organic matter contributes some P, but most of the plant available P comes from the slow dissolution of sparingly soluble mineral sources.This relies on the P sorption potential of soils and the balance between strongly and weakly 'held' pools of P (Dubeux *et al.*, 2007).

As with N, the availability of P and other nutrients have an initial flush in availability (the 'run-up') when vegetation is cleared and burnt (and in some instances the soil cultivated), but there is a decline with time as pastures age. Figure 5 and Figure 6 shows trends in P availability over time after clearing and burning within three mini-catchment areas at the Brigalow Research Station (Cowie *et al.*, 2007; Thornton *et al.*, 2010). The pasture catchment had buffel grass pasture established. The cropping catchment was cropped for grain production but was established with butterfly pea in the twenty-seventh year. As available P is extracted from the soil and accumulates in plant material and soil organic matter, the plant available Colwell P in the soil declined from the initial flush at clearing. Acid extractable P (BSES P), which extracts more of the mineral reserves, declined in a similar manner to bicarbonate P (Figure 6).

The cropping catchment in this study has not had fertiliser applied and, in comparison to the buffel grass catchment, has higher levels of available P. The Colwell P and BSES P levels are higher in the cropped catchment despite the higher removal rates in produce and higher rates of erosion. This indicates that P availability declines under continuous pasture, while available P remains higher with cropping, due to accumulation of available P during fallows. Colwell P and BSES P levels seem to be converging between the cropped and the pasture catchments since the cropped catchment was established with a pasture legume (butterfly pea) in the twenty-seventh year.

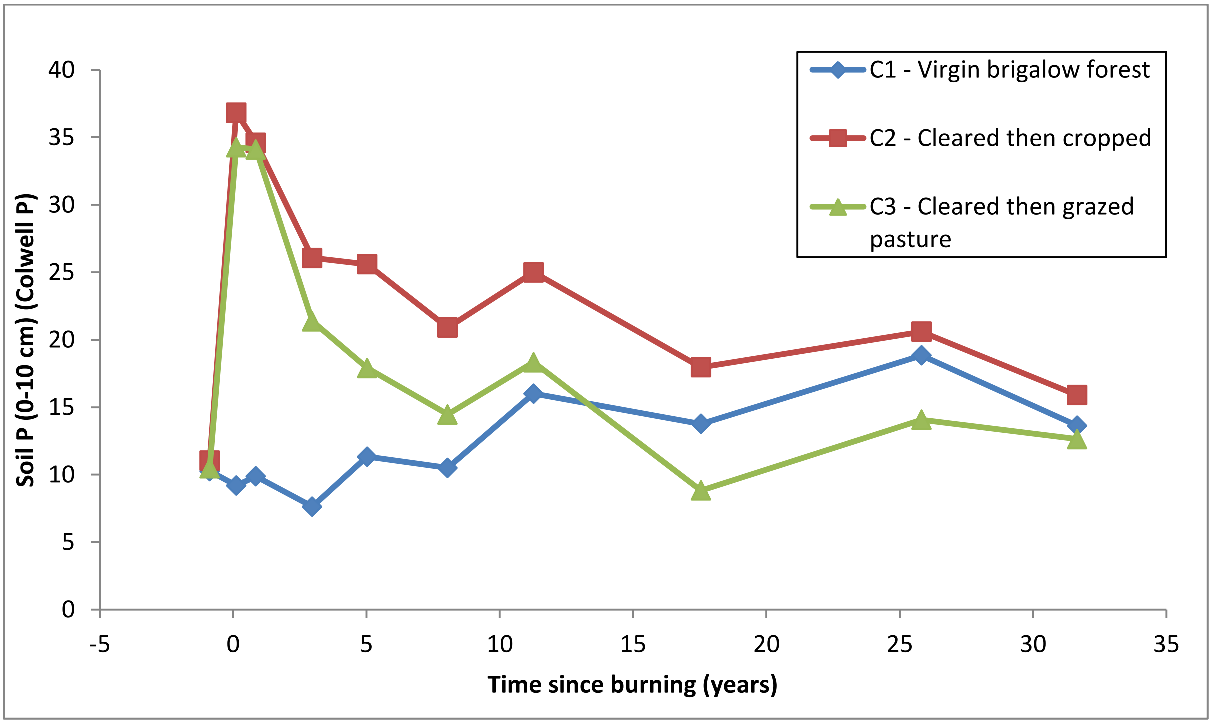

Figure 5: Phosphorus availability (Colwell P) with time since clearing and burning of Brigalow forest (Thornton *et al.*, 2010)

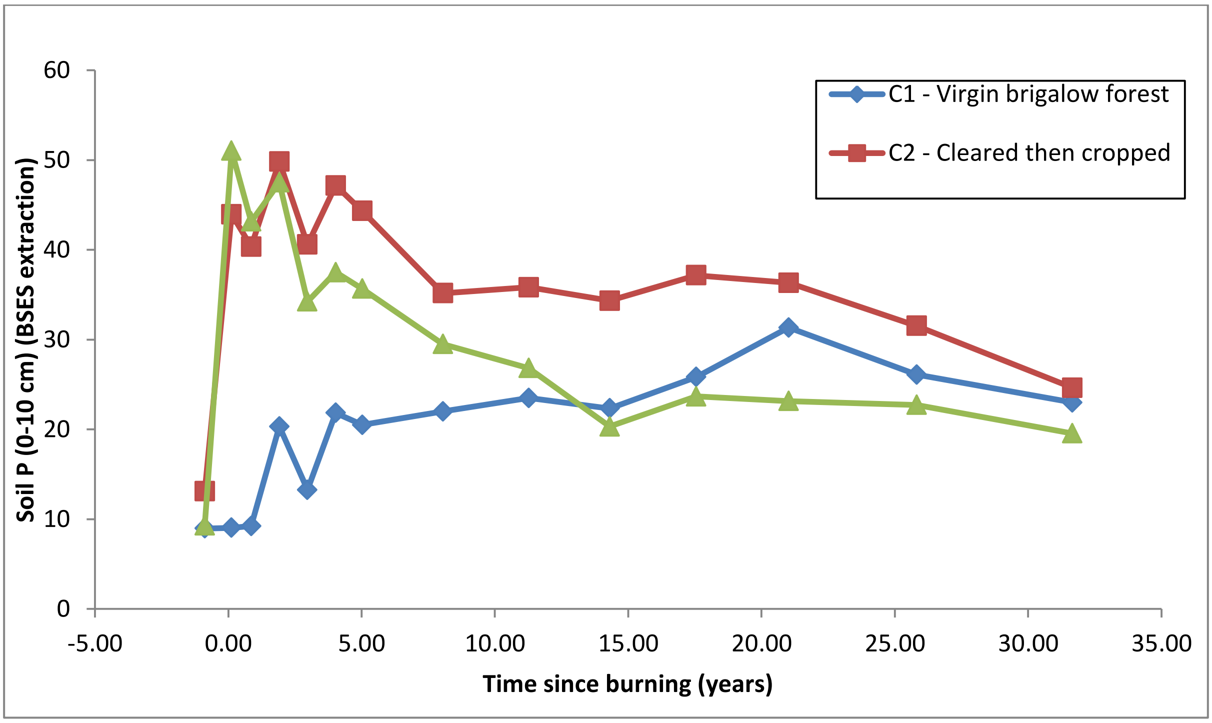

Figure 6: Acid extractable phosphorus (BSES P) levels over time since clearing and burning of Brigalow forest (Thornton *et al.* un-published data)

The apparent increase in available P in the virgin Brigalow forest in the 10 years after clearing is most likely due to nutrient redistribution from wallaby grazing, where they grazed the adjacent pasture areas but camped in the Brigalow remnant. An open ended wallaby fence was erected to maintain wallaby numbers to a more natural level. The P levels in the Brigalow forest catchment seem to have stabilised.

Figure 5 and Figure 6 demonstrate that, even where plant available P is adequate when pastures are established, it will decline with time and could lead to P deficiency for pasture legumes.

2.4.4 Phosphorus removal on mixed farms

Removal of nutrients in grain without replacement fertiliser is inducing P and other nutrient deficiencies on cropped soils in the Brigalow Belt (Bell *et al.*, 2010). Testing of cropped soils compared to adjacent un-cropped areas showed that current acid extractable P levels were as low as 20% of pre-cropping levels, with an average of 68% across southern and central Queensland cropping districts (Bell *et al.*, 2010).

The Brigalow Catchment Study (BCS) has monitored the land-use impacts of clearing Brigalow scrub and development either for pasture or grain cropping (Cowie *et al.*, 2007). The amounts of P removed in produce in the first five years after clearing were 7.0 kg/ha/year under cropping and 0.8 kg/ha/year under grazing (Cowie, 1993). In the same study, over 21 years after clearing, the amount of N exported in produce was 36.1 kg/ha/year from the cropping catchment, but only 1.6 kg/ha/year in cattle (calculated from liveweight gain). Total soil N at 0-0.3 m declined by an average rate of 84 kg/ha/year under cropping, but there was no significant decline under grazing (Radford *et al.*, 2007). Soil organic carbon (SOC) declined by an average rate of 1004 kg/ha/year in the cropped catchment (Radford *et al.*, 2007).

Induced nutrient deficiencies from long histories of cropping are an emerging issue for the red meat industries. When soils can no longer reliably produce a crop, they are normally sown (or abandoned) to pasture. The pastures established on these soils then often grow poorly with the legumes being unable to grow well enough to fix large amounts of N to counteract the effect of ‘pasture rundown’ (i.e. reduced N availability as it is tied up in soil organic matter as pasture stands age). The impact of reduced N availability is often expressed quicker on these soils compared to non-cropped soils due to the lower N mineralisation rates at pasture establishment.

Nutrient levels on ex-cropping soils are critical for long-term sustainability and high productivity from pastures. Pasture grasses require a large amount of N and other nutrients to grow well and contribute to improving SOC levels after cropping. For high pasture productivity, pasture legumes must grow well to replace the large amount of N that is removed through a history of grain cropping. Phosphorus, and other nutrients, are likely to be a major determinant of whether incorporating legumes into pastures on ex-cropping soils is successful or not.

2.4.5 Soil phosphorus conclusions

The paradigm within the beef industry that phosphorus is adequate for pasture growth and animal production on Brigalow soils needs to be reassessed. Although there are areas with good soil phosphorus levels, there are large areas where pasture growth is likely to be limited if legumes are established, and there are also areas where animals are likely to be deficient. These issues of reduced P availability present a major challenge to improving long-term beef production in the region.

2.5 Cattle performance in relation to soil phosphorus

Phosphorus deficiency has a severe impact on beef cattle production in northern Australia (Jackson *et al.*, 2012). Phosphorus deficiency results in poor appetite and feed intake, poor growth, higher breeder mortality, reduced fertility and milk production, bone breakage and, in severe cases, bone deformities. Added to the poor performance is an increased risk of livestock deaths from botulism when unvaccinated cattle chew bones and carcases in their craving for P.

Supplementing stock with P when they are deficient can provide large livestock productivity gains. Figure 7 shows the liveweight response of supplemented and un-supplemented stock grazing native pastures over-sown with pasture legumes at different soil P levels. Indicative livestock responses to P supplementation for different levels of deficiency and corresponding typical soil Colwell P levels are shown in Table 5.

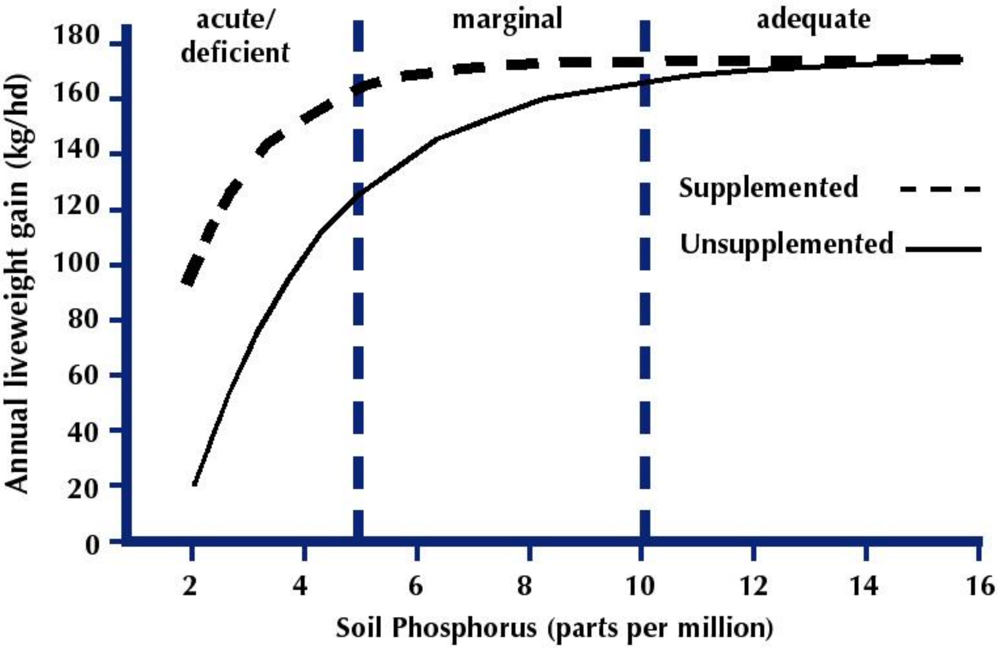

Figure 7: Relationship between annual liveweight gain and bicarbonate extractable soil P for P-supplemented and non-supplemented cattle grazing legume based pastures at four sites in the semi-arid tropics of northern Australia (Kerridge *et al.*, 1990)

Table 5: Likely response of cattle to feeding of P supplements grazing native pastures and stylo augmented native pastures on P deficient soils in northern Australia (Jackson *et al.*, 2012)

	Acutely deficient	Deficient	Marginal
Typical soil Colwell P (mg/kg)	<4	5	6-8
Likely weight response to P supplement by growing cattle (kg/Year)			
Native pasture	30 - 40	20 - 40	0 - 20
Stylo pasture	45 - 70	40 - 60	0 - 40
Likely weight response to P supplement by breeder cattle grazing native pasture			
Increased weaning rate (%)	10 - 30	10 - 20	0 - 10
Increase in calf weight at weaning (kg)	10 – 20	5 – 15	0 - 10

Trials and commercial experience in northern Australia have been summarised as generalised rules for when to supplement stock for different soil P levels by Jackson *et al.* (2012):

- Deficient (Colwell P 5mg/kg or less), all classes of stock are likely to respond to feeding P
- Marginal (Colwell P 6-8mg/kg), young breeders are likely to respond to feeding P
- Where Colwell P exceeds 8mg/kg, the economic benefit from feeding mature cows diminishes.

As liveweight gain increases, P requirements in the diet increase. When feeding supplement, this means higher rates of intake of P supplements are required(Jackson *et al.*, 2012).

2.6 Phosphorus requirements of pasture legumes

A considerable amount of research was undertaken on P responses of tropical pastures in northern Australia during the 1960s–1980s. Many of these studies showed pasture yield responses and liveweight gain improvements to applied P on legume based pastures containing either native or sown grasses (McIvor *et al.*, 2011; Jones, 1990).

Critical P levels were determined for many of the legume species used in the Brigalow Belt - Table 6 ranks legumes in order of increasing P requirements. Legumes that have not had trials to determine critical P levels have been included, with their place in the order based on field observations.

Table 6: Critical P requirements for legumes (to achieve 95% of maximum yield potential) that have potential as permanent pastures in the Brigalow Belt

Species	Critical P* (mg/kg)	Trial type	Reference
Shrubby stylo (cv Seca)	8	Field	Gilbert and Shaw (1987)
Caribbean stylo (cv Verano)	10-12	Field	Probert and Williams (1985); Hall (1993)
Fine-stem stylo	?		
Round-leaf cassia	?		
Caatinga stylo	?		
Desmanthus	?		
Siratro	10-14	Field	Rayment *et al.* (1977)
Leucaena	>15 25	Field observation	Dalzell *et al.* (2006); Buck pers. comm.
Butterfly pea (cv Milgarra)	25	Pot	Haling *et al.* (2013)
Annual medics	12-30	Field	Reuter *et al.* (1995)

* Expressed for Colwell P except shrubby stylo which is acid extractable P and Caribbean stylo where both Colwell and acid extractable P critical P levels were similar.
? No trial results found which determined critical P levels.

In other trials, round-leaf cassia, desmanthus and fine-stem stylo were responsive to P fertiliser but critical soil P levels were not determined (Partridge and Wright, 1993; Spies *et al.*, 1998; Kelly, 1983).

Critical soil P requirements vary with the P buffering capacity of the soil, that is, critical P requirements decrease with decreasing buffering capacity (Moody, 2007). Phosphorus buffering capacity of soils is measured as the P buffering Index (PBI). Brigalow soils, as a general rule, have low to moderate P buffering with PBI values between 100 and 200.

The relationship between critical Colwell P and PBI varies for different plant species (Moody, 2007). Figure 8 shows the impact changes in PBI have on critical Colwell P levels for temperate pastures based on clovers in southern Australia. The critical P levels described in Table 6, therefore, need to be interpreted relative to the buffering capacity of the soil, which was not measured for most trials on sub-tropical species.

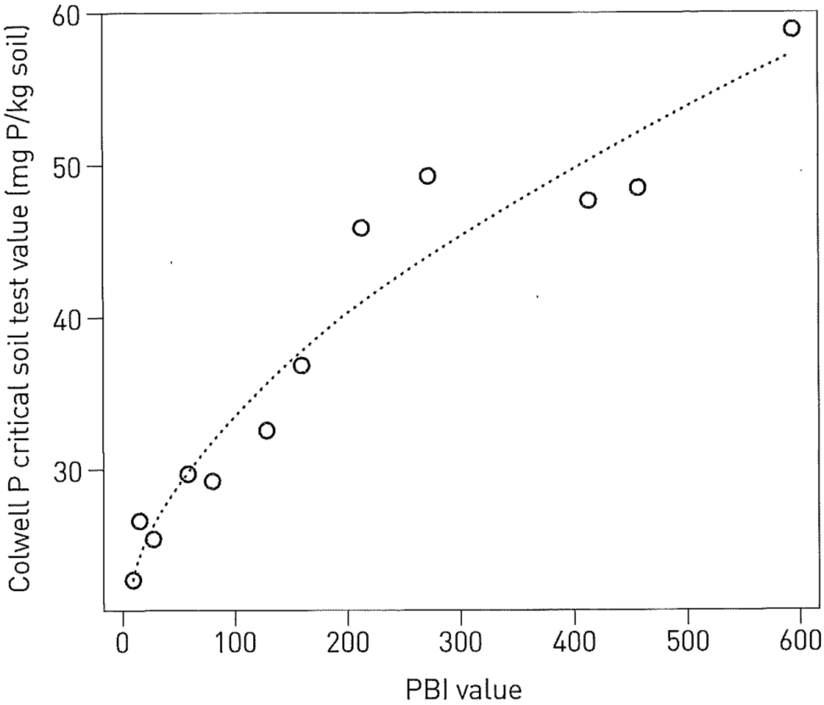

Figure 8: Relationship between critical Colwell P and Phosphorus Buffering Index (PBI) of soils for temperate pastures based on subterranean and white clover collated nationally (Gourley *et al.*, 2007). Critical Colwell P is the soil test value predicted to produce 95% of maximum pasture yield.

2.7 Pasture legume and animal responses to P in the Brigalow Belt

There have been relatively few P fertiliser trials in the Brigalow Belt with most studies undertaken in locations either further north or south. Studies that have occurred in the region have shown similar results, i.e. on low P soils, legumes respond dramatically to applied P fertiliser (e.g. Figure 9).

Radrizzani *et al.* (2010) showed that leucaena responded to P and S on many soils in the Brigalow Belt. Five out of eight trial sites responded to applied fertiliser with the study concluding that fertiliser application had the potential to increase rainfall use efficiency by 50%, with an expected parallel increase in liveweight gains. Despite these results, there is very little use of P fertiliser on leucaena (or other legume) based pastures (Radrizzani *et al.*, 2007; Brodie, 2006).

In a survey of 124 commercial pastures, graziers reported declining productivity in 58% of pastures (Radrizzani *et al.*, 2007). Only 10% of the pastures were fertilised with P at establishment and only 2% had maintenance fertiliser applications. The very low use of P fertiliser, despite these trial results, suggest that the paradigm that soil fertility is high in clay soils of the region and that fertiliser does not pay, remains strong within the grazier community. As a generalisation, industry considers leucaena with grass pastures to be highly productive, however, Radrizzani *et al* (2010) have demonstrated that in many instances it could be higher. The paradigm across the grazing industry in the Brigalow Belt is that “you don’t fertilise pastures”.

Current and on-going trials in the region show great potential to increase legume and grass growth through the use of P fertiliser. The response of a buffel grass with Caatinga stylo pasture is shown in Figure 9. This trial shows the characteristic response of increasing legume yield with increasing P fertiliser up to a maximum yield which then plateaus. Cattle grazing the un-fertilised pastures in this trial had blood P levels indicative of a marginal P deficiency during the growing season.

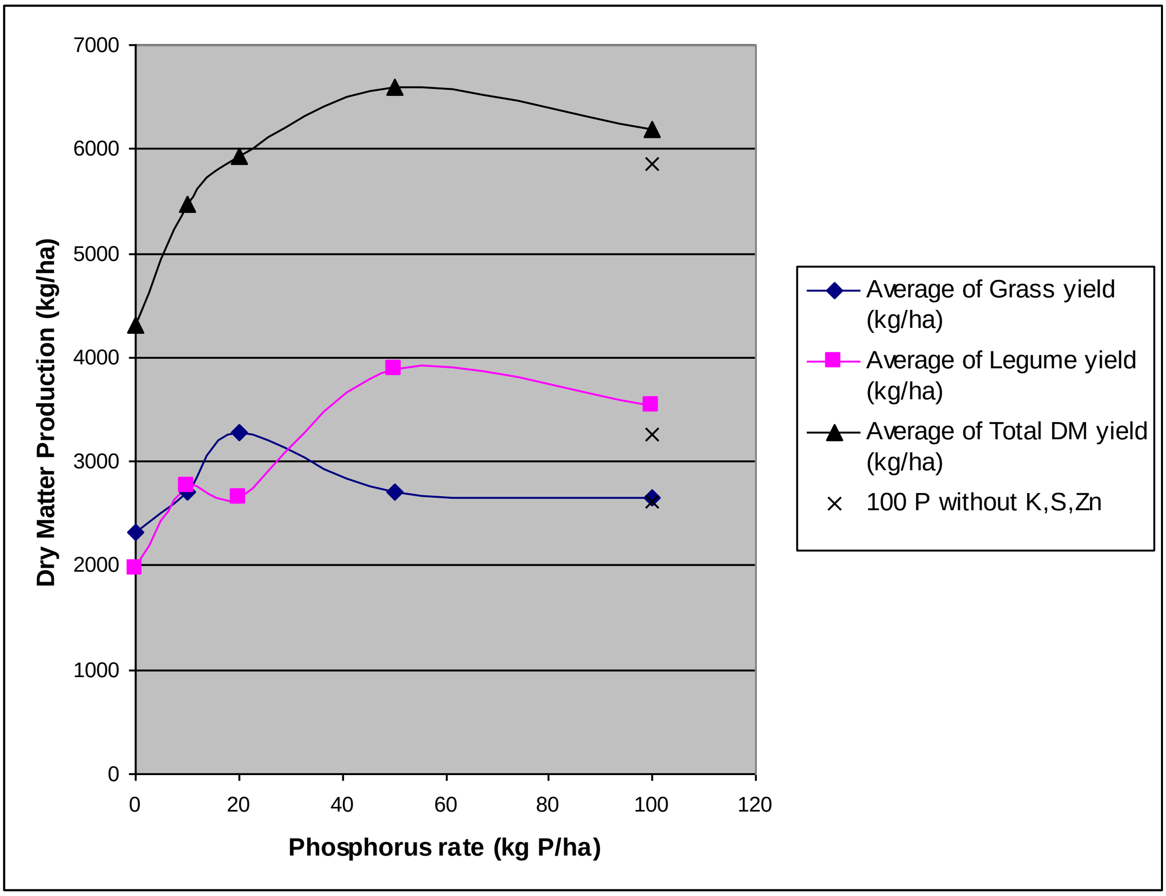

Figure 9: Dry Matter production from August 2012 to April 2013 from a mixed buffel grass, Caatinga stylo pasture (Peck *et al*. unpublished data)

Cattle grazing pastures on low P soils (Colwell <10 mg/kg) in the region are also likely be P deficient. At a grazing trial near Wandoan, where stock grazed desmanthus, buffel and Queensland bluegrass pastures growing on a Brigalow Clay soil (Colwell P levels of 2 - 5 mg/kg), steers had low blood P levels during the growing season and were subsequently supplemented (Peck et. al. un-published data). Stock were supplemented with dicalcium phosphate mixed with varying levels of molasses to manage intakes and had a copper bullet inserted into the rumen. The rainfall was comparable between the weighing periods, however, stock were in poorer condition when they entered the grazing trial in the second year with compensatory growth being part of the reason for the exceptional growth rates. The second draft of steers, which grazed the trial in the second year, had much better growth rates than the steers in the first year, which indicates a strong response to the supplements offered (Figure 10, Table 7).

Figure 10: Steers from a desmanthus and buffel grass grazing trial on a Brigalow clay soil showing classical P deficiency symptoms of very poor growth and rough coats (Peck *et. al.* un-published data)

Table 7: Average liveweight gain at Wandoan on a grass-only compared to grass with desmanthus pasture. 2012 grazing period was from 31 December 2011 until 12 April. 2013 grazing period was from 10 February to 25 May with phosphorus and copper supplementation of stock (Peck *et. al.* un-published data)

Site and Treatment	Grass-only#	Grass and desmanthus#
2012 Average gain per head (kg/hd/day)	0.02	0.18*
2013 Average gain per head (kg/hd/day)	1.5	1.9
2012 Gain per hectare (kg/ha)	0.8	11.2*
2013 Gain per hectare (kg/ha)	78	119

Grass-only paddock had 5 steers, grass with desmanthus paddocks had 6 steers.

* One animal excluded from average due to illness, per hectare liveweight calculated assuming all 6 animals grew at average rate.

2.8 Fertiliser application techniques

Phosphorus moves very little in all soils, except acid, sandy soils and fertiliser P, therefore, generally stays very close to where it is applied. Highest yields in crops are achieved when adequate P is available in moist soil throughout the life of the crop. In rainfed cropping, the surface of the soil is often dry for much of the crops growing season, therefore, P fertiliser drilled in at depth can be more reliable to produce a crop growth response than when surface applied. However, most fertiliser used on pastures is surface broadcast due to cost and ease of application. There is, therefore, a trade-off between cost and effectiveness of application method.

Recommended application methods vary depending on soil type, crop type and tillage operations. For high P buffering soils, it is recommended to band fertiliser to saturate P binding sites, and to time application to maximise the likelihood of the crop absorbing the P before it is bound by the soil (i.e. at the start of the growing season). For low to moderate P buffering soils (such as alkaline clay soils typical of the Brigalow Belt), it is generally recommended to enrich a greater volume of soil to maximise responses to fertiliser.

Due to the considerations described above, the general recommendation for P is to apply and incorporate fertiliser at establishment as part of tillage operations, with maintenance fertiliser being broadcast on the soil surface. Leucaena is generally planted in hedge rows which presents an opportunity for zonal placement of fertiliser. Zonal placement could meet the legume's P requirements while reducing the rate per hectare. However, different fertiliser application techniques have not been tested on pastures in the region.

An MLA-supported project in southern Australia has focussed on cycling of P in soils and has begun investigating different placement strategies to ensure adequate P throughout the root zone. Placement strategies can be constrained by shallow soil depth and rockiness but, in Brigalow clays, placement at depths down to 10 cm is a reasonable expectation. However, the effect of deeper placement on cycling of P in rundown pastures remains unknown. Providing reserves of P at depth, (where root activity removes P and places it in the surface 5 cm through bio-cycling and leaf senescence, may provide P to pastures more efficiently. Limiting the tie-up (immobilisation) of P in surface residues by placement below these soil layers warrants further investigation. Large responses in cropping soils of the Brigalow region have been observed by producers using this strategy. It is unknown whether this strategy will improve responses in summer active sown pastures.

2.9 Other nutrient deficiencies

Phosphorus is generally considered to be the most limiting nutrient for pasture legumes for much of Australia; however, other nutrients can limit productivity. Sulphur is known to be limiting in many soils in the Brigalow Belt bio-region (Ahern *et al.*, 1994; Radrizzani *et al.*, 2010; Spies *et al.*, 1998). Other nutrients have been shown to be limiting in some instances. Therefore, other plant nutrients need to be considered when using P fertiliser to maximise the growth response of pastures.

3 Bio-economic analysis methodology

The objective of the analysis is to indicate where and when the application of P, as either animal supplement or fertiliser, is most likely to provide an economic benefit. Spreadsheet-based pasture production and economic models were used to evaluate the potential returns from applying P fertiliser to low P soils with either an existing grass-legume pasture, or when establishing a legume into a grass-only pasture. Three soil fertility levels, three legume P response types and two fertiliser strategies were used to cover a wide range of likely scenarios.

More detail is provided in the following sections of the report, however, broadly speaking, the scenarios analysed were:

- soil fertility levels – very low, low and moderate soil P levels (4, 8, and 12 mg/kg Colwell P)
- 3 legume P responsiveness – low, moderate and high critical soil P requirement
- 2 fertiliser strategies – applying P fertiliser to achieve maximum legume production or 75% of maximum
- 4 pasture situations
    - establishing legumes into grass-only pasture
    - legume-based pasture where legume has low P requirement

  - legume-based pasture where legume has moderate P requirement
  - legume-based pasture where legume has high P requirement.
- with and without P supplements when soil Colwell P was <10mg/kg. Without P supplements when Colwell P was >10mg/kg.

3.1 Soil phosphorus levels and baseline pasture production

The base-line pasture dry matter production level and corresponding soil Colwell P levels are shown in Table 8. Baseline grass pastures were assumed to be rundown buffel grass pastures typical of the region. Base-line pasture production was estimated through a combination of GRASP pasture growth models, back calculation from carrying capacity described in local consensus data reports (Clarke *et al.*, 1992) and other published sources (Dalzell *et al.*, 2006; Middleton, 2001 ; Partridge, 1996).

Table 8: Baseline pasture production and corresponding soil Colwell P levels for grass-only and grass plus low P requiring legumes.

	Very low P soil	Low P soil	Moderate P soil
Dry matter production (kg /ha/year) grass-only	1700	3400	4800
Dry matter production (kg /ha/year) grass and legume*	2000	4150	6000
Colwell P (mg/kg)	4	8	12

* Low P legume

3.2 Pasture production modelling

Stocking rates for the rundown buffel grass scenario were calculated from pasture production estimates (Table 8) with the following assumptions:

- an average pasture utilisation rate of 25%
- stocking rates calculated as hectares per Adult Equivalent (AE)
- average dry matter intake per AE was estimated to be 2.2% of body weight (450 kg live) over the year. On this basis, each AE consumed approximately 10 kg per day or 3,650 kg of dry matter per year, and the stocking rate (in AEs) was derived by dividing 3,650 by the amount of pasture available to be consumed per hectare.
- a level of pasture spoilage, residual pasture and expected weight gain per AE per annum. Pasture spoilage rates were calculated as a percentage of annual dry matter production at the following rates:
  - 15% when <4500 kg DM/ha/yr
  - 20% 4500-7500 kg DM/ha/yr
  - 25% >7500 kg DM/ha/yr
- weight gains per head were based on the quality of the pasture and the level of available P
- benchmark residual biomass at the end of dry season for the three soil fertilities for rundown buffel were calculated as annual pasture production minus forage grazed by stock (from the utilisation rate) minus spoilage.

Pasture production for modelled scenarios was determined as a function of the rundown buffel baseline and the expected N fixation levels from the legume. Nitrogen fixation, which cycles to become available to companion grasses, was calculated as being 1.5% of legume dry matter production (Lloyd *et al.*, 2007). The extra pasture dry matter production through increased N availability was calculated as being 30 kg DM/kg N fixation (Graham *et al.*, 1981), which was then added to the grass-only baseline production. The stocking rates for mitigation strategies were calculated to achieve the same residual pasture biomass as the rundown buffel, that is, stock numbers were increased to utilise any extra forage with the same end of dry season residual biomass. Forage for animal consumption for mitigation strategies was calculated as follows:

Annual forage production - residual - spoilage = forage for animal consumption

3.3 Legume phosphorus responses

The legume P responsiveness assumptions are shown in Table 9. For the purpose of this analysis, the legume species were not specified. Phosphorus response curves for pasture legumes growing in the Brigalow Belt have not been developed, therefore, this analysis assumed three P response types to cover the likely responsiveness of adapted legumes. Although not specifically described, examples of the different types of legumes are:

- Low critical P – some of the Stylosanthes species and perhaps round-leaf cassia
- Medium critical P – Siratro and possibly desmanthus and Caatinga stylo
- High critical P – Leucaena, butterfly pea and medics.

Table 9: Pasture legume phosphorus response assumptions

	Low critical P legume, low response	Medium critical P legume, medium response	High critical P legume, high response
<10% yield level	2	6	10
75% maximum yield (mg P /kg)	8	12	18
Critical Colwell P level (mg P /kg)	10	15	25

3.4 Fertiliser strategies

Two different fertiliser strategies were assessed. The fertiliser strategies were:

Fertiliser strategy 1:
This was targeted to provide 75% of the maximum legume yield in the year of fertiliser application. Fertiliser is reapplied every five years or when soil Colwell P levels decline back to the baseline levels described in Table 8.

Fertiliser strategy 2:
This was targeted to provide maximum yield in the year of fertiliser application. Fertiliser is reapplied every five years or when soil Colwell P levels decline to the 75% of maximum legume production levels described in Table 9.

Fertiliser application rates were calculated assuming a 0.3 mg/kg increase in Colwell P for every kilogram of P applied as fertiliser and are shown in Table 10. The assumed fertiliser requirement to raise Colwell P is on the high end of the range for low to moderate PBI soils (Simpson *et al.*, 2009).

Fertiliser reapplication rates were calculated assuming P replacement requirements of 1 kg P/DSE/ha/year (taken as equivalent to 8 kg P/AE/ha/year) based on studies from the New England Tablelands (Guppy *et al.*, 2013). The assumed maintenance fertiliser requirement is on the high end of the spectrum compared to temperate pasture based on clover (Simpson *et al.*, 2009). No such studies have been conducted on Brigalow soils. The P removal rates are unlikely to be significantly different from New England systems based on temperate pastures, but the Colwell P response rates may vary in unknown ways. For example, P supply on New England soils is more likely to be dominated by sorption processes, whereas in Brigalow soils, dissolution and precipitation of P sources may control available P levels. The effect this has on the increase in available P following fertiliser additions is not known; however, over the short term (5-10 years) applied P fertilisers are likely to stay in sorbed fractions in Brigalow soils and, hence, the assumptions are reasonably valid in the absence of trial results.

Table 10: Fertiliser application rates for the two fertiliser strategies for the different soils and legumes

	Low critical P legume, low response (kg P/ha)	Medium critical P legume, medium response (kg P/ha)	High critical P legume, high response (kg P/ha)
V. Low P soil, fertiliser strategy 1	13.3	26.7	46.7
V. Low P soil, fertiliser strategy 2	20.0	36.7	70.0
Low P soil, fertiliser strategy 1	0	13.3	33.3
Low P soil, fertiliser strategy 2	6.7	23.3	56.7
Moderate P soil, fertiliser strategy 1	0	0.0	20.0
Moderate P soil, fertiliser strategy 2	0	10.0	43.3

* It is assumed that a 0.3 mg/kg increase in Colwell P is gained for each kilogram of P fertiliser applied and that P removal and fixation is 1 kg P/DSE/ha/year or 8 kg P/AE/ha/year.

Fertiliser was reapplied every five years for most scenarios, but was reapplied at shorter intervals to maintain production levels, where soil Colwell P levels dropped below the reapplication triggers described above. The scenarios with shorter reapplication periods are described in Table 11.

Table 11: Scenarios with fertiliser reapplication frequencies less than 5 years

Soil	Legume	Fertiliser Rate	Supplements	Re-fertilise frequency (years)
V. Low P soil	Low P leg	Fertiliser strategy 2	+Supplement	2
		Fertiliser strategy 2	-Supplement	2
	Med P leg	Fertiliser strategy 2	-Supplement	3
Low P soil	Low P leg	Fertiliser strategy 2	+Supplement	1
		Fertiliser strategy 2	-Supplement	1
	Med P leg	Fertiliser strategy 2	-Supplement	2
		Fertiliser strategy 1	+Supplement	4
		Fertiliser strategy 1	-Supplement	4
Med P soil	Med P leg	Fertiliser strategy 2	-Supplement	1
	High P leg	Fertiliser strategy 2	-Supplement	3
		Fertiliser strategy 1	-Supplement	4

3.5 Legume establishment

The legume establishment scenarios assumed that the paddock started with a rundown grass-only sown pasture. Legume establishment costs were based on planting the legume in six metre wide cultivated strips with four metres of grass pasture retained between the cultivated strips. The direct cost of legume establishment was based on the use of machinery owned by the business, not contract rates, and totalled about $140 per hectare before the addition of any P fertiliser. This is a more expensive method than generally used commercially for legume species other than leucaena, however, most commercial legume plantings fail largely due to competition from the existing grass pasture. For the purposes of this review, it was decided to keep the assumptions the same for all legume types, and use a more reliable legume establishment technique.

Livestock numbers were adjusted to allow for the reduced amount of grass pasture in the establishment year, and to allow for good legume establishment in the first few years after establishment. Pasture and animal assumptions were:

- In the year of sowing, grazing pressure was reduced by 80% compared to the rundown grass pasture.
- In the second year after sowing, grazing pressure was reduced by 40% compared to the rundown grass pasture, but individual animal performance is improved by the legume.
- In years three and four, stock numbers are at the rundown grass pasture levels with improved individual animal performance from the legume.
- From year five onwards, it is assumed that the legume has established sufficiently well to provide nitrogen fixation benefits to enable total pasture production from the improved grass and legume pasture.

The spelling periods described above are very conservative with significantly lower grazing pressures than often used on commercial properties, but they provide a high level of assurance that a viable, long lived improved pasture will be established.

3.6 Scenarios analysed

3.6.1 Very Low P soil

Figure 11 shows the fifteen scenarios analysed for the very low P soil which were compared against the baseline pasture (i.e. grass-only; grass with either a low, medium or high P requirements legume). The column on the left of the figure shows the starting condition (baseline scenario) of the pasture with each comparison analysis identified to the right. Where applications of fertiliser P were adequate to meet plant and animal requirements, the scenario of adding P as an animal supplement was not analysed.

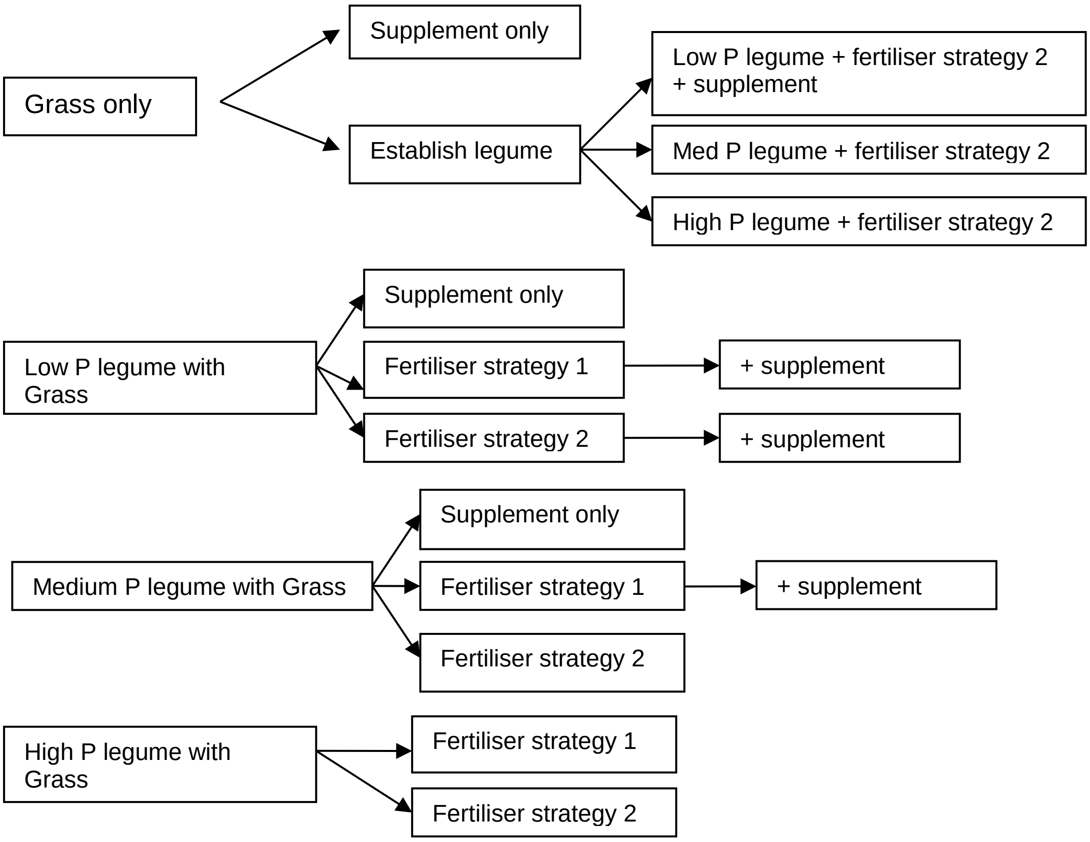

Figure 11: Scenarios analysed for very low phosphorus soil

Table 12 indicates the pasture productivity for the very low P soil starting scenarios and the calculation of stocking rates and liveweight gains for each base case. The productivity of the legume pastures depend upon the assumption that a viable legume pasture has previously been established.

Table 12: Very low P soil base pasture productivity calculations

	Grass Baseline	Low P legume	Medium P legume	High P legume
Colwell P level	4	4	4	4
N fixation added (kg N/ha/yr)	0	10	5	0
Legume DM production		667	333	0
Extra weight gain (via supplement P) (kg/AE/yr)	0	0	0	0
Extra weight gain (via Protein) (kg/ae/yr)	0	10	10	0
Total weight gain (kg/AE/yr)	**100**	**110**	**110**	**100**
Pasture response kg DM /kg N	30	30	30	30
Extra pasture produced (kg DM/ha)	0	300	150	0
Increase in DM production	0%	18%	9%	0%
Pasture production (kg DM/ha/yr)	**1700**	**2000**	**1850**	**1700**
Spoilage %	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	255	300	277.5	255
Residual (kg DM/ha/yr)	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	425	680	552.5	425
Increase in forage consumed (kg DM/ha/yr)	0	255	127.5	0
Consumption increase	**0%**	**60%**	**30%**	**0%**
Stocking rate (ha/AE)	8.59	5.37	6.61	8.59
Stocking rate (AE/ha)	0.12	0.19	0.15	0.12
New weight gain (kg/AE/yr)	100	110	110	100
Liveweight (kg live wt/ha/yr)	11.64	20.49	16.65	11.64
Increase in liveweight (per ha) (compared to grass-only)	**0%**	**76%**	**43%**	**0%**

Examples of the detailed tables that show the expected production response of scenarios that required variable inputs of fertiliser over time, where there was an existing grass with legume pasture, are provided for this soil type in appendix 8.3.

The calculated stocking rate and liveweight gain per head for each scenario was used to populate the livestock production models and compile livestock gross margins. Where the stocking rates and liveweight gains varied over time within each scenario due to the variation of available P in the system, a livestock model and gross margin was calculated for each year of the scenario.

3.6.2 Low P soil

Figure 12 shows the fifteen scenarios analysed for the low P soil, which were compared against the baseline pasture (i.e. grass-only; grass with either a low, medium or high P requirements legume).

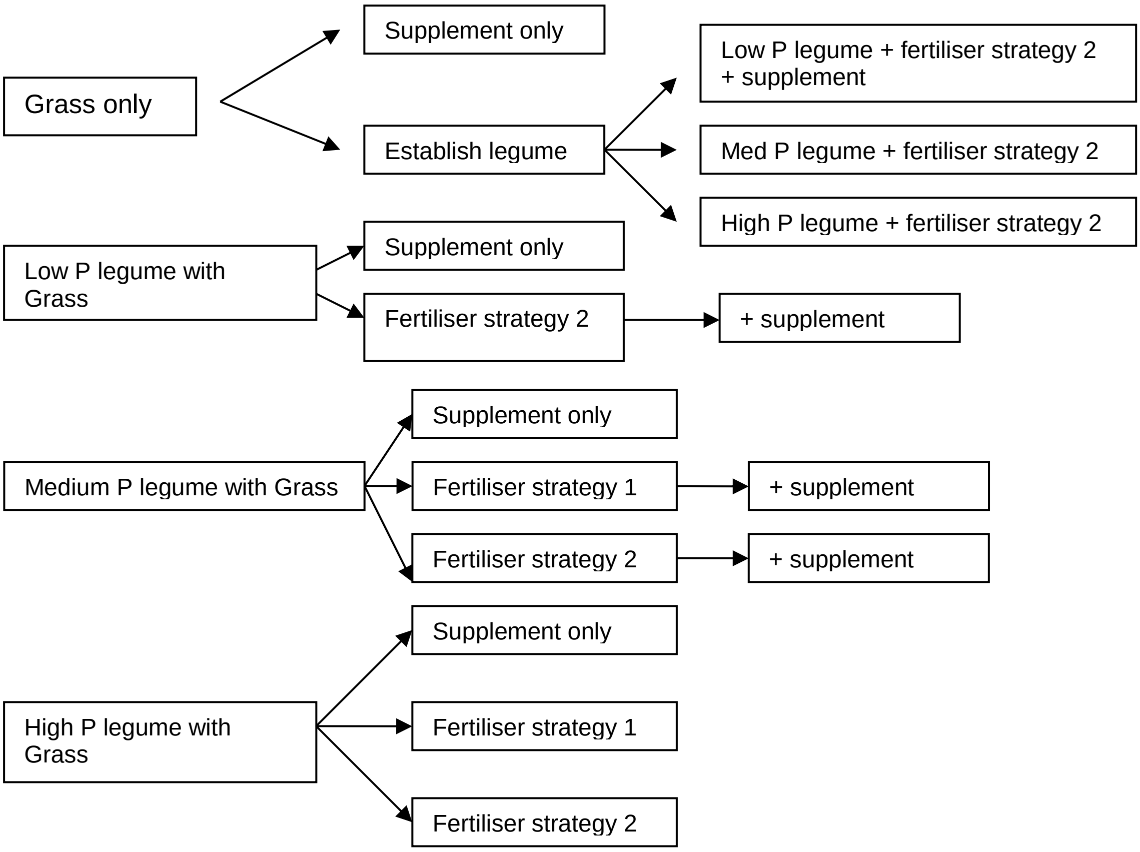

Figure 12: Scenarios analysed for the low phosphorus soil

Table 13 indicates the pasture productivity for the low P soil starting scenarios and the calculation of stocking rates and liveweight gains for each base case.

Table 13: Low P soil base pasture productivity calculations

	Grass Baseline	Low P legume	Medium P legume	High P legume
Colwell P level	8.0	8.0	8.0	8.0
N fixation added (kg N/ha/yr)	0	25	15	10
Legume DM production	0	1667	1000	667
Extra weight gain (via P) (kg/AE/yr)	0	0	0	0
Extra weight gain (via Protein) (kg/ae/yr)	0	30	20	10
Total weight gain (kg/AE/yr)	**140**	**170**	**160**	**150**
Pasture response kg DM/kg N	30	30	30	30
Extra pasture produced (kg DM/ha)	0	750	450	300
Increase in DM production	0%	22%	13%	9%
Pasture production (kg DM/ha/yr)	**3400**	**4150**	**3850**	**3700**
Spoilage %	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	510	622.5	577.5	555
Residual (kg DM/ha/yr)	2040	2040	2040	2040
Available for consumption (kg DM/ha/yr)	850	1487.5	1232.5	1105
Increase in forage consumed (kg DM/ha/yr)	0	637.5	382.5	255
Consumption increase	**0%**	**75%**	**45%**	**30%**
Stocking rate (ha/AE)	4.29	2.45	2.96	3.30
Stocking rate (AE/ha)	0.23	0.41	0.34	0.30
New weight gain (kg/AE/yr)	140	170	160	150
Liveweight (kg live wt/ha/yr)	32.60	69.28	54.03	45.41
Increase in liveweight (per ha)compared to grass	**0%**	**113%**	**66%**	**39%**

3.6.3 Moderate P soil

Figure 13 shows the six scenarios analysed for the moderate P soil which were compared against the baseline pasture (i.e. grass-only; grass with either a low, medium or high P requirements legume).

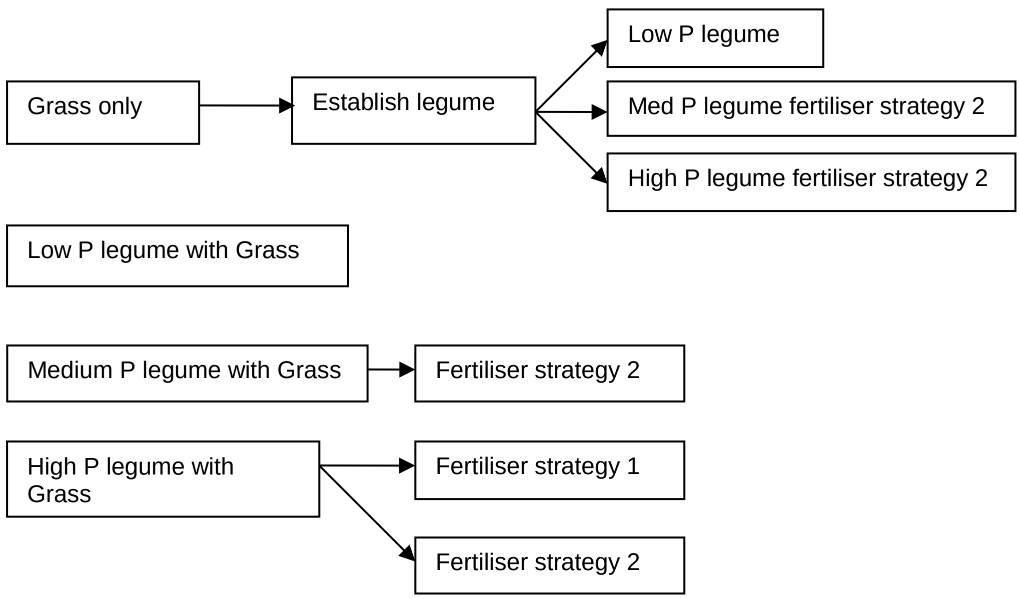

Figure 13: Scenarios analysed for the moderate phosphorus soil.

Table 14 indicates the pasture productivity for the moderate P soil starting scenarios and the calculation of stocking rates and liveweight gains for each base case.

Table 14: Moderate P soil base pasture productivity calculations

	Grass Baseline	Low P legume	Medium P legume	High P legume
New Colwell P level	12.0	12.0	12.0	12.0
N fixation added (kg N/ha/yr)	0	40	35	30
Legume DM production	0	2667	2333	2000
Extra weight gain (via P) (kg/AE/yr)	0	0	0	0
Extra weight gain (via Protein) (kg/ae/yr)	0	60	50	50
Total weight gain (kg/AE/yr)	**160**	**220**	**210**	**210**
Pasture response kg DM/kg N	30	30	30	30
Extra pasture produced (kg DM/ha)	0	1200	1050	900
Increase in DM production	0%	25%	22%	19%
Pasture production (kg DM/ha/yr)	**4800**	**6000**	**5850**	**5700**
Spoilage %	20%	20%	20%	20%
Spoilage (kg DM/ha/yr)	960	1200	1170	1140
Residual (kg DM/ha/yr)	2640	2640	2640	2640
Available for consumption (kg DM/ha/yr)	1200	2160	2040	1920
Increase in forage consumed (kg DM/ha/yr)	0	960	840	720
Consumption increase	**0%**	**80%**	**70%**	**60%**
Stocking rate (ha/AE)	3.04	1.69	1.79	1.90
Stocking rate (AE/ha)	0.33	0.59	0.56	0.53
New weight gain (kg/AE/yr)	160	220	210	210
Liveweight (kg live wt/ha/yr)	52.60	130.19	117.37	110.47
Increase in liveweight (per ha) compared to grass	**0%**	**148%**	**123%**	**110%**

3.7 Economic analysis

The economic impact of P application on pasture and beef production was assessed using paddock level enterprise budgets and partial discounted cash flow techniques (DCF). These were applied to identify the marginal returns that accrued to any change. The economic indicators used were paddock gross margin, Net Present Value (NPV) at the required rate of return and the Internal Rate of Return (IRR). The main goal of the analysis was to identify potentially economic responses to P at the paddock level, not to identify whether the application of P was the most economic use of the funds invested. Even so, inclusion of a range of discount rates, where responses were analysed over longer periods of time, provides some insight into the likely impact on the profitability of investments in P fertiliser or P supplements, under the circumstances analysed.

The activity modelled was a steer turnover/bullock production activity that purchased store steers and sold finished Ox to the abattoir. The boundaries of the activity were the physical paddock boundaries. The only expenses incurred were those that varied with the number of cattle run in the paddock, such as husbandry and selling costs. An allowance was made for the amount of additional effort and cost required to apply the fertiliser. This form of activity was chosen as it allows close matching of the inputs of the economic model with the estimates of weight gain, and stocking rate for the scenarios analysed.

The relative profitability of varying inputs of P within paddocks was analysed using activity budgets compiled as either paddock level gross margins or partial discounted cash flow (DCF) budgets. The use of a partial discounted cash flow allowed the costs and incomes associated with the remainder of the business that did not change with a change in P inputs, to be ignored, thereby simplifying the analysis.

The DCF process was used where strategies had a variable impact on the timing of income and costs. Discounting adjusts expected future costs and benefits to values at a common point in time (typically the present), to account for the time preference of money. With discounting, a stream of funds occurring at different time periods in the future is reduced to a single figure by summing their present value equivalents to arrive at a Net Present Value (NPV). The application of the discounting process allowed the comparison of strategies that have impacts on productivity at differing periods of time. The NPV was converted to its amortised equivalent at the respective discount rate and over the period of the investment to allow an annualised value for the return to be calculated.

3.7.1 Activity budget notes

Some activities involve the use of resources that have an effective life of more than one production period or are used across a number of different activities within the farm business. For example, farming plant normally lasts for a number of years and can contribute to the production of many activities.

In most analyses that use gross margin or partial DCF techniques, the costs of farming plant to an enterprise or activity are usually apportioned on an hourly rate of use basis. This allows inclusion of the proportional amount of operating costs of the farming plant used by each enterprise or activity, improving the validity of the comparison where different treatments require different amounts of machinery inputs.

Farming plant is normally costed in an activity level analysis on the basis of the Fuel, Oil, Repairs and Maintenance (FORM) used on a per hour basis in the production of the output. Note that the ownership costs of the plant are not included.

For each tractor and implement combination used in the activity modelled, the following rule of thumb calculations for the share of FORM costs are made:

- Fuel = fuel consumption (litres per hour) multiplied by the fuel cost (cents per litre net of rebates)
- Oil cost is assessed as 10% of fuel cost.
- Repairs and Maintenance. To calculate a share of repairs and maintenance, the expected replacement cost of the machine is firstly identified. This can be the current new value of the machine or the second hand value if it is going to be replaced with a used machine. The total costs of all repairs likely to be incurred over the life of the machine are then identified and calculated as a percentage of the replacement value. The longer the machine is kept the higher the percentage – up to 70% or more for a tractor that is kept a long time (> 5000 hours) and used to undertake heavy work. To calculate the hourly cost of repairs and maintenance, the replacement cost of the machine is multiplied by the percentage of the replacement cost of the machine spent on repairs over the life of the machine and divided by the hours of life of the machine. For example, if a machine costs $10,000 and about $3,000 is expected to be spent on repairs and maintenance over its five year life, then about 30% of the cost of the machine will be spent on repairs. If the machine is used for 100 hours per annum, the hourly cost of repairs and maintenance is about $6 per hour of use.

These rules of thumb are sufficiently accurate to allow the inclusion of the proportional costs of FORM associated with machinery use in this analysis.

The gross margins and DCF budgets calculated also include an allowance for the labour costs associated with machinery operation. This allows identification of the value of the additional labour required to apply P to the paddock – whether it is paid or unpaid.

3.7.2 The paddock

The hypothetical paddock chosen to explore the impact of P application is located about 180 kilometres from the Gracemere stock selling centre and about 580 kilometres from the Dinmore abattoirs. This would theoretically place the paddock somewhere in southern central Queensland. The two selling centres were chosen due to the availability of representative price data and for no other reason.

The paddock has a total area of 100 hectares and is modelled with three separate levels of inherent P fertility (very low, low and moderate). For each level of starting P fertility, four pasture combinations were modelled. They were:

- improved pasture (generally taken to be established buffel grass)
- an established legume grass pasture which has a legume with a low critical P requirement
- an established legume grass pasture which has a legume with medium critical P requirement
- an established legume grass pasture which has a legume with high critical P requirements.

Examples of perennial legumes that have a low critical P requirement are many of the Stylo species. Medium P legumes include Siratro; and possibly desmanthus and Caatinga stylo. Leucaena and medics are the commonly planted legumes with a higher critical P requirement.

Other than the different scenarios described above, the starting condition of the paddock is considered to be similar. For the different soil P levels, it was assumed that there would be other constraints that may limit productivity (e.g. low levels of other nutrients, sub-soil constraints etc.), such that a lower P soil had lower pasture and animal productivity. For a given pasture type (i.e. grass only, grass with low P legume, grass with medium P legume or grass with high P requiring legume), the pasture and animal productivity was greatest for the moderate P soil and lowest for the very low P soil, with the low P soil being intermediate. In all scenarios it was assumed that the main limitation to pasture legume growth was P availability.

3.7.3 Paddock operations

The modelled activity is a steer growing or fattening activity that relies on the purchase of store steers from Gracemere sale yards, at weights that allow the steers to be sold after twelve months of grazing on the pasture as either feed-on or finished steers.

The starting weight of the steers was generally taken as 350 kilograms liveweight, except where the modelled pasture condition prevented the steers achieving slaughter weight and condition over the twelve month period. In such cases, heavier steers were purchased and resold as stores suitable for finishing, as the aim was to keep the average weight of the steers at about 450 kilograms (or one adult equivalent). Steers greater than approximately 580 kg liveweight were sold to the abattoir, while lighter steers were sold as stores. There was some adjustment to the cut-off weight based on liveweight gain, that is, if they had a high liveweight gain, they were sold as fats at slightly lower weights.Conversely, low liveweight gain scenarios needed to be heavier to be considered to meet market specifications for the abattoir. The transfer of livestock into and out of the paddock generally occurred mid-year. Steer prices in the enterprise budgets were set at the average market values of the last four years at the respective purchase or selling centre for the relevant class of livestock. The only other expenses incurred by the enterprise are those that vary with the number of cattle run in the paddock, such as steer purchase, husbandry and selling costs, plus the cost of purchasing and applying the P as fertiliser or supplement.

Where steers were fed a P supplement, the cost was uniformly added to the budget at $15 per head per annum. This cost included a nominal amount for distributing the supplement. Fertiliser was applied as triple superphosphate at a landed cost of $890 per tonne and was spread at a uniform cost of $12 per hectare.

The chosen grazing system is fairly typical of the way improved pastures are used in the Brigalow lands, although it is applied in this analysis as a turnover system in which stock are bought and sold each year. This may be a more costly system than others available and it indicates that the results of the analysis should be used to identify the relative profitability of the various strategies – not necessarily the absolute impact on profit of incorporating P supplements or P fertiliser where P is deficient. Different grazing systems may be more (or less) profitable than the one chosen but the value of using of P within them is unlikely to change in a relative sense.

3.7.4 Steer prices

Price quotes provided by Elders Pty Ltd for Gracemere store sales and by Australian Meat Holdings for Dinmore abattoir have been compared for correlation and trend. Figure 14 shows the relationship over recent years between the prices of medium sized store steers at Gracemere and grass fed Jap Ox at Dinmore.

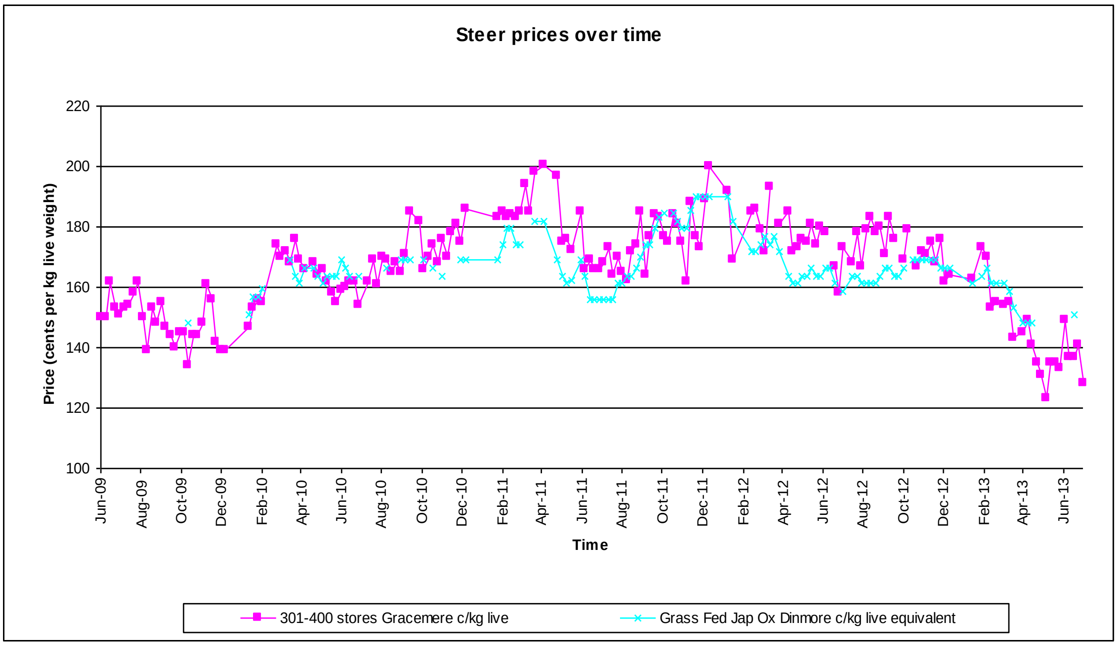

Figure 14: Steer selling prices over time

The price margin expected for buying and selling steers was estimated by comparing purchase and selling prices 12 months apart for each class of animal. The correlation between steer purchase and selling prices over this period was identified as being 0.12 – or hardly any correlation at all. There also appears to be no set basis (or margin) over time between the purchase price of the store steers and the sale price of the finished Jap Ox.

The price basis can be up to 40 cents per kilogram positive or negative when measured on an equivalent liveweight basis with a 12 month lag between the purchase date and sale price.

There is little or no correlation between the purchase and sale price of the classes of steers used in the analysis, and no easily recognisable or predictable pattern over time to establish a basis between the price of medium stores at Gracemere and Jap Ox at Dinmore.

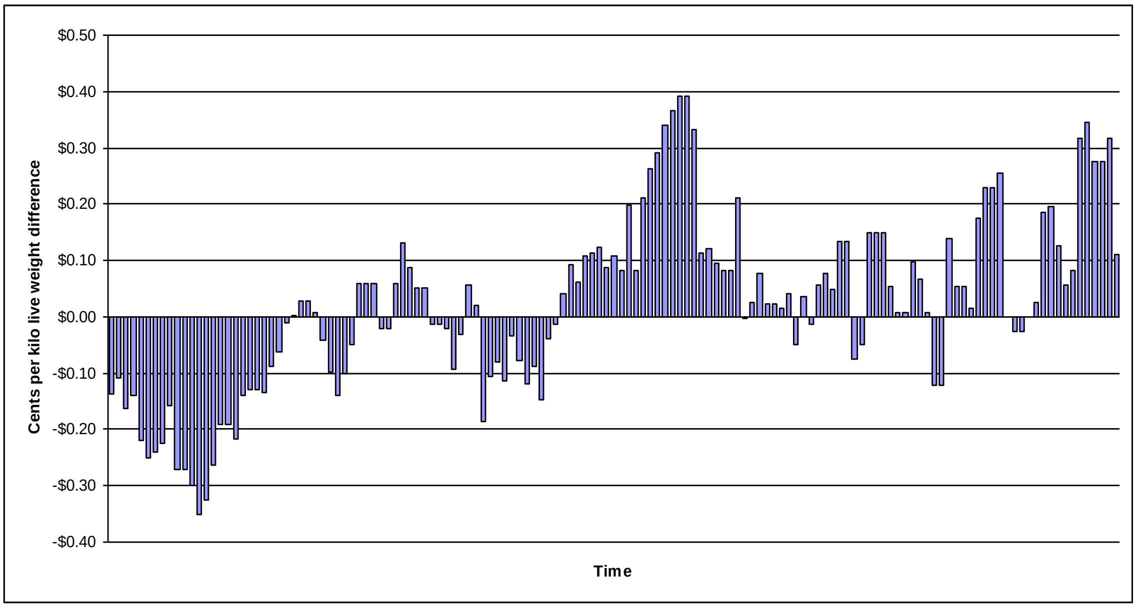

Figure 15: Difference between medium stores at Gracemere and Dinmore Ox prices with a twelve month lag starting in 2009

The average (and median) price for Ox since 2009 at Dinmore over recent years is about $3.20 per kilogram dressed or $1.66 when expressed on an equivalent liveweight basis at a 52% dressing percentage. The maximum and minimum prices paid over the same period are $3.55 and $2.75 ($1.85 and $1.43 live). On this basis, variation about the median over the period is about 15%.

The average price for medium stores at Gracemere over the same period is about $1.64 per kilogram live with a maximum and minimum of $2.00 and $1.23. The variation in store steer prices around the median is about 25% over the same period.

3.7.5 Budget parameters

The input parameters for the base scenario budgets are identified in Table 15 to Table 17. The number of steers purchased was derived from the stocking rate in hectares per AE, the weight gain per AE predicted and the chosen starting weight of the steers. Each livestock budget purchases “fractions” of steers to match the stocking rate calculated in the production estimates with those calculated in the economic model.

Table 15: Input parameters and stocking rates for very low P soil base scenarios

Livestock parameters	Grass only	Low P legume	Medium P legume	High P legume
Average age of purchased steers (months)	18	18	18	18
Number of steers purchased	11.74	18.63	15.14	11.64
Purchase price steers ($/kg live)	$1.64	$1.64	$1.64	$1.64
Purchase weight steers (kg live)	395	395	395	400
Cost of purchased steers	$7,606	$12,069	$9,805	$7,638
Gross cost of purchased steers (per head)	$648	$648	$648	$656
Stocking rate (head per hectare)	0.12	0.19	0.15	0.11
Stocking rate (hectare per head)	5.52	5.37	6.61	8.59
Stocking rate (AE per hectare)	0.12	0.19	0.15	0.11
Stocking rate (hectare per AE)	8.59	5.37	6.60	8.59
Weight gain per day	0.27	0.30	0.3	0.27
Total days held	365	365	365	365

Table 16: Input parameters and stocking rates for low P soil base scenarios

Livestock parameters	Grass only	Low P legume	Medium P legume	High P legume
Average age of purchased steers (months)	18	18	18	18
Number of steers purchased	24.52	41.80	34.94	31.60
Purchase price steers ($/kg live)	$1.64	$1.64	$1.64	$1.64
Purchase weight steers (kg live)	350	350	350	350
Cost of purchased steers	$14,077	$23,994	$20,054	$18,138
Gross cost of purchased steers (per head)	$574	$574	$574	$574
Stocking rate (head per hectare)	0.25	0.42	0.35	0.32
Stocking rate (hectare per head)	4.08	2.39	2.86	3.16
Stocking rate (AE per hectare)	0.23	0.41	0.34	0.30
Stocking rate (hectare per AE)	4.29	2.45	2.96	3.30
Weight gain per day	0.38	0.47	0.44	0.41
Total days held	365	365	365	365

Table 17: Input parameters and stocking rates for moderate P soil base scenarios

Livestock parameters	Grass only	Low P legume	Medium P legume	High P legume
Average age of purchased steers (months)	18	18	18	18
Number of steers purchased	34.02	58.21	55.43	52.17
Purchase price steers ($/kg live)	$1.64	$1.64	$1.64	$1.64
Purchase weight steers (kg live)	350	350	350	350
Cost of purchased steers	$19,525	$33,413	$31,817	$29,944
Gross cost of purchased steers (per head)	$574	$574	$574	$574
Stocking rate (head per hectare)	0.34	0.58	0.55	0.52
Stocking rate (hectare per head)	2.94	1.72	1.8	1.92
Stocking rate (AE per hectare)	0.33	0.59	0.56	0.53
Stocking rate (hectare per AE)	3.04	1.69	1.79	1.9
Weight gain per day	0.44	0.60	0.58	0.58
Total days held	365	365	365	365

Please note that the calculation of AE weighting in the enterprise budget is based on the formula (POWER ([(opening weight + closing weight)/2], 0.75)/97.7). This formula gives a slightly different answer to that gained through applying the more simple process of dividing by 3650 as used in the initial calculation of stocking rate.

4 Results and discussion

A full description of P fertiliser rates, soil P levels, legume production, total pasture production, stocking rates and animal performance are provided in Appendix 8.1 for baseline and fertiliser applied to existing legume-based pasture scenarios. An example of the pasture and animal production assumptions for scenarios that established legumes into grass-only pastures is provided in Appendix 8.2.

4.1 Pasture production

Annual dry matter production in the year of fertiliser application or at steady state (for the non-fertiliser scenarios) for the legumes and soils used in the analysis are shown in Figure 16 to Figure 18. Relationships for legume dry matter production versus soil Colwell P levels were developed for each legume and soil type from these graphs. These equations were then used to calculate the legume DM production for intervening years between fertiliser applications.

Expected changes in Colwell P levels were calculated assuming a P maintenance requirement of 1 kg P/DSE/ha/yr (Guppy *et al.*, 2013) and a soil Colwell P responsiveness of 0.3 mg/kg (Simpson *et al.*, 2009) for every kilogram of P lost through the maintenance requirement. Examples of these calculations and their impact on fertiliser re-application periods are provided in Appendix 8.3.

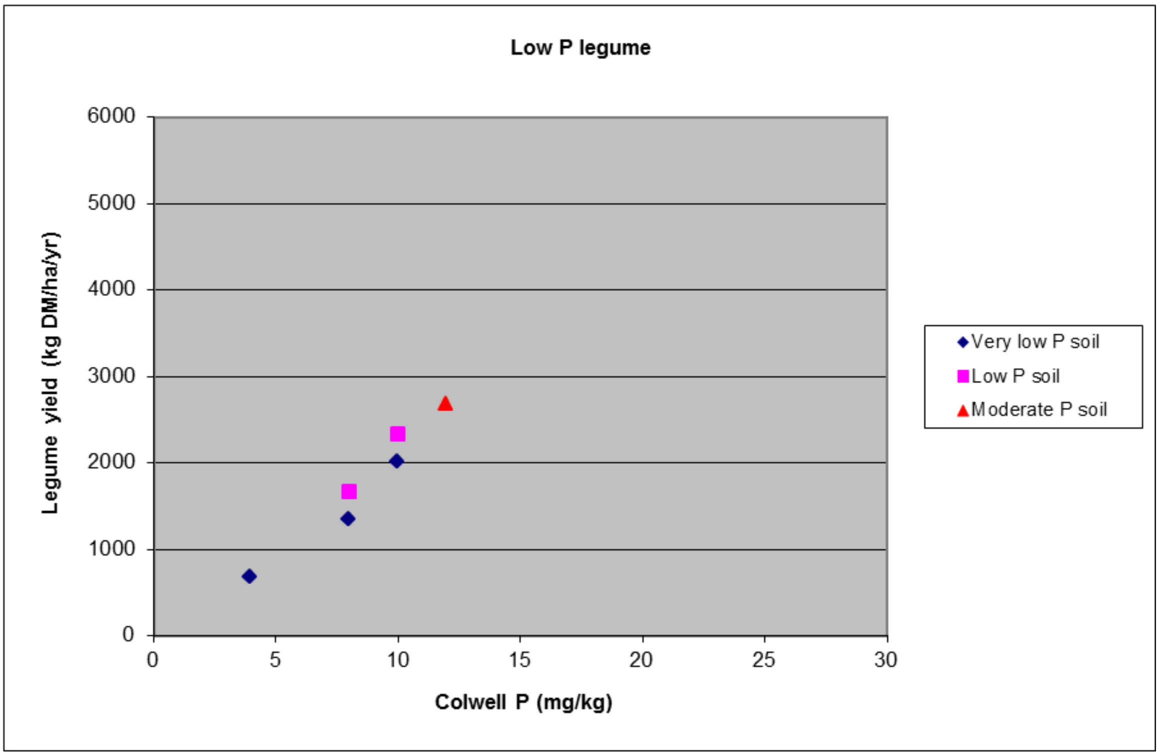

Figure 16: Annual dry matter yield for low P requiring legumes in the year of fertiliser application

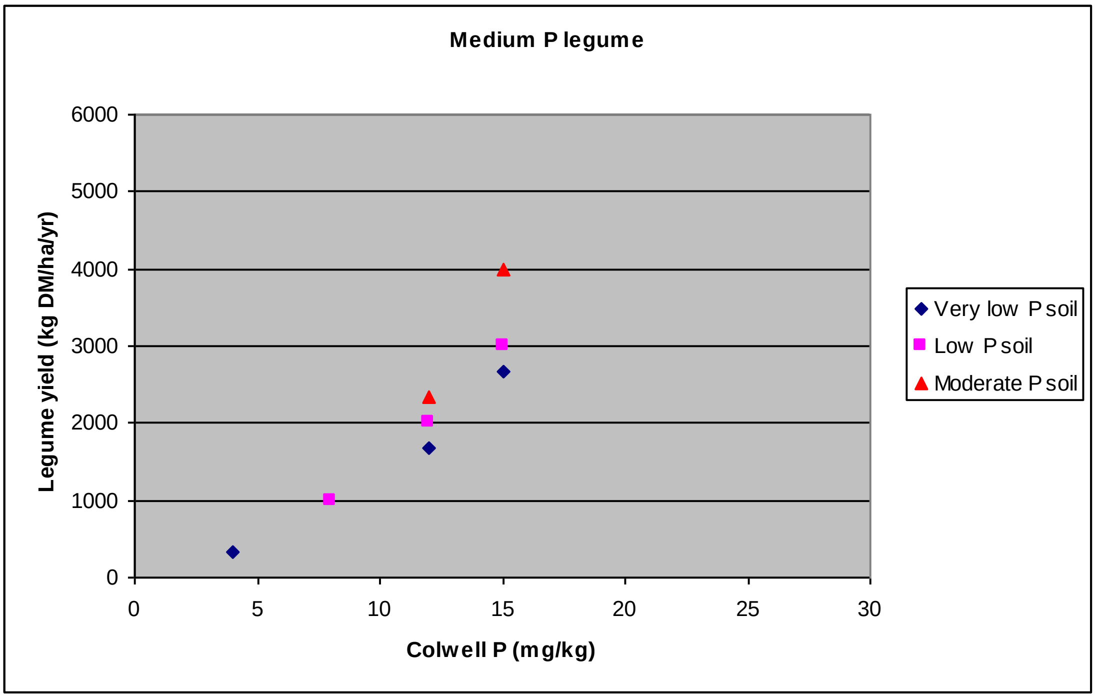

Figure 17: Annual dry matter yield for medium P requiring legumes in the year of fertiliser application

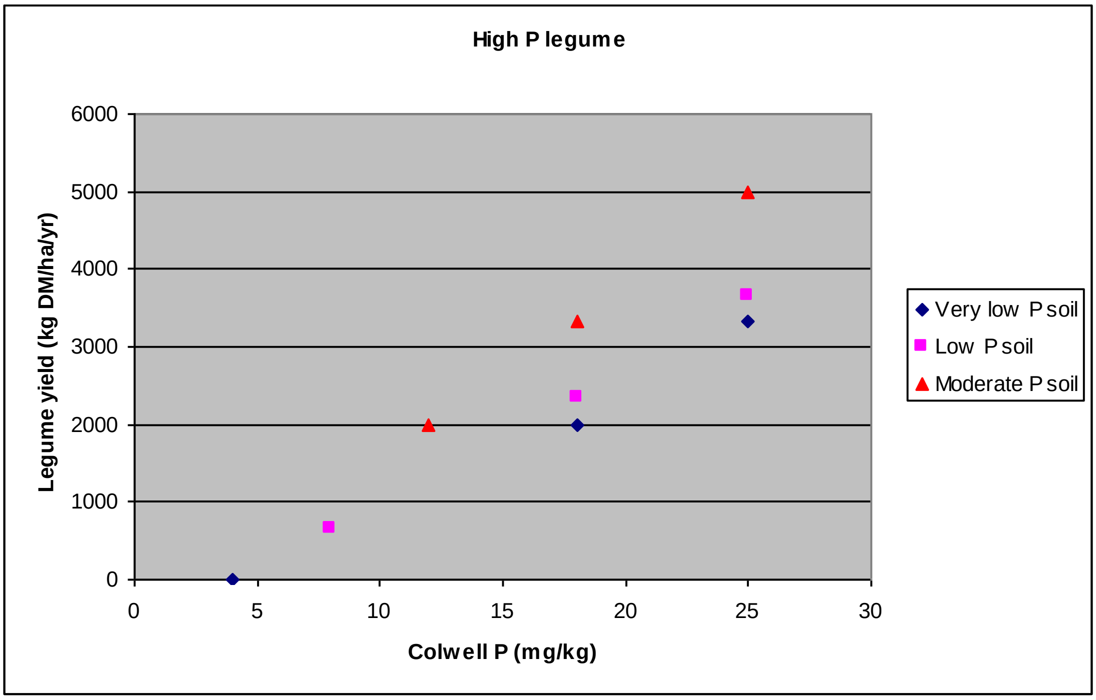

Figure 18: Annual dry matter yield for high P requiring legumes in the year of fertiliser application

The pasture growth assumptions for the three legume types described in Figure 16 to Figure 18 shows primarily a response to different levels of plant available P in the soil. Low P soils often also have other traits that limit plant growth, such as lower water holding capacity, sub-soil constraints or low levels of other nutrients (e.g. potassium or sulphur) (Ahern *et al.*, 1994). For the purposes of this analysis, the legume dry matter production assumed there would be other limitations to plant growth, such that, for any particular soil P level the legume DM production was:

DM production very low P soil < low P soil < moderate P soil.

4.2 Animal production

Figure 19 to Figure 21 show summarised relationships for supplemented or un-supplemented stock grazing legume-based pastures compared to soil P levels for the three soil types used in the analysis.

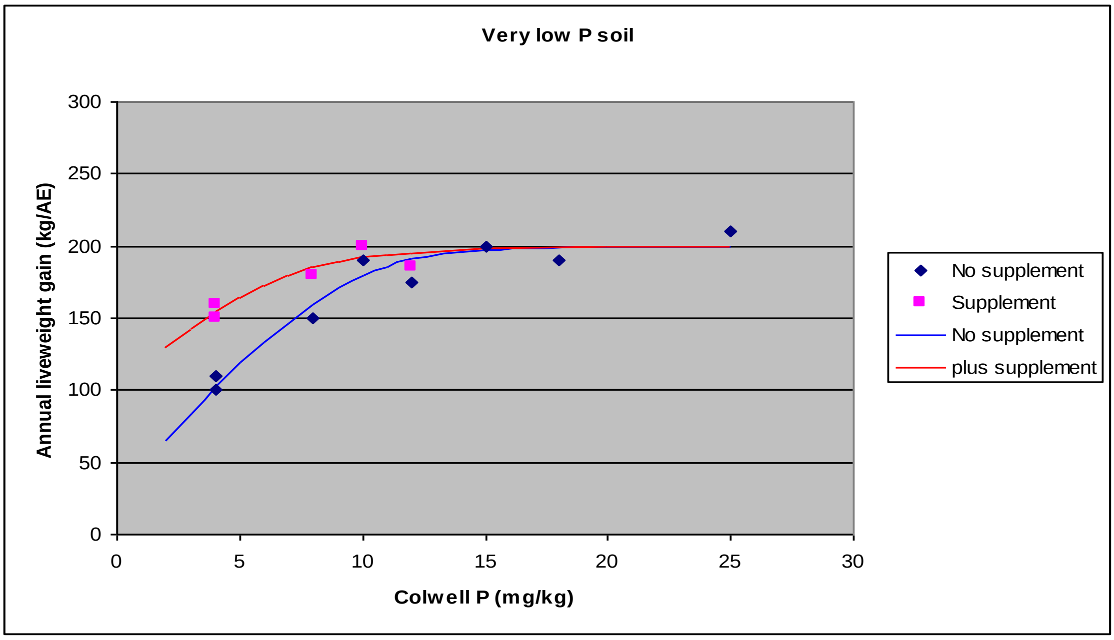

Figure 19: Steer liveweight gains across all scenarios on the very low P soil.

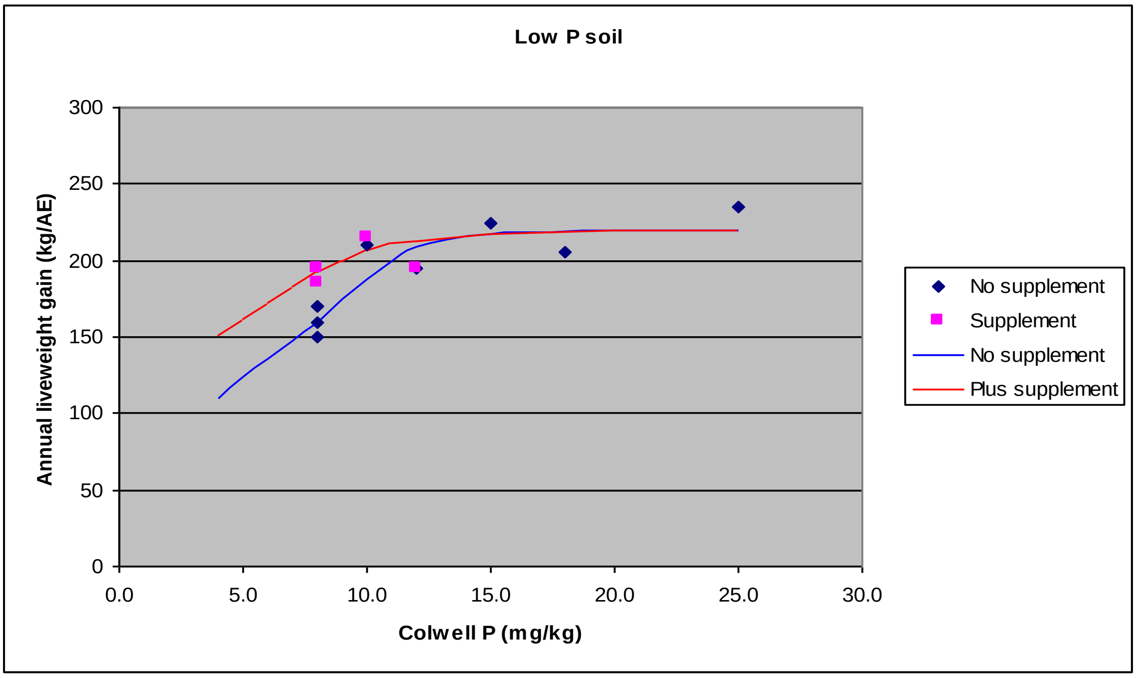

Figure 20: Steer liveweight gains across all scenarios on the low P soil

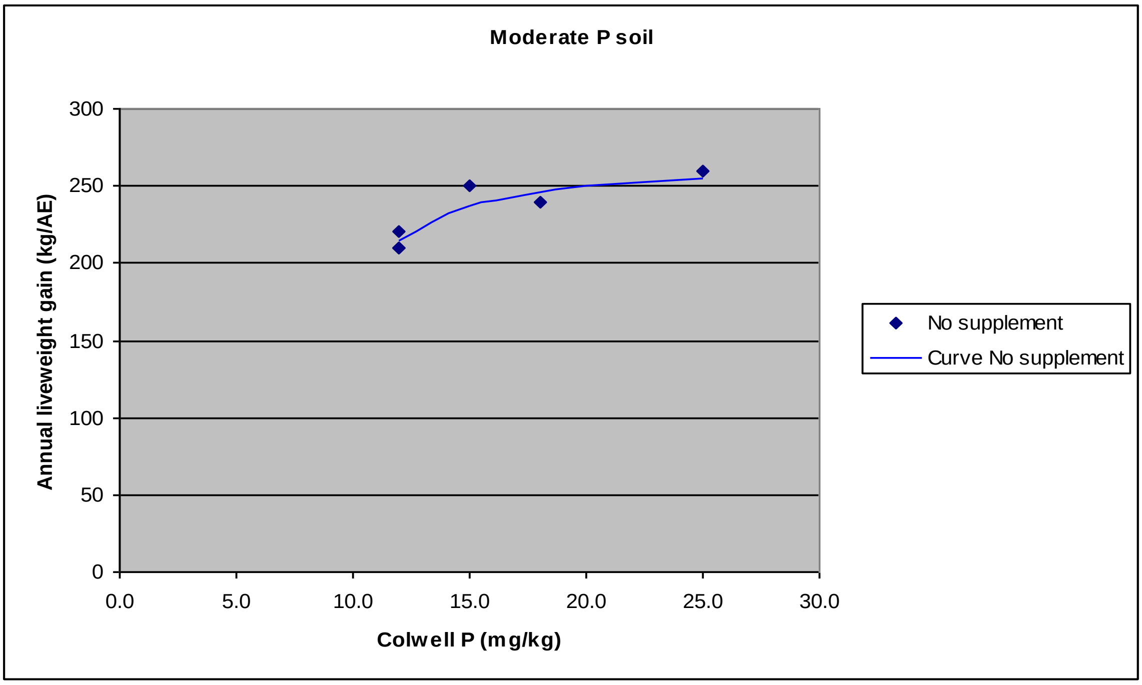

Figure 21: Steer liveweight gains across all scenarios on the moderate P soil

Relationships for liveweight gain versus soil Colwell P levels were developed for each soil type by legume and supplementation level (i.e. with or without supplements)An example is shown in Figure 22. These equations were then used to calculate the annual liveweight gain for intervening years between fertiliser applications. Expected changes in Colwell P levels were calculated assuming a P maintenance requirement of 1 kg P/DSE/ha/yr (Guppy *et al.*, 2013) and a soil Colwell P responsiveness of 0.3 mg/kg for every kilogram of P (Simpson *et al.*, 2009) lost through the maintenance requirement.

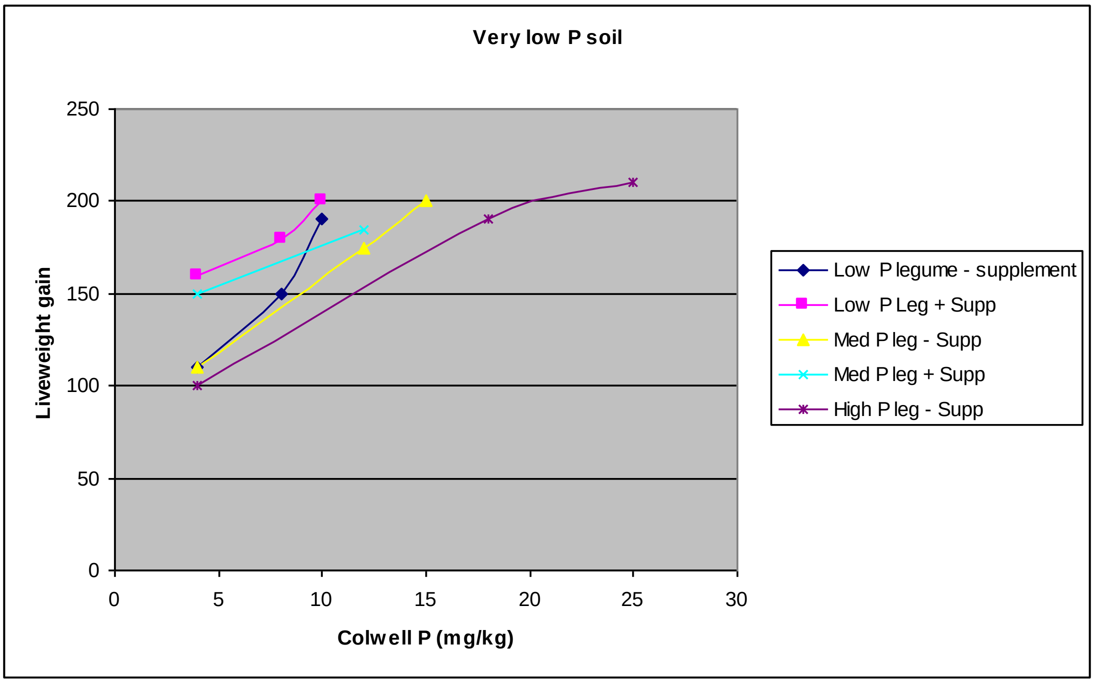

Figure 22: Steer liveweight gains for all scenarios on the very low P soil

4.3 Base scenario gross margins

The enterprise gross margins for each initial carrying capacity of the paddock are shown in Table 18 to Table 20. These budgets represent the expected performance of the paddock, on average, over time. No fertiliser or supplement is added to these budgets.

The opportunity cost of the capital tied up when steers are purchased is deducted from the gross margin to calculate the value of the gross margin after interest at an annual rate of 5%. Only the opportunity cost of steer capital has been included as no other capital costs differ significantly between the various treatments. The costs of transporting the steers to and from the property, minor health costs and selling costs are the other main variable costs included in the enterprise budgets.

Table 18: Base scenario gross margins for very low P soil

Gross margin for	Grass only	Low P legume	Medium P legume	High P legume
	/ha/annum	/ha/annum	/ha/annum	/ha/annum
Livestock Sales	$97	$158	$117	$97
Variable costs				
Livestock Purchases	$76	$121	$87	$76
Freight In	$2	$2	$2	$1
Freight Out	$2	$3	$2	$2
Treatment Expenses	$0	$0	$0	$0
Selling Expenses	$1	$1	$1	$1
Forage growing costs	$0	$0	$0	$0
Total Expenses	$80	$127	$92	$80
Gross Margin	**$17**	**$30**	**$25**	**$17**
Gross Margin (after interest)	$13	$24	$20	$13
Kilograms of liveweight gain	12	20	17	12

The poor gross margin for the high P legume is an indication of the impact of very low P soils on the productivity of these plants. Some trials have demonstrated that legumes may grow so poorly that they fail to persist under grazing if their P requirements are not met (Jones *et al.*, 1993; Shakhane *et al.*, 2013). The medium P legume also does not have its P needs met and fails to perform as well as the low P legume on these soils. In general, the overall production and economic performance of improved pastures on very low P soils is quite modest.

Table 19: Base scenario gross margins for low P soil

Gross margin for	Grass only	Low P legume	Medium P legume	High P legume
	/ha/annum	/ha/annum	/ha/annum	/ha/annum
Livestock Sales	$201	$365	$298	$265
Variable costs				
Livestock Purchases	$141	$240	$201	$181
Freight In	$3	$5	$4	$4
Freight Out	$3	$6	$5	$5
Treatment Expenses	$0	$1	$1	$1
Selling Expenses	$1	$2	$2	$2
Forage growing costs	$0	$0	$0	$0
Total Expenses	$149	$254	$212	$192
Gross Margin	**$52**	**$110**	**$86**	**$73**
Gross Margin (after interest)	$45	$98	$76	$64
Kilograms of liveweight gain	34	71	56	47

The low P soils also show reduced productivity and profitability for the medium P and high P legumes, significantly reducing the economic performance of the pasture when compared to a legume with lower critical P requirements.

Table 20: Base scenario gross margins for moderate P soil

Gross margin for	Grass only	Low P legume	Medium P legume	High P legume
	/ha/annum	/ha/annum	/ha/annum	/ha/annum
Livestock Sales	$290	$556	$520	$489
Variable costs				
Livestock Purchases	$195	$334	$318	$299
Freight In	$4	$7	$6	$6
Freight Out	$5	$30	$28	$26
Treatment Expenses	$1	$1	$1	$1
Selling Expenses	$2	$3	$3	$3
Forage growing costs	$0	$0	$0	$0
Total Expenses	$206	$375	$356	$335
Gross Margin	**$84**	**$180**	**$164**	**$154**
Gross Margin (after interest)	$74	$164	$148	$139
Kilograms of liveweight gain	54	128	116	110

The assumptions used in this analysis meant that there is insufficient available P in soils with moderate P levels to meet the full needs of legumes with medium and high critical P requirements. The inherent P status of soils appears to significantly impact the potential gross margin (if it is the most limiting factor). Moving from a very low P soil to a low P soil improves the potential gross margin for all pasture scenarios by almost 400%, and moving from a low P soil to a moderate P soil almost doubles the gross margin in most pasture scenarios. This aligns with the general recommendation for sown pastures of establishing pastures on better soils first (Lloyd *et al.*, 2007).

4.4 Benefits of P fertiliser and animal supplements for existing grass with legume pastures

Table 21 to Table 23 indicate the net annual benefit of adding either a supplement or fertiliser (or both) to the baseline pastures growing in the very low P, low P or moderate P soils.

The starting soil P level impacts the amount of additional fertiliser required to meet the requirements of fertiliser strategy 1 or 2 when applied to each legume type.

The benefit is recorded as either the difference between two steady state gross margins or as the marginal return on the additional capital invested in fertiliser, livestock and/or supplement. In each case the comparison is to the base scenario for each treatment, that is, grass with legume base line pasture when applying fertiliser.

The average annual benefit calculated at a 10% discount rate is also shown where variable rates of fertiliser were applied. A 10% discount rate is considered the least discount rate at which to identify the scenarios likely to be sufficiently profitable for a property owner to consider implementing.

4.4.1 Very low P soil

Table 21 shows the net annual benefit of adding either a supplement or fertiliser or both to the base pastures growing in the very low P soil.

Table 21: Net annual benefit of P supplement or P fertiliser on a very low P soil

Treatment	Annual benefit at a 10% discount rate ($/ha)	Marginal return on extra inputs
Grass-only + supplement	$2.18	n/a
Low P legume + supplement	$4.26	n/a
Medium P legume + supplement	$5.22	n/a
Low P legume, fertiliser 1 - supplement	-$1.59	7.15%
Low P legume, fertiliser 1 + supplement	$0.80	11.10%
Low P legume, fertiliser 2 - supplement	$14.21	20.53%
Low P legume, fertiliser 2 + supplement	$14.95	20.93%
Medium P legume, fertiliser 1 - supplement	$8.56	15.87%
Medium P legume, fertiliser 1 + supplement	$8.29	14.72%
Medium P legume, fertiliser 2 - supplement	$17.81	17.88%
High P legume, fertiliser 1 - supplement	$17.26	16.02%
High P legume, fertiliser 2 - supplement	$23.63	15.44%

The rates of fertiliser applied produce some benefit in most scenarios on the very low P soil. Grass only pastures and grass with either a low or medium P legume showed an economic benefit to feeding P supplements.

The best returns (annual benefit) are achieved where a high productivity legume has its full P requirements met. Medium P requiring legumes fertilised to meet its critical P requirement produced good returns (annual benefit) and higher marginal return. The low P requiring legumes also provided good returns and the highest marginal returns. However, research has shown that legumes may not persist under grazing when their P requirements are not met (Shakhane *et al.*, 2013; Jones *et al.*, 1993). A sufficiently large population of the legumes need to be present to respond to the fertiliser application to achieve these returns. This conundrum may mean that there is a lag between fertiliser application and pasture legumes reaching their production potential as plant numbers increase to sufficient levels.

Legumes with a low critical P requirement may not respond sufficiently to suboptimal rates of P fertiliser (fertiliser strategy 1) to justify its use. Incorporating a livestock supplement with fertiliser strategy 1 on low critical P legume pastures does not help much. For low P legumes, fertiliser strategy 1 is targeting a Colwell P level of 8 mg/kg in the year of application (Table 9).Therefore the liveweight gain differences between supplemented and un-supplemented stock is not large enough to warrant the cost (Figure 19). In these scenarios, the extra benefits are less than the extra costs.

Adding a P supplement with fertiliser has variable benefits on very low P soils. A legume with a low critical P requirement that receives an appropriate fertiliser rate to meet its needs, may need to be combined with an animal supplement to get the best animal production. In this case, the fertiliser meets the needs of the plants, but the assumptions used in the analysis, which were based on Kerridge *et al*. (1990), mean there was still some deficiency for livestock for maximum growth rates. However, responses to P supplements is variable at these soil P levels (i.e. 8-10 mg/kg Colwell P), therefore economic responses will also be unreliable.

Adding an animal supplement to the medium P legume system that is receiving fertiliser according to fertiliser strategy one slightly reduces returns. The uniform cost of the P supplement applied to all supplemented treatments possibly causes part of this effect, but part would be due to the economically inefficient P response in this treatment as soil Colwell P levels are at a level where small or no response in liveweight gain would be expected from P supplements.

4.4.2 Low P soil

Table 22 shows the net annual benefit of adding either a supplement or fertiliser (or both) to the base pastures growing in the low P soil.

Table 22: Net annual benefit of P supplement or P fertiliser on a low P soil

Treatment	Annual benefit at a 10% discount rate ($/ha)	Marginal return on extra inputs
Grass-only + supplement	$0.94	n/a
Low P legume + supplement	$5.05	n/a
Medium P legume + supplement	$4.30	n/a
High P legume + supplement	-$0.88	n/a
Low P legume, fertiliser 2 - supplement	$1.80	11.51%
Low P legume, fertiliser 2 + supplement	-$2.25	8.14%
Med P legume, fertiliser 1 - supplement	-$5.38	-0.70%
Med P legume, fertiliser 1 + supplement	-$7.52	-5.39%
Med P legume, fertiliser 2 - supplement	$24.08	21.45%
High P legume, fertiliser 1 - supplement	$9.44	14.21%
High P legume, fertiliser 2 - supplement	$37.55	18.8%

The low P soil showed some different economic responses than the very low P soil; that is, not all fertiliser scenarios provide positive returns. Medium and high P requiring legumes fertilised to their critical P requirement provided good returns. The addition of fertiliser to low P-requiring legumes growing on a low P soil may not pay, due to the low responsiveness to fertiliser. The soil starting P level (Colwell P 8 mg/kg) is already at the low P legumes 75% of maximum yield level (Table 9) with relatively small gains achieved from increasing soil P levels to a Colwell of 10 mg/kg (Figure 16).

Providing stock with P supplements on grass only pastures and grass with either a low or medium P legume showed an economic response.

Moderate or high P requiring legumes that are optimally fertilised show positive returns. The high P legume provides the highest returns per hectare. The medium P requiring legume produced the best marginal return.

4.4.3 Moderate P soil

Table 23 shows the net annual benefit of adding fertiliser to the base pastures growing in the moderate P soil.

Table 23: Net annual benefit of P fertiliser on a moderate P soil.

Treatment	Annual benefit at a 10% discount rate ($/ha)	Marginal return on extra inputs
Med P legume, fertiliser 2 - supplement	$25.51	22.72%
High P legume, fertiliser 1 - supplement	$4.30	13.22%
High P legume, fertiliser 2 - supplement	$52.42	23.63%

A low P legume has its requirements met by the inherent level of soil P and, therefore, will not respond to additional fertiliser, and is not included. The gross margins provided earlier for the base scenarios (Table 20) indicate that the expected gross margin for a low P legume in this soil is sound, and likely to be higher than the medium P and high P legumes growing in the same soil without fertiliser.

The addition of fertiliser to the medium P and high P legumes does improve returns above the base case scenarios. The best returns are gained by appropriately fertilising a high P legume. The final combination of legume and P fertiliser applied in the paddock could depend upon the availability of capital to the investor and the areas of each type of P deficient soil available for development.

4.4.4 Implications for existing grass-legume pastures

The analysis suggests that the economic performance of an established medium P or high P-requiring legume pasture will improve if it is fertilised at a rate that maximises plant performance. It appears that it will not be economic to fertilise low P legumes unless they are growing in very low P soils and they are fertilised at the optimal rate.

When using P fertiliser on existing legume-based pastures, total economic returns ($/ha) were greater with higher production potential legumes, even though they had a higher P requirement (and therefore fertiliser rate). However, lower P requiring legumes can provide similar or better marginal returns. Where graziers can afford the initial costs, the higher fertiliser and stocking rates with high P requiring legumes may provide the best investment. However, lower P requiring legumes with lower fertiliser rates maybe a better investment where cash flow is tight. This is more a comment about capital limitations than risk. It takes less capital to develop low P legumes where less fertiliser is required. It may be better to develop more hectares of low P legumes than fewer hectares of high P legumes. The final decision would depend upon the soils, paddock layout, beef enterprise, borrowing capacity of the business, interest rates etc. of the particular property being developed.

Feeding supplements to stock grazing unfertilised pastures on very low or low P soils can be profitable. However, returns from fertilising legume-based pastures are likely to be higher in this region.

Producers must consider both the costs and the benefits likely to be incurred in their production system when looking at each strategy. The analysis indicates that it is economically better to target the phosphorus nutrition of the plants than the livestock, and to target legumes with higher productivity when doing so. The P needs of the livestock are adequately met using this approach.

4.5 Establishing legumes into grass pastures

Planting legumes into improved grass pastures has proven problematic. The most widely used establishment methods by industry are low cost, resulting in low reliability with most attempts failing, due to competition for moisture and nutrients between the existing pasture grasses and the legume seedlings (Peck *et al.*, 2011; Cook *et al.*, 1993). Reliable establishment of legumes into existing grass pastures requires the control of competition from pasture grasses and weeds.

In the scenario analysis, all legume types (i.e. high, medium and low P requirements) were assumed to be established the same way, therefore the only differences in costs were fertiliser rates and costs associated with stock numbers. The method costed here is based on the full cultivation and treatment of six metre wide strips that are set on ten metre centres. This provides a four metre strip to re-establish the improved grass pastures across the paddock, and also minimises competition with the establishing legume pasture. The residual grass strip is also sprayed to suppress grass growth immediately after the planting of the legumes. This method is seen as the most reliable, and probably the most economic, method of establishing legume pastures into existing grass pastures.

In this analysis, the establishment phase of each legume is extended beyond normal industry expectations, to allow sufficient time for the low P and medium P legumes to spread and enhance the productivity of the grass pasture through an increased supply of nitrates. This ensures the long-term success of the legume pasture but significantly reduces the amount of grazing available early in the development.

Figure 23 shows the typical net cash flow for a paddock that is purchased and either planted to a legume with P fertiliser, or maintained as improved grass pasture. The slow rate of development for the legume is shown as the slow growth in net cash flow for the first six or seven years of the scenario.

The legume investment eventually matches the total cash flow of the grass-only investment by about the thirteenth year and is subsequently first to produce a positive total cash flow. From then on the cash flow of the legume pasture is significantly ahead of the grass-only investment.

The cash flow of the final year of each scenario captures all residual benefits of the investment through the nominal sale of the property. This includes an allowance for the ongoing extra carrying capacity provided by the legume, as well as the value of the livestock sold in the last year of the investment.

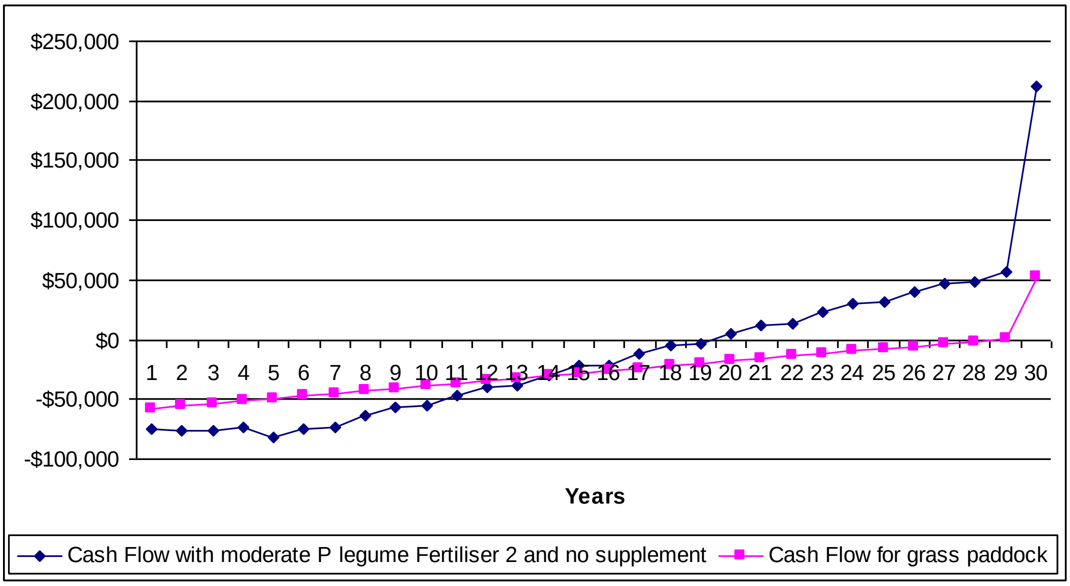

Figure 23: Example paddock cash flow with and without legume development

The extended period before the investment breaks, even for either scenario, together with the extra deficit accumulated through the investments in legumes and fertiliser, should be taken into account when the purchase of Brigalow lands for development to legumes is being considered. Investors who currently own the land will face a similar series of cash flows except for the cost of land. The net difference between the two scenarios is identical in either case, and this is what is used to measure the benefits of legume pasture establishment and P fertiliser use.

All investment scenarios were modelled for 30 year periods to allow for the variety of fertiliser and legume treatments. The benefit is recorded as the return on the additional capital invested in fertiliser, livestock and/or supplement.

The Net Present Value (NPV) and the amortised value of the NPV are calculated at a range of discount rates. In each case, if the NPV is positive, then the investment in establishing legumes has returned more than the discount rate shown immediately above the calculated NPV.

The 10% discount rate is considered to be the rate at which to identify the scenarios that are likely to be sufficiently profitable for a property owner to consider implementing.

4.5.1 Very low P soil

Table 24 to Table 26 show the expected returns from establishing legumes on very low P soils. Only fertiliser strategy 2 was analysed for establishing legumes into grass pastures as it is likely to be the most profitable fertilising technique (section 4.4). In each case, the Internal Rate of Return (IRR) is slightly below 10%, indicating that the hurdle of the 10% discount rate has not quite been achieved. Developing very low P soils to legumes may not be the highest priority investment on beef properties in the Brigalow bioregion.

Table 24: Very low P soil grass pasture converted to Low P legume with fertiliser strategy 2 and supplement

Internal Rate of Return	**9.51%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$26,702**	**$8,550**	**-$1,568**	**-$7,453**
Annual value per ha	$34.58	$12.46	-$2.55	-$13.46

Table 25: Very low P soil grass pasture converted to Moderate P legume with fertiliser strategy 2 and no supplement

Internal Rate of Return	**9.42%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$33,449**	**$10,466**	**-$2,368**	**-$9,846**
Annual value per ha	$43.32	$15.25	-$3.85	-$17.78

Table 26: Very low P soil grass pasture converted to High P legume with fertiliser strategy 2 and no supplement

Internal Rate of Return	**9.16%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$40,938**	**$11,901**	**-$4,608**	**-$14,440**
Annual value per ha	$53.02	$17.34	-$7.50	-$26.08

The IRR across all legume types is similar, however, the annual benefit increases with increasing P fertiliser rates and legume responsiveness. Producers who can afford the higher initial costs may, therefore, be better off establishing the high P requiring legume. However, the higher fertiliser and stocking rates are likely to be a higher risk investment depending on seasonal, price and production fluctuations. The low P requiring legume requires lower expenditure and may be a lower risk strategy.

4.5.2 Low P soil

Table 27 to Table 29 show the expected returns from establishing legumes on low P soils.

Once again, the IRR is about 10%. Developing low P soils to legumes may also not be the highest priority investment on beef properties in the Brigalow bioregion.

Table 27: Low P soil grass pasture converted to Low P legume with fertiliser strategy 2 and supplement

Internal Rate of Return	**11.40%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$33,017**	**$14,686**	**$3,991**	**-$2,478**
Annual value per ha	$42.76	$21.40	$6.50	-$4.48

Table 28: Low P soil grass pasture converted to Moderate P legume with fertiliser strategy 2 and no supplement

Internal Rate of Return	**9.70%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$26,516**	**$9,222**	**-$953**	**-$7,178**
Annual value per ha	$34.34	$13.44	-$1.55	-$12.97

Table 29: Low P soil grass pasture converted to High P legume with fertiliser strategy 2 and no supplement.

Internal Rate of Return	**8.91%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$30,075**	**$8,114**	**-$4,916**	**-$12,974**
Annual value per ha	$38.95	$11.82	-$8.00	-$23.43

The low P requiring legume provides the best IRR and NPV. On low P soils it is likely to be a better investment to plant a legume adapted to lower P level with modest fertiliser requirements, than fertilising higher P requiring legumes.

4.5.3 Moderate P soil

Table 30 to Table 32 show the expected returns from establishing legumes on moderate P soils.

In each case the IRR is above 10%. Developing moderate P soils to legumes should provide a reasonable return on investment on beef properties in the Brigalow Belt bioregion.

Table 30: Moderate P soil grass pasture converted to Low P legume with no fertiliser and no supplement

Internal Rate of Return	**15.12%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$48,666**	**$26,842**	**$13,693**	**$5,488**
Annual value per ha	$63.02	$39.11	$22.28	$9.91

Table 31: Moderate P soil grass pasture converted to Moderate P legume with fertiliser strategy 2 and no supplement

Internal Rate of Return	**12.41%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$63,825**	**$31,537**	**$11,967**	**-$337**
Annual value per ha	$82.66	$45.94	$19.48	-$0.61

Table 32: Moderate P soil grass pasture converted to High P legume with fertiliser strategy 2 and no supplement

Internal Rate of Return	**15.32%**			
Required rate of return for alternative use of funds	5.00%	7.50%	10.00%	12.50%
Net Present Value of investment	**$93,722**	**$52,747**	**$27,630**	**$11,631**
Annual value per ha	$121.37	$76.84	$44.97	$21.01

The high P requiring legume provided the best NPV, with the moderate P legume and low P legume having similar NPV's. However, the low P legume provided similar IRR as the high P legume. The high P legume should be the best investment where the grazier can afford the initial expenses. However, planting a legume that does not require P fertiliser on this soil is a good investment especially when access to capital is restricted.

4.5.4 Establishing legumes into soils with adequate phosphorus

The only scenario in this economic analysis that assessed establishing a legume into a soil above its critical P requirement, was for a low P legume established into the moderate P soil (Table 30). The low P legume provided an IRR of 15%.

An analysis by Best and Symes (2010) determined an IRR of 22% for leucaena established on soils without the need for fertiliser. Separate analysis by Fred Chudleigh (cited from Dalzell *et al.* 2006) suggested an IRR of 30% for establishing leucaena into buffel grass pastures.

From the analysis conducted as part of this review and previous studies for leucaena, IRR of 15-30% are possible when establishing legumes into grass pastures on soils with adequate P.

4.5.5 Recommendations for establishing legumes into grass pastures

In most cases, the planting of legumes into improved grass pastures in the Brigalow Belt looks to be worthy of consideration by beef producers. Where there is a desire to plant legumes and a choice is available, soils with the highest P status should be developed to legumes first as, across all scenarios, the returns were generally better in soils with higher P levels.

The choice of which legume to plant depends on the situation. High P requiring legumes are able to provide a higher NPV in some situations, but not all. Low P requiring legumes are able to provide similar or higher IRR and in some situations higher NPV.

Economic returns between the legume P responsiveness types are influenced by the assumptions about their response rates and maximum productivity assumptions (Figure 16 to Figure 18). The relative performance and P responsiveness of legumes for permanent pastures in the Brigalow Belt is unknown. Research is required to be able to more clearly recommend which legume types are better to plant for different soil P levels.

4.6 Research, development and extension priorities

There is limited trial data and very limited commercial experience in using P fertiliser on sown grass with legume pastures in the Brigalow Belt. This paucity of information limits the capacity to conduct detailed bio-economic assessments of P fertiliser use. RD&E priorities, therefore, focus on improving the understanding and quantification of responses to fertiliser application. The review identified the following RD&E priorities:

- demonstrate the commercial impacts of P fertiliser applied to legume-based pastures
- develop comparative response curves for adapted legumes to establish critical P requirements and rate of response to applied P
- test the field response of legumes to applied fertiliser (rate and application method)
- understand Brigalow clay soil responses to P fertiliser
- develop a better understanding of the extent and impact of P deficiency on red meat production in the Brigalow Belt
- test the extent of other nutrient deficiencies (e.g. sulphur, potassium) for pasture legumes in the Brigalow Belt.

4.6.1 Demonstrate the commercial impacts of phosphorus fertiliser

There is very limited (almost zero) use of P fertiliser on pastures and insufficient use of P fertiliser on grain crops in the Brigalow Belt (Radrizzani *et al.*, 2007; Bell *et al.*, 2010; Brodie, 2006). Graziers and their advisors have generally thought that applying P fertiliser to pastures is not viable. For industry to overcome these pre-conceptions, there needs to be strong evidence and demonstration at the commercial scale.

Key areas for investment in RD&E within an extension framework include:

- demonstrate pasture legume, grass, animal production and economic benefits from P fertiliser application for important legume species currently used in the Brigalow Belt. Leucaena and medic are the most widely used legumes and would provide the best opportunity to identify economic performance.
- improving pasture managers and their advisor's understanding of sown pasture legume production and nitrogen fixation in relation to P fertiliser application
- develop fertiliser recommendations for leucaena, medic and other important emerging legumes (e.g. desmanthus and Caatinga stylo).

4.6.2 Comparative response curves for adapted legumes

There have been some trials testing the fertiliser response and critical P requirement of legumes used in the Brigalow Belt. However, these trials tended to happen in isolation from each other with inconsistent testing techniques on soils with different characteristics. To gain a fairly rapid indication of relative phosphorus requirements and response rates for adapted legume species, it is recommended that pot trials be conducted. These trials should also be supported with field trials.

4.6.3 Field response of legumes to applied phosphorus

Field trials of P fertiliser response to applied P should be targeted to support the pot trials described above. For leucaena and some of the medic species, it is likely that appropriate trial sites (i.e. uniform soil, good pasture composition, low soil P) would be available with existing grass and legume pastures. The other legume species have not been well established widely (i.e. good legume populations). It is therefore likely to be difficult to find appropriate trial sites. If appropriate trial sites were not found, it would necessitate the establishment of the pasture, as well as the application of fertiliser. Multiple trial sites would be required due to the different soil adaptations of the different legumes. Key research questions for the trial sites include the dry matter response, N fixation response, effect on pasture composition and whether fertiliser application method (e.g. drilled, broadcast, banded) affects response rates.

4.6.4 Understand Brigalow clay soils responses to phosphorus fertiliser

'How much' and 'how often' are two key questions when applying fertiliser to pastures. How much fertiliser is required to raise a soil to the critical P requirement of a particular legume species needs to be determined. Secondly, how quickly do plant available P levels in the soil decline to a level where re-application provides good returns. Recommendations from the New England Tablelands were used for the bio-economic modelling in this review. The assumptions adopted for this review need to be clarified for Brigalow clay soils.

4.6.5 Test the extent of P deficiency of stock in the Brigalow Belt

Two grazing demonstration trials conducted as part of the "Improving productivity of rundown sown grass pastures" project, have shown marginal or deficient blood P levels in cattle grazing sown pastures on Brigalow clay soils (Peck *et al.* un-published data). If this trial experience is indicative of the broader grazing industry in the Brigalow Belt, then P deficiency could be limiting a larger proportion of the northern Australian beef industry than previously thought. Herds should be screened for P status to gain a better understanding of the extent of the P deficiency across the Brigalow Belt.

4.6.6 Test the extent of other nutrient deficiencies for legumes in the Brigalow Belt

This review focuses on P deficiency as it is thought to be the most commonly limiting nutrient for pasture legumes. However, it is known that other nutrients limit production as well. Sulphur is known to limit legume production on many soils (e.g. Radrizzani *et al.*, 2010), and evidence from one of the databases reviewed in this project suggested co-incident P and S deficiency in a high proportion of soils. Potassium levels have been shown to be declining under grain cropping (Bell *et al.*, 2010). These other nutrients should be considered when conducting RD&E on pasture legumes. The extent of deficiencies in S and K for legume productivity should be determined.

5 Impact on meat and livestock industry

It is clear that 'pasture rundown' is significantly reducing production and economic performance of the meat and livestock industries in the Brigalow Belt (Peck *et al.*, 2011; Myers and Robbins, 1991). 'Pasture rundown' is the decline in grass growth due to a decline in available N in the soil with increasing age of the pasture stand as N is 'tied-up' in organic matter (Graham *et al.*, 1981; Robertson *et al.*, 1997).

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from rundown sown grass pastures through their ability to biologically fix atmospheric nitrogen (Peck *et al.*, 2012). Legumes require adequate nutrition to grow well and fix large amounts of N. Phosphorus is the most commonly limiting nutrient for pasture legume growth, with significant areas of the Brigalow Belt likely to be responsive to P fertiliser (Section 2.4).

The Brigalow Belt carries approximately 30% of northern Australia's beef herd on 15% of the grazed land. Practices that can improve the economic returns of grazing in the Brigalow Belt are, therefore, likely to have a large impact on the industry as a whole. From this review, the adoption of legumes, with P fertiliser where required, has been shown to provide good economic returns at the paddock scale. Therefore, when extrapolated to the industry scale, it is likely to provide significant economic benefits.

5.1 Area of sown pastures

Of the total area planted to sown pasture in northern Australia, 70% has been sown only with tropical grasses with buffel grass (*Pennisetum ciliare*) being the most widely adapted and planted sown species. It comprises over 75% of the area sown to tropical grasses (Walker *et al.*, 1997; Walker and Weston, 1990). Figure 24 shows the distribution of buffel grass pastures across Queensland and indicates the scope for improving the productivity of sown pastures in Queensland.

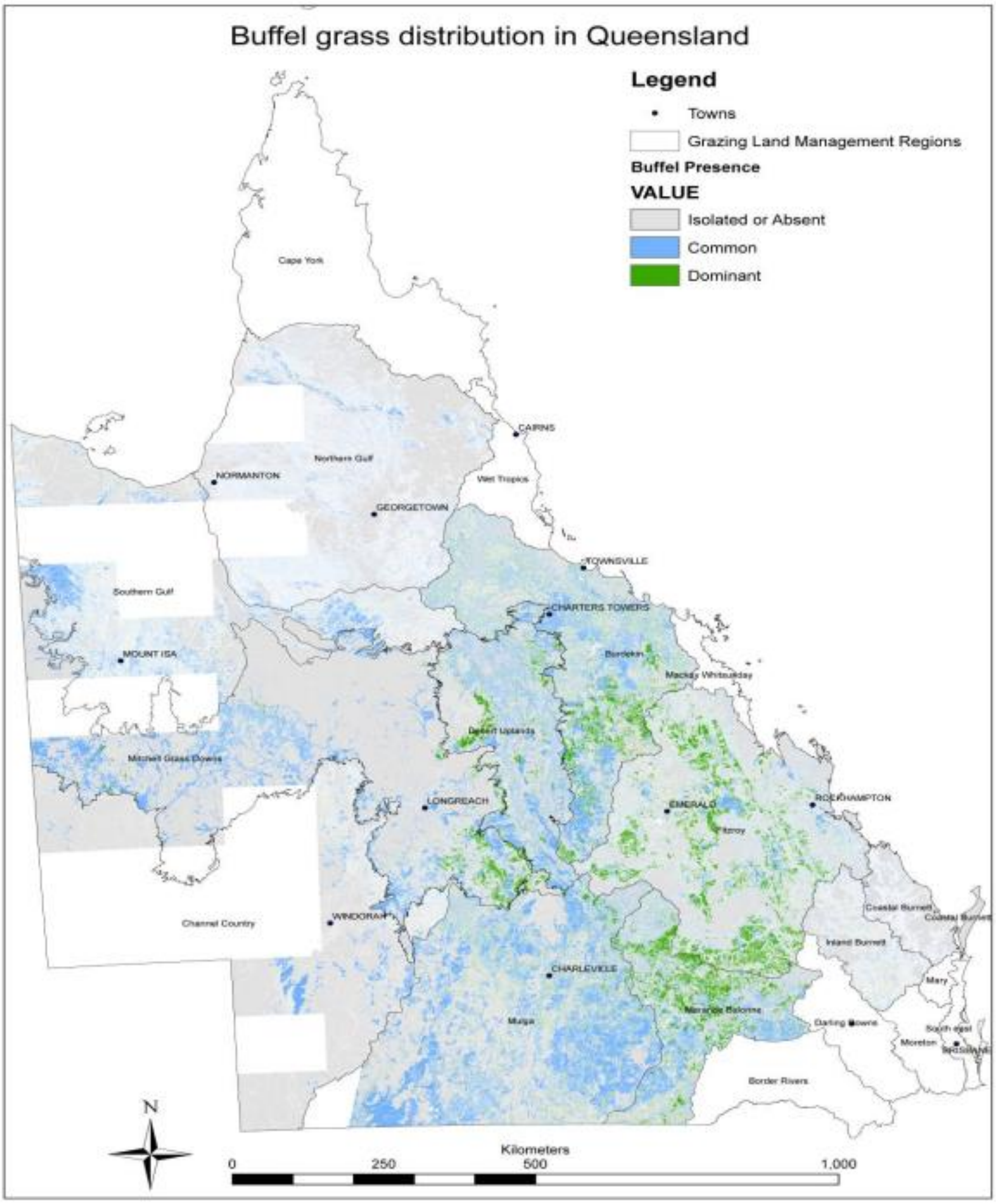

Figure 24: Buffel grass distribution in Queensland (Peck *et al.*, 2011)

Spatial analysis identified 5.8M ha where buffel grass pastures were 'dominant' with a further 25.9M ha where buffel grass pastures were 'common' (Peck *et al.*, 2011). Approximately 13M ha of the 31.7M ha of buffel grass pastures described above are in the Brigalow Belt. Unfortunately, this analysis underestimates the area of buffel grass pastures in the Brigalow Belt, due to missing spatial datasets for parts of southern inland Queensland. Most of the land sown to improved pasture grasses is considered to be in a rundown state that could be ameliorated with the introduction of perennial legumes (Peck *et al.*, 2011).

5.1.1 Area with low phosphorus in sown pastures in the Brigalow Belt

As part of this review, two soils databases were interrogated for soil P levels and are described in section 2.4.2. The relative percentages of the soil samples with different soil P levels are shown in Table 33. If it is assumed that the relative percentage of samples within different soil P levels is an approximation of the spatial variability in P levels, then we can use them to calculate approximate areas of P deficiency in the Brigalow Belt. The approximate areas of sown pastures within different soil P levels calculated from the average percentage of samples between the two data bases is shown in Table 33.

Table 33: Percentage of soil samples with different soil Colwell P levels and approximate area in the Brigalow Belt.

Colwell P (mg/kg)	Percentage of soil samples			Area* (M ha)
	DAF (%)	Incitec (%)	Average (%)	
<10	23	31	27	3.51
10-25	43	30	36.5	4.76
>25	34	39	36.5	4.76

* Area based on 13 M ha of sown pasture multiplied by the percentage of soil samples averaged across the two databases. More information on the databases is in section 1.4.2.

There are up to 8.3M hectares of sown pastures in the Brigalow Belt where higher P requiring legumes are likely to respond to P fertiliser if, or when, they are established. There are approximately 3.51M hectares where stock may have marginal or low P levels and all legumes are likely to respond to fertiliser if they are established.

These large areas demonstrate that better use of P fertiliser when establishing legumes will be important for industry in improving the productivity of rundown sown grass pastures. Improving productivity of rundown sown grass pastures has the potential to dramatically increase beef production in Queensland.

5.1.2 Area of sown pasture legumes with low phosphorus

The Leucaena Network has estimated that there are approximately 250,000 ha planted to leucaena. Based on the analysis of Peck *et al.* (2011), this is approximately 3% of the area that leucaena is adapted to in Queensland. There are not good estimates of the areas of other pasture legumes.

Phosphorus fertiliser use is very low in leucaena pastures. In a survey of 124 commercial pastures, only 10% of pastures were fertilised with P at establishment, and only 2% had maintenance fertiliser applied (Radrizzani *et al.*, 2007). It is likely that P fertiliser use on other pasture legumes is as low, or lower, than what occurs on leucaena.

Estimated areas of sown pasture legumes with different soil P levels and area that has a P fertiliser program are shown in Table 34. These areas are based on:

- the areas described in Table 33
- 3% successful adoption of legumes (from the leucaena estimates described above)
- 2% of pasture legumes having a maintenance fertiliser program (Radrizzani *et al.*, 2007).

Table 34: Area of legume based pastures with fertiliser programs with different soil P levels

	Area of legume pastures (ha)	Area of legume pasture with P fertiliser program
All P levels	390,000	7800
<10	105,300	2106
10 - 25	247,650	4953

Phosphorus fertiliser use is very low on pasture legumes in the Brigalow Belt, however, there are relatively large areas of pasture legumes that are likely to respond to P fertiliser. Good economic returns from fertilising legume based pastures are possible in the Brigalow Belt of 12-24% (section 4.4). There is a significant opportunity for industry to improve the productivity of existing sown legume pastures.

6 Conclusions and recommendations

6.1 Pasture legumes and phosphorus

Pasture legumes are the most promising option for improving the productivity of rundown sown grass pastures in the Brigalow Belt. For legumes to realise this promise, they need to become more reliably productive on commercial properties. Ensuring adequate P (and other nutrients) is likely to be a large part of the solution to improving the commercial productivity of legumes and the associated grasses in Brigalow Belt pastures.

6.2 Phosphorus deficiency in the Brigalow Belt

Soil phosphorus levels in Brigalow soils have been widely thought to be adequate for both grazing animals and pasture species, which has led to very low use of P fertiliser on pastures. Unfortunately, there is increasing evidence that suggests this widely held belief is inaccurate, specifically that evidence includes:

- Soils mapping of north east Queensland shows there is wide variation in P levels across soils in the Brigalow Belt (Ahern *et al.*, 1994).
- A departmental soils database shows wide variation in P levels within Brigalow clay soils, and only approximately 30% of soils have soil P levels above which all pasture legumes are unlikely to respond to P fertiliser (Lawrence *et al*. un-published data).
- Declining P availability under buffel grass pastures on Brigalow soils (Thornton *et al.*, 2010).
- Long histories of cropping and export of P in grain has led to reductions in soil P levels (and other nutrients) (Bell *et al.*, 2010). Many of these soils have been established with pastures which are then P deficient.
- Pasture legumes that are either commonly used, or show promise as permanent pastures, can respond strongly to applied fertiliser P on low P soils.
- Cattle in current grazing trials have low or marginal P levels that may indicate that P deficiency of stock is more widespread than previously thought (Peck *et al*. un-published data).

6.3 Overcoming phosphorus deficiency

Bio-economic modelling conducted as part of this review for the Brigalow Belt suggests:

- Highly profitable returns when applying P fertiliser to already established grass with legume pastures. Returns of 12 – 24% on the extra input costs are achievable.
- The returns from establishing legumes into existing sown grass pastures are also positive. Internal rates of return ranged from 9-15%. The modelling assumed a relatively high cost but more reliable legume establishment technique; cheaper establishment techniques should be possible for some of the legume species.
- Returns from establishing legumes into existing grass pastures are generally higher with soils inherently higher in P. Where possible, soils with higher P levels should be developed with legumes first. Establishing legumes into soils with adequate P can provide returns of 15-30%.

- Direct supplementing of stock on P deficient soils will often provide good returns.

6.4 Research, Development and Extension priorities

There is limited trial data and very limited commercial experience in using P fertiliser on sown grass with legume pastures in the Brigalow Belt. RD&E priorities, therefore, focus on improving the understanding of soil, plant and animal responses to applied phosphorus. The review identified the following RD&E priorities:

1. Demonstrate the commercial impacts of P fertiliser applied to grass with legume pastures:
   a. demonstrate pasture and animal response from P fertiliser on widely established legumes (i.e. Leucaena and medics)
   b. improve pasture managers and their advisors understanding of P fertiliser impacts on productivity
   c. develop P fertiliser recommendations for important legume species.
2. Pot trials to develop comparative response curves for adapted legumes to establish critical P requirements and rate of response to applied phosphorus.
3. Test the field response of legumes to applied fertiliser (rate and application method):
   a. DM response
   b. nitrogen fixation response
   c. pasture composition response
   d. impact of fertiliser application method (e.g. drilled, broadcast, banded) on response rates.
4. Understand Brigalow clay soil responses to fertiliser P:
   a. how big a response in plant available P per unit of applied P fertiliser
   b. how quickly does available P decline after fertiliser application.
5. Develop a better understanding of the extent and impact of P deficiency on red meat production in the Brigalow Belt:
   a. screen herds for P status
6. Test the extent of other nutrient deficiencies (e.g. sulphur, potassium) for pasture legumes in the Brigalow Belt.

A targeted RD&E program has the potential to provide large returns to industry. Improving the productivity of rundown sown grass pastures through greater adoption of legumes with appropriate P nutrition, has the potential to substantially increase the number of high quality cattle produced in Queensland.

6.5 Recommendations

This report recommends that the grazing industry, through MLA and other stakeholders, invest in targeted RD&E to facilitate the wider adoption of improved nutrition of legumes based pastures.

Pasture productivity has dramatically declined in sown grass pastures across Queensland due to a decline in plant available nitrogen levels in the soil (a process often called ‘pasture rundown’). Pasture legumes are the most promising option for improving the productivity of rundown sown grass pastures in the Brigalow Belt. For legumes to realise this promise, they need to become more reliably productive on commercial properties. Ensuring adequate phosphorus (and other nutrients) is likely to be a large part of the solution to improving the commercial productivity of legumes and the associated grasses in Brigalow Belt pastures.

The potential economic returns from adoption of productive legumes with grass pastures to individual graziers and the industry, as a whole, are large, and provide a persuasive argument for significant RD&E investment. As well as improving the economic sustainability of grazing enterprises, mitigating pasture rundown can improve environmental performance of sown grass pastures through improved pasture stability, improved soil health and reduced erosion. To realise this potential, pasture legumes need to grow well which requires adequate P nutrition.

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8 Appendices

8.1 Appendix 1: Pasture, stock and fertiliser assumptions

8.1.1 Pasture, stock and fertiliser assumptions on the very low P soil

Table 35: Pasture, stock and fertiliser assumptions for base line pasture and baseline with supplementation scenarios on the very low P soil

	Grass Baseline	Grass-only + supplement	Low P legume	Medium P legume	High P legume	Low P legume + supplement	Medium P legume + supplement
Phosphorus fertiliser rate (kg P/ha)							
New Colwell P level	**4**	**4**	**4**	**4**	**4**	**4**	**4**
N fixation added (kg N/ha/yr)	0	0	10	5	0	10	5
Legume DM production		0	667	333	0	667	333
Extra weight gain (via P) (kg/AE/yr)	0	30	0	0	0	40	40
Extra weight gain (via Protein) (kg/AE/yr)	0	0	10	10	0	20	10
Total weight gain (kg/AE/yr)	**100**	**130**	**110**	**110**	**100**	**160**	**150**
Pasture response/	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	0	300	150	0	300	150
Increase in DM production	**0%**	**0%**	**18%**	**9%**	**0%**	**18%**	**9%**
Pasture production (kg DM/ha/yr)	**1700**	**1700**	**2000**	**1850**	**1700**	**2000**	**1850**
Spoilage %	15%	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	255	255	300	277.5	255	300	277.5
Residual (kg DM/ha/yr)	1020	1020	1020	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	425	425	680	552.5	425	680	552.5
Increase in forage consumed (kg DM/ha/yr)	0	0	255	127.5	0	255	127.5
Consumption increase	0%	0%	60%	30%	0%	60%	30%
Stocking rate (ha/AE)	8.59	8.59	5.37	6.61	8.59	5.37	6.61
Stocking rate (AE/ha)	0.12	0.12	0.19	0.15	0.12	0.19	0.15
New weight gain (kg/AE/yr)	100	130	110	110	100	160	150
Liveweight (kg live wt/ha/yr)	**11.64**	**15.14**	**20.49**	**16.65**	**11.64**	**29.81**	**22.71**
Increase in liveweight (per ha)	**0%**	**30%**	**76%**	**43%**	**0%**	**156%**	**95%**

Table 36: Pasture, stock and fertiliser assumptions for fertiliser strategy 1 (low fertiliser rate) scenarios

	Grass Baseline	Low P leg, low fert - supplement	Low P leg, low fert + supplement	Med P leg, low fert - supplement	Med P leg, low fert + supplement	High P leg, low fert - supplement
Phosphorus fertiliser rate (kg P/ha)		13.3	13.3	26.7	26.7	46.7
New Colwell P level	**4**	**8.0**	**8.0**	**12.0**	**12.0**	**18.0**
N fixation added (kg N/ha/yr)	0	20	20	25	25	30
Legume DM production		1333	1333	1667	1667	2000
Extra weight gain (via P) (kg/AE/yr)	0	20	40	30	40	40
Extra weight gain (via Protein) (kg/AE/yr)	0	30	40	45	45	50
Total weight gain (kg/AE/yr)	**100**	**150**	**180**	**175**	**185**	**190**
Pasture response/	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	600	600	750	750	900
Increase in DM production	**0%**	**35%**	**35%**	**44%**	**44%**	**53%**
Pasture production (kg DM/ha/yr)	**1700**	**2300**	**2300**	**2450**	**2450**	**2600**
Spoilage %	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	255	345	345	367.5	367.5	390
Residual (kg DM/ha/yr)	1020	1020	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	425	935	935	1062.5	1062.5	1190
Increase in forage consumed (kg DM/ha/yr)	0	510	510	637.5	637.5	765
Consumption increase	0%	120%	120%	150%	150%	180%
Stocking rate (ha/AE)	8.59	3.90	3.90	3.44	3.44	3.07
Stocking rate (AE/ha)	0.12	0.26	0.26	0.29	0.29	0.33
New weight gain (kg/AE/yr)	100	150	180	175	185	190
Liveweight (kg live wt/ha/yr)	**11.64**	**38.42**	**46.11**	**50.94**	**53.85**	**61.95**
Increase in liveweight (per ha)	**0%**	**230%**	**296%**	**338%**	**363%**	**432%**

Table 37: Pasture, stock and fertiliser assumptions for fertiliser strategy 2 (high fertiliser rate) scenarios

	Grass Baseline	Low P leg, high fert - supplement	Low P leg, high fert + supplement	Med P leg, high fert - supplement	High P leg, high fert - supplement
Supplement and fertiliser					
Phosphorus fertiliser rate (kg P/ha)		20.0	20.0	36.7	70.0
New Colwell P level	**4**	**10.0**	**10.0**	**15.0**	**25.0**
N fixation added (kg N/ha/yr)	0	30	30	40	50
Legume DM production		2000	2000	2667	3333
Extra weight gain (via P) (kg/AE/yr)	0	30	40	40	40
Extra weight gain (via Protein) (kg/AE/yr)	0	60	60	60	70
Total weight gain (kg/AE/yr)	**100**	**190**	**200**	**200**	**210**
Pasture response/	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	900	900	1200	1500
Increase in DM production	**0%**	**53%**	**53%**	**71%**	**88%**
Pasture production (kg DM/ha/yr)	**1700**	**2600**	**2600**	**2900**	**3200**
Spoilage %	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	255	390	390	435	480
Residual (kg DM/ha/yr)	1020	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	425	1190	1190	1445	1700
Increase in forage consumed (kg DM/ha/yr)	0	765	765	1020	1275
Consumption increase	0%	180%	180%	240%	300%
Stocking rate (ha/AE)	8.59	3.07	3.07	2.53	2.15
Stocking rate (AE/ha)	0.12	0.33	0.33	0.40	0.47
New weight gain (kg/AE/yr)	100	190	200	200	210
Liveweight (kg live wt/ha/yr)	**11.64**	**61.95**	**65.21**	**79.18**	**97.81**
Increase in liveweight (per ha)	**0%**	**432%**	**460%**	**580%**	**740%**

8.1.2 Pasture, stock and fertiliser assumptions on the low P soil

Table 38: Pasture, stock and fertiliser assumptions for base line pasture and baseline with supplementation scenarios on the low P soil

	Grass Baseline	Grass-only + supplement	Low P legume	Medium P legume	High P legume	Low P legume + supplement	Medium P legume + supplement	High P legume + supplement
Phosphorus fertiliser rate (kg P/ha)								
New Colwell P level	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
N fixation added (kg N/ha/yr)	0	0	25	15	10	25	15	10
Legume DM production	0	0	1667	1000	667	1667	1000	667
Extra weight gain (via P) (kg/AE/yr)	0	15	0	0	0	15	15	15
Extra weight gain (via Protein) (kg/AE/yr)	0	0	30	20	10	40	30	20
Total weight gain (kg/AE/yr)	**140**	**155**	**170**	**160**	**150**	**195**	**185**	**175**
Pasture response/	30	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	0	750	450	300	750	450	300
Increase in DM production	**0%**	**0%**	**22%**	**13%**	**9%**	**22%**	**13%**	**9%**
New annual production (kg DM/ha/yr)	**3400**	**3400**	**4150**	**3850**	**3700**	**4150**	**3850**	**3700**
Spoilage %	15%	15%	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	510	510	622.5	577.5	555	622.5	577.5	555
Residual (kg DM/ha/yr)	2040	2040	2040	2040	2040	2040	2040	2040
Available for consumption (kg DM/ha/yr)	850	850	1487.5	1232.5	1105	1487.5	1232.5	1105
Increase in forage consumed (kg DM/ha/yr)	0	0	637.5	382.5	255	637.5	382.5	255
Consumption increase	0%	0%	75%	45%	30%	75%	45%	30%
Stocking rate (ha/AE)	4.29	4.29	2.45	2.96	3.30	2.45	2.96	3.30
Stocking rate (AE/ha)	0.23	0.23	0.41	0.34	0.30	0.41	0.34	0.30
New weight gain (kg/AE/yr)	140	155	170	160	150	195	185	175
Liveweight (kg live wt/ha/yr)	**32.60**	**36.10**	**69.28**	**54.03**	**45.41**	**79.47**	**62.47**	**52.98**
Increase in liveweight (per ha)	**0%**	**11%**	**113%**	**66%**	**39%**	**144%**	**92%**	**63%**

Table 39: Pasture, stock and fertiliser assumptions for fertiliser scenarios on the low P soil

	Grass Baseline	Med P leg, low fert - supplement	Med P leg, low fert + supplement	High P leg, low fert - supplement	Low P leg, high fert - supplement	Low P leg, high fert + supplement	Med P leg, high fert - supplement	High P leg, high fert - supplement
Phosphorus fertiliser rate (kg P/ha)		13.3	13.3	33.3	6.7	6.7	23.3	56.7
New Colwell P level	**8.0**	**12.0**	**12.0**	**18.0**	**10.0**	**10.0**	**15.0**	**25.0**
N fixation added (kg N/ha/yr)	0	30	30	35	35	35	45	55
Legume DM production	0	2000	2000	2333	2333	2333	3000	3667
Extra weight gain (via P) (kg/AE/yr)	0	15	15	15	10	15	15	15
Extra weight gain (via Protein) (kg/AE/yr)	0	40	40	50	60	60	70	80
Total weight gain (kg/AE/yr)	**140**	**195**	**195**	**205**	**210**	**215**	**225**	**235**
Pasture response/	30	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	900	900	1050	1050	1050	1350	1650
Increase in DM production	**0%**	**26%**	**26%**	**31%**	**31%**	**31%**	**40%**	**49%**
New annual production (kg DM/ha/yr)	**3400**	**4300**	**4300**	**4450**	**4450**	**4450**	**4750**	**5050**
Spoilage %	15%	15%	15%	15%	15%	15%	20%	20%
Spoilage (kg DM/ha/yr)	510	645	645	667.5	667.5	667.5	950	1010
Residual (kg DM/ha/yr)	2040	2040	2040	2040	2040	2040	2040	2040
Available for consumption (kg DM/ha/yr)	850	1615	1615	1742.5	1742.5	1742.5	1760	2000
Increase in forage consumed (kg DM/ha/yr)	0	765	765	892.5	892.5	892.5	910	1150
Consumption increase	0%	90%	90%	105%	105%	105%	107%	135%
Stocking rate (ha/AE)	4.29	2.26	2.26	2.09	2.09	2.09	2.07	1.83
Stocking rate (AE/ha)	0.23	0.44	0.44	0.48	0.48	0.48	0.48	0.55
New weight gain (kg/AE/yr)	140	195	195	205	210	215	225	235
Liveweight (kg live wt/ha/yr)	**32.60**	**86.28**	**86.28**	**97.87**	**100.25**	**102.64**	**108.49**	**128.77**
Increase in liveweight (per ha)	**0%**	**165%**	**165%**	**200%**	**208%**	**215%**	**233%**	**295%**

8.1.3 Pasture, stock and fertiliser assumptions on the moderate P soil

Table 40: Pasture, stock and fertiliser assumptions for all scenarios on the moderate P soil

	Grass Baseline	Low P legume	Medium P legume	High P legume	High P leg, low fert - supplement	Med P leg, high fert - supplement	High P leg, high fert - supplement
Phosphorus fertiliser rate (kg P/ha)					20.0	10.0	43.3
New Colwell P level	**12.0**	**12.0**	**12.0**	**12.0**	**18.0**	**15.0**	**25.0**
N fixation added (kg N/ha/yr)	0	40	35	30	50	60	75
Legume DM production	0	2667	2333	2000	3333	4000	5000
Extra weight gain (via P) (kg/AE/yr)	0	0	0	0	0	0	0
Extra weight gain (via Protein) (kg/AE/yr)	0	60	50	50	80	90	100
Total weight gain (kg/AE/yr)	**160**	**220**	**210**	**210**	**240**	**250**	**260**
Pasture response/	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	1200	1050	900	1500	1800	2250
Increase in DM production	**0%**	**25%**	**22%**	**19%**	**31%**	**38%**	**47%**
New annual production (kg DM/ha/yr)	**4800**	**6000**	**5850**	**5700**	**6300**	**6600**	**7050**
Spoilage %	20%	20%	20%	20%	20%	20%	20%
Spoilage (kg DM/ha/yr)	960	1200	1170	1140	1260	1320	1410
Residual (kg DM/ha/yr)	2640	2640	2640	2640	2640	2640	2640
Available for consumption (kg DM/ha/yr)	1200	2160	2040	1920	2400	2640	3000
Increase in forage consumed (kg DM/ha/yr)	0	960	840	720	1200	1440	1800
Consumption increase	0%	80%	70%	60%	100%	120%	150%
Stocking rate (ha/AE)	3.04	1.69	1.79	1.90	1.52	1.38	1.22
Stocking rate (AE/ha)	0.33	0.59	0.56	0.53	0.66	0.72	0.82
New weight gain (kg/AE/yr)	160	220	210	210	240	250	260
Liveweight (kg live wt/ha/yr)	**52.60**	**130.19**	**117.37**	**110.47**	**157.81**	**180.82**	**213.70**
Increase in liveweight (per ha)	**0%**	**148%**	**123%**	**110%**	**200%**	**244%**	**306%**

8.2 Appendix 2: Example of assumptions for establishing legumes

Table 41: Pasture, stock and fertiliser assumptions for establishing a low P requiring legume, with fertiliser strategy 2 with supplements into an existing grass pasture growing on a low P soil

Low P leg, high fert + supplement	Grass-only + supplement	Low P leg, high fert + supplement	Establishment Year	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Phosphorus fertiliser rate (kg P/ha)		**6.7**	**6.7**				**5.2**	**3.8**	**3.8**
Maintenance P (kg P removed) (prior yr)				0.4	1.1	1.9	1.9	3.8	3.8
New Colwell P level	**8.0**	**10.0**	**10.0**	**9.9**	**9.6**	**9.0**	**10.0**	**10.0**	**10.0**
N fixation added (kg N/ha/yr)	0	35	0	0	0	0	35.0	35.0	35.0
Legume DM production	0	2333	0	0	0	0	2333.3	2333.3	2333.3
Extra weight gain (via P) (kg/AE/yr)	15	15	15	15	15	15	14	15	15
Extra weight gain (via Protein) (kg/AE/yr)	0	60	0	0	55.5	49.9	61.0	60.0	60.0
Total weight gain (kg/AE/yr)	155	215	155	155	210.5	204.9	215.0	215.0	215.0
Pasture response/	30	30	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	0	1050	0	0	0	0	1050.0	1050.0	1050.0
Increase in DM production	**0%**	**31%**	**0%**	**0%**	**0%**	**0%**	**31%**	**31%**	**31%**
New annual production (kg DM/ha/yr)	**3400**	**4450**	**3400**	**3400**	**3400**	**3400**	**4450.0**	**4450.0**	**4450.0**
Spoilage %	15%	15%	15%	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	510	667.5	510	510	510	510	667.5	667.5	667.5
Residual (kg DM/ha/yr)	2040	2040	2040	2040	2040	2040	2040	2040	2040
Available for consumption (kg DM/ha/yr)	850	1742.5	170	510	850	850	1742.5	1742.5	1742.5
Increase in forage consumed (kg DM/ha/yr)	0	892.5	-680	-340	0	0	892.5	892.5	892.5
Consumption increase	0%	105%	-80%	-40%	0%	0%	105.0%	105.0%	105.0%
Stocking rate (ha/AE)	4.29	2.09	21.47	7.16	4.29	4.29	2.09	2.09	2.09
Stocking rate (AE/ha)	0.23	0.48	0.05	0.14	0.23	0.23	0.48	0.48	0.48
New weight gain (kg/AE/yr)	155	215	155	155	211	205	215	215	215
Liveweight (kg live wt/ha/yr)	**36.10**	**102.64**	**7.22**	**21.66**	**49.03**	**47.73**	**102.64**	**102.64**	**102.64**
Increase in liveweight (per ha)	**11%**	**215%**	**-78%**	**-34%**	**50%**	**46%**	**215%**	**215%**	**215%**

8.3 Appendix 3: Example maintenance fertiliser assumptions

Table 42: Maintenance fertiliser requirements, pasture and stock assumptions for a low P requiring legume with grass pasture growing on a very low P soil using fertiliser strategy 2 and P supplements

	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7
Phosphorus fertiliser rate (kg P/ha)	20.0		5.0		4.9		4.9
Maintenance P (kg P removed)		**2.6**	**2.4**	**2.5**	**2.4**	**2.5**	**2.4**
New Colwell P level	**10.0**	**9.2**	**10.0**	**9.2**	**10.0**	**9.2**	**10.0**
N fixation added (kg N/ha/yr)	30	26.1	28.6	26.1	28.6	26.1	28.6
Legume DM production	2000	1737.1	1904.8	1742.3	1904.8	1742.3	1904.8
Extra weight gain (via P) (kg/AE/yr)	40	40	40	40	40	40	40
Extra weight gain (via Protein) (kg/ae/yr)	60	52.1	57.1	52.3	57.1	52.3	57.1
Total weight gain (kg/AE/yr)	**200**	**192.1**	**197.1**	**192.3**	**197.1**	**192.3**	**197.1**
Pasture response/	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	900	781.7	857.2	784.0	857.2	784.0	857.2
Increase in DM production	**53%**	**46%**	**50%**	**46%**	**50%**	**46%**	**50%**
New annual production (kg DM/ha/yr)	**2600**	**2481.7**	**2557.2**	**2484.0**	**2557.2**	**2484.0**	**2557.2**
Spoilage %	15%	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	390	372.3	383.6	372.6	383.6	372.6	383.6
Residual (kg DM/ha/yr)	1020	1020	1020	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	1190	1089.5	1153.6	1091.4	1153.6	1091.4	1153.6
Increase in forage consumed (kg DM/ha/yr)	765	664.5	728.6	666.4	728.6	666.4	728.6
Consumption increase	180%	156%	171%	157%	171%	157%	171%
Stocking rate (ha/AE)	3.07	3.35	3.16	3.34	3.16	3.34	3.16
Stocking rate (AE/ha)	0.33	0.30	0.32	0.30	0.32	0.30	0.32
New weight gain (kg/AE/yr)	200	192	197	192	197	192	197
Liveweight (kg live wt/ha/yr)	**65.21**	**57.34**	**62.31**	**57.49**	**62.31**	**57.49**	**62.31**
Increase in liveweight (per ha)	**460%**	**392%**	**435%**	**394%**	**435%**	**394%**	**435%**

Table 43: Maintenance fertiliser requirements, pasture and stock assumptions for a medium P requiring legume with grass pasture growing on a very low P soil using fertiliser strategy 2 and P supplements

	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7
Phosphorus fertiliser rate (kg P/ha)	36.7			8.8			8.6
Maintenance P (kg P removed)		**3.2**	**2.9**	**2.7**	**3.0**	**2.9**	**2.7**
New Colwell P level	**15.0**	**14.0**	**13.2**	**15.0**	**14.1**	**13.2**	**15.0**
N fixation added (kg N/ha/yr)	40	34.6	32.0	37.5	34.8	32.1	37.5
Legume DM production	2667	2309.1	2134.7	2501.7	2317.5	2142.7	2501.7
Extra weight gain (via P) (kg/AE/yr)	40	40	40	40	40	41	42
Extra weight gain (via Protein) (kg/ae/yr)	60	52.0	45.0	59.8	52.4	44.3	57.8
Total weight gain (kg/AE/yr)	**200**	**192.0**	**185.0**	**199.8**	**192.4**	**185.3**	**199.8**
Pasture response/	30	30	30	30	30	30	30
Extra pasture produced (kg DM/ha)	1200	1039.1	960.6	1125.8	1042.9	964.2	1125.8
Increase in DM production	**71%**	**61%**	**57%**	**66%**	**61%**	**57%**	**66%**
New annual production (kg DM/ha/yr)	**2900**	**2739.1**	**2660.6**	**2825.8**	**2742.9**	**2664.2**	**2825.8**
Spoilage %	15%	15%	15%	15%	15%	15%	15%
Spoilage (kg DM/ha/yr)	435	410.9	399.1	423.9	411.4	399.6	423.9
Residual (kg DM/ha/yr)	1020	1020	1020	1020	1020	1020	1020
Available for consumption (kg DM/ha/yr)	1445	1308.2	1241.5	1381.9	1311.4	1244.6	1381.9
Increase in forage consumed (kg DM/ha/yr)	1020	883.2	816.5	956.9	886.4	819.6	956.9
Consumption increase	240%	208%	192%	225%	209%	193%	225%
Stocking rate (ha/AE)	2.53	2.79	2.94	2.64	2.78	2.93	2.64
Stocking rate (AE/ha)	0.40	0.36	0.34	0.38	0.36	0.34	0.38
New weight gain (kg/AE/yr)	200	192	185	200	192	185	200
Liveweight (kg live wt/ha/yr)	**79.18**	**68.83**	**62.93**	**75.64**	**69.12**	**63.19**	**75.64**
Increase in liveweight (per ha)	**580%**	**491%**	**440%**	**550%**	**494%**	**443%**	**550%**