finalreport

Improved Pastures

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Review of productivity decline in sown grass pastures

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Abstract

Productivity decline in sown grass pastures is widespread in northern Australia and reduces production by approximately 50%, a farm gate cost to industry of > $17B over the next 30 years. Buffel grass is the most widely established sown species (>75% of plantings) and has been estimated to be “dominant” on 5.8 M hectares and “common” on a further 25.9 M hectares of Queensland. Legumes are the most cost effective mitigation option and can reclaim 30-50% of lost production. Commercial use of legumes has achieved mixed results with notable successes but many failures. 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. This review recommends the grazing industry invest in targeted R,D&E to assist industry in improving production and sustainability of rundown pastures.

Executive Summary

Productivity decline in sown grass pastures is widespread in northern Australia and reduces production by approximately 50%. The economic impact of the decline is estimated at over $17B over the next 30 years. Graziers, the seed industry and researchers are all concerned that this 'rundown' is continuing. This report recommends that Meat and Livestock Australia (and other agencies) invest in targeted research, development and extension (R,D&E) to mitigate the effects of pasture rundown. The returns from effectively reducing the impact of pasture productivity decline are significant.

Project objectives
Graziers in southern and central Queensland have become increasingly concerned about the continuing decline in productivity of their sown grass pastures, especially in the large areas dominated by buffel grass. This concern is shared by researchers and the red meat industry through Meat & Livestock Australia (MLA). Key research in the 1980s and early 1990s documented the decline in productivity as grass pastures age, and identified the underlying cause to be reduced available soil nitrogen for pasture growth. However, concern about the continuing decline in productivity suggests that current mitigation strategies and/or the way they are used on farms must be improved.

The review builds on this early research with more recent findings and commercial experiences to provide a contemporary overview of the primary causes, extent and impacts of sown grass pasture 'rundown', and to review the mode-of-action and cost-effectiveness of options for mitigating its impact. Extensive consultations with graziers, the seed industry, agronomists and pasture researchers provided data and experience to review these options and their economic impacts. Ultimately, the findings and recommendations of the review have been developed to inform R,D&E investment, that is, whether to invest and to identify the best 'value propositions' for mitigating the effects of rundown and lifting long-term pasture production and animal performance.

Significant results
Consultations confirmed that productivity decline in sown grass pastures remains a major issue across southern and central Queensland. This 'rundown' is most severe with buffel grass, northern Australia's dominant sown species. Carrying capacity in older buffel pastures (>10-20 years since establishment) has declined by up to 50% in all districts. Many graziers believed this decline was continuing. The large reduction in animal production provides major incentive for future R,D&E investment to develop reliable solutions.

The decline in pasture productivity with age is directly attributable to a lack of available nitrogen in the soil as the nitrogen and other nutrients become 'tied-up' in soil organic matter, roots and crowns of old grass plants. This lack of available nitrogen limits dry matter production and may be exacerbated by overgrazing that leads to reduced pasture condition and land degradation.

Graziers are using a range of mitigation strategies to reduce the impact of 'rundown'. Most have accepted lower productivity either through not adopting or having poor results from mitigation strategies. Mechanical tillage to stimulate mineralisation of organic soil nitrogen has been used. However, economic analyses suggest the best options are to establish pasture legumes that introduce more nitrogen, or on arable land to use fallows of at least 3 months to mineralise large amounts of the organic nitrogen in the pastures. The only long-term solution that provides good

economic returns for the beef industry and individual graziers is to establish a range of adapted legumes into the existing grass-only pastures. Establishing legumes into a grass pasture can reclaim 30-50% of the lost production from pasture rundown and improve economic returns.

There are clear opportunities for targeted RD&E programs to improve the reliability of establishment and productivity of legumes. Whole farm returns of up to $1,300/ha over 30 years, and benefit:cost ratios of 4 -10 provide a serious incentive to invest in RD&E. Key priorities for targeting future RD&E include:

1. Development and extension - Poor agronomy and variable results mean that establishing legumes into existing pastures is considered risky. Good agronomy using current technology may help 'claw-back' up to 30-50% of the productivity decline. However, significant D&E investment is needed to support graziers to:
    - Understand the process of rundown and ways to supply available N for better grass production;
    - Build knowledge and skills to apply economically feasible options using existing technology, and;
    - Assess and demonstrate the impacts of legumes and more available nitrogen on grass production, animal performance and the profitability of commercial properties.

A key part of any extension program will be to develop and support clear management packages for the best adapted and emerging legumes, such as desmanthus, caatinga stylo, Shrubby/Caribbean stylos, and medics with tropical grasses

2. Research – Existing technology and practices can improve legume establishment. However, several key areas of research are needed to ensure legumes reach their full potential:
    - Develop new 'agronomically-sound' techniques and adapt current technologies used in other agricultural systems to establish legumes in existing pastures. For example, cultivate or use herbicide to maintain fallow strips before sowing legumes into grass pastures.
    - Assess the nutritional requirements of pastures. The phosphorus nutrition of legumes and its effects on legume establishment, on-going growth & nitrogen fixation, and contribution to increased pasture production/animal performance is a clear priority.
    - Assess and compare the productivity of emerging and best-adapted legumes (including leucaena, desmanthus, caatinga stylo) across the range of soils and locations in Queensland.

3. Market adjustment – Legumes present the major opportunity to address pasture rundown. However, seed of key species (namely, caatinga and desmanthus) is often unavailable. The beef industry must address this 'market failure' in the short term to overcome rundown and sustain productivity into the future

The economic analyses of this review confirm that productivity decline in sown grass pastures is a major issue for the beef industry of Queensland and northern Australia, and the consensus that legumes are the obvious solution to mitigating its impacts on the beef industry and individual farms. However, poor agronomy and variable results mean that establishing legumes into existing pastures is considered risky. There are opportunities to improve this reliability with better understanding and use of existing agronomic techniques. However, further targeted research will be needed to ensure legumes reach their full potential to minimise the impact of rundown and maintain productivity of sown pastures. Significant investment in R,D&E will be required, but the potential benefits are large.

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1.1 Introduction

Sown pastures have been very successful in northern Australia. Well adapted sown pastures enable higher productivity and profitability in grazing enterprises because they can produce more feed, of a better quality, for a longer period of the year than native pastures (Quirk and McIvor 2005). They have been widely sown and continue to improve production and economic returns from grazing, especially the beef industry (Chudleigh and Bramwell 1996; Walker *et al.* 1997).

The precise area of sown pastures across northern Australian is unclear. Initial estimates were optimistic, with over 41M ha of land in Queensland and a further 6M ha across the rest of northern Australia considered suitable for sown pastures (Walker *et al.* 1997; Walker and Weston 1990; Weston *et al.* 1984). This was subsequently reduced to 22.1M ha of "easily attainable" sown pastures in Queensland, and a further 0.5M ha across northern Australia (Walker *et al.* 1997; Walker and Weston 1990). Over 5M ha of sown pastures had been developed across Queensland and northern Australia by 1997, with these species naturalising onto a further 5M ha. The net annual increase of 210,000 ha (Walker and Weston 1990) is now estimated to be 150,000 ha/year due to restrictions on tree clearing and land development. If sown pasture areas have increased by 150,000 ha/year since 1997, the current area of sown pastures in northern Australia is approximately 12M ha.

Most sown pasture development in inland Queensland has occurred on fertile soils that have been cleared of brigalow and gidgee woodlands. It is estimated that up to 70% of the total area planted have been sown to "grass-only" pastures (Walker *et al.* 1997; Walker and Weston 1990). Buffel grass is the main species, comprising over 75% of the area sown to tropical grasses. There are significant areas of other grasses such as Bambatsi panic, purple pigeon grass, green and Gatton panic, Rhodes grass, signal grass and creeping blue grass; with lesser areas of digit grasses, setaria and sabi grass.

The productivity of native and sown pastures in northern Australia has been widely observed to have declined over time. This decline results from changes in land condition that can affect both native and sown pastures, and changes in available soil nitrogen (N) that mainly affects sown grasses and leads to "pasture rundown" (Myers and Robbins 1991; Pressland and Graham 1989; Tothill and Gillies 1992).

This report focuses on "pasture rundown", the productivity decline that results from a lack of available soil N as sown pastures age. However, there is substantial overlap and interaction between the impacts of land condition and N availability on pasture productivity. Conceptually the distinction between land condition and pasture rundown is described in section 1.2.

1.2 Grazing land condition

Grazing land condition is defined as "the capacity of land and pasture to respond to rain and produce useful forage" and has three components (Quirk and McIvor 2005):

- **Soil condition** – the capacity of the soil to absorb and store rainfall, to store and cycle nutrients, to provide habitat for seed germination and plant growth, and to resist erosion. It is measured by the amount of ground cover, and the condition of the soil surface;
- **Pasture condition** – the capacity of the pasture to capture solar energy into green leaf, to use rainfall efficiently, to conserve soil condition and to cycle nutrients. It is measured by the types of perennial grasses present, their density and vigour; and
- **Woodland condition** – the capacity of the woodland to grow pasture, to cycle nutrients and to regulate groundwater. It is measured by the balance of woody plants and pasture.

Grazing land condition directly affects rainfall use efficiency, and therefore, pasture growth of a managed parcel of land. Pasture condition is primarily determined by the presence or absence of perennial, productive and palatable (3P) grasses. Other determinants are the presence or absence of annual grasses and weeds.

The definition of land condition theoretically includes pasture rundown as reduced nutrient availability reduces rainfall use efficiency. However, in practice land condition does not measure nutrient availability and land condition can change independently of nutrient availability.

The major management factor to influence land condition over time is grazing management. Excessive grazing pressure, particularly in times of stress and when pastures are regrowing (e.g. when young growing tillers emerge at the beginning of the growing season), can cause land condition to decline. Land condition can change independently of the amount of nitrogen (and other nutrients) cycling at any point in time and nutrient rundown occurs even when land condition is maintained at a high level.

Land condition and pasture rundown clearly interact and a reduction in land condition will exacerbate the rundown process. However, it is important to separate the two processes to understand their impacts. Most of the remainder of this review will deal with nutrient rundown independent of land condition.

1.3 The impacts of productivity decline in sown grass pastures

Sown pasture grasses are very productive when they are planted after clearing or into fertile cropping soils. However, the productivity of these pastures typically declines with time, a phenomenon often described as "pasture rundown".

The large quantities of dry matter produced in this initial pasture phase 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.* 1985; Jones *et al.* 1995; Myers and Robbins 1991). Some authors suggest that the "rundown" state indicates the ecological limits of productivity and should be considered the "normal" or unamended level of production for the rainfall and soil fertility of the location (Burrows 1991; Dubeux *et al.* 2007; Myers and Robbins 1991; Pressland and Graham 1989).

Researchers, graziers and their advisers in the wider grazing industry recognise the symptoms of pasture "rundown" and its impacts on:

- Pasture and animal production through reduced pasture growth, reduced carrying capacities and lower weight gains that make it difficult to reach market specifications;
- Pasture composition with more native grasses and exotic grasses that are tolerant of lower nitrogen levels (e.g. sabi grass, Indian couch);
- Pasture density with smaller and / or fewer tussocks of sown grasses;
- Land degradation from reduced ground cover and higher erosion risk; and ultimately
- Economics and long-term profitability.

This report focuses on the "pasture rundown" effect, its impacts and the options to address pasture productivity decline in grass pastures. The processes involved in pasture rundown are described in more detail below.

1.3.1 Pasture and animal production impacts

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 soil and seasons (Figure 1) (Graham *et al.* 1981; Jones *et al.* 1995; Myers and Robbins 1991; Radford *et al.* 2007; Robbins 1984; Robbins *et al.* 1987; Robbins *et al.* 1986).

Animal production shows a similar trend with a linear decline of 20-70% in live weight gains over the first five years of pastures when stocking rates are held constant (Figure 2) (Jones *et al.* 1995; Radford *et al.* 2007; Robbins *et al.* 1987; Rudder *et al.* 1982). However, individual animal performance can be maintained if stocking rates are reduced (Figure 3) (Burrows 1991; Radford *et al.* 2007). Graziers consulted in this review confirm that carrying capacities decline by up to 50% as their sown grass pastures age. These declines in both pasture and animal production are clearly reflected in the lower live weight gains and reduced stocking rates commonly experienced as buffel grass pastures 'rundown' on commercial properties (Table 1).

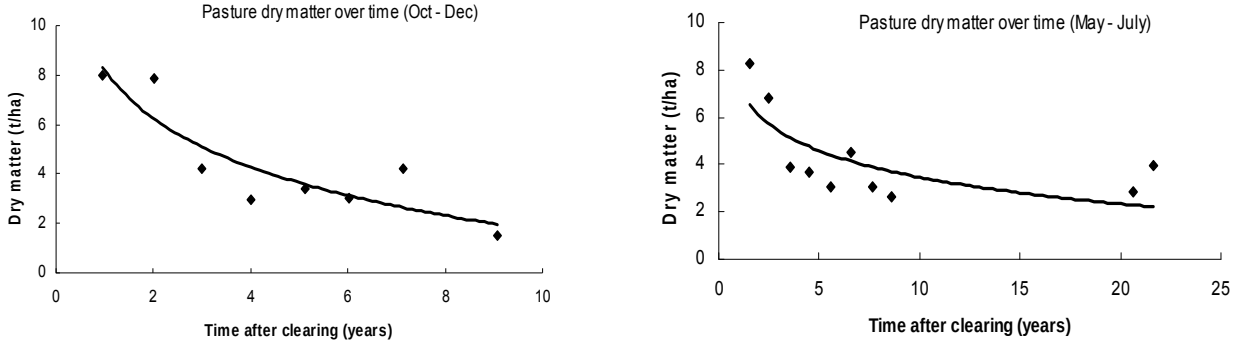

Figure 1: Pasture dry matter on offer during 22 years since clearing. Measurements taken in October – December at the start of the growing season R^2 =0.71, P<0.01, n=8. Y=8.21 – 2.83 ln (T) where Y is dry matter and T is time after clearing. Measurements taken in May – July at the end of the growing season R^2 =0.41, P<0.05, n=10. Y=7.19 – 1.62 ln (T) where Y is dry matter and T is time after clearing. (Radford *et al.* 2007)

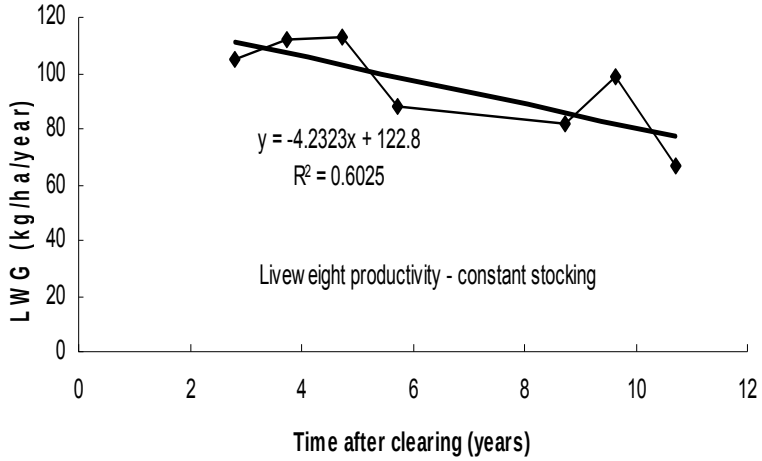

Figure 2: Annual live weight gain per hectare subsequent to buffel grass establishment at a constant stocking rate of 0.59 head/ha. R^2 =0.60, P<0.05, n=7. Y=122.8 – 4.23T where Y is LWG and T is time after clearing.(Radford *et al.* 2007)

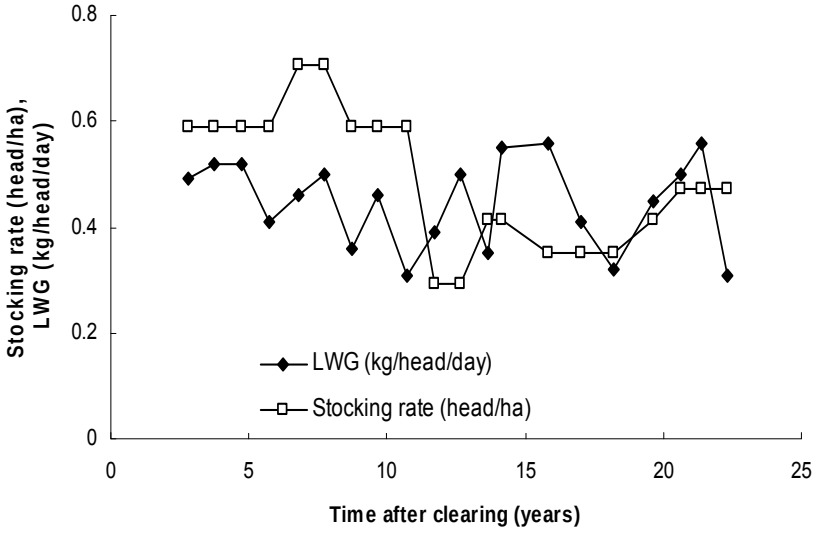

Figure 3: Stocking rate and average daily live weight gain for cattle grazing buffel grass pastures during 21 years since clearing brigalow scrub (Radford *et al.* 2007).

Table 1 : Average commercial steer performance from a range of pasture systems in central Queensland (Middleton 2001).

Forage system	Av stocking rate (ha/Beast)	Kg live weight gain per year	
		Per steer	Per ha
Native pasture	4	100-140	25-35
Native pasture - stylo	4	140-170	35-45
Buffel grass – new	2	170-190	85-95
Buffel grass – rundown	3	140-150	45-50
Leucaena – buffel	1.5	250-280	165-185

1.3.2 Pasture composition changes

Pasture composition changes in response to rundown and a lack of available mineral N (Burrows 2001; Jones *et al.* 1995; Myers and Robbins 1991). Indeed, soil nitrogen status may determine competitive advantage of different sown grass species. Over large areas of Queensland, Rhodes grass and green panic were sown, initially dominated pastures but have since commonly been replaced by buffel grass (Appendix 1). Drought, grazing management and N availability have all contributed to this change in composition, however Rhodes grass and green panic initially tolerated drought and high grazing pressure but are less resilient to stresses after N availability declines (Jones *et al.* 1995). As N availability has declined further there has been an increase in native grasses and exotic grasses that are more tolerant of low fertility (e.g. Sabi grass, creeping blue grass, Indian couch) in buffel grass pastures.

All pasture grasses will produce more dry matter with increasing levels of available N. Some species, including many of the early introduced pasture grasses from the Panicoid genera (e.g. green panic) are very responsive to additional nitrogen and become more competitive in soils with high available nitrogen. Conversely, some of the more recently introduced pasture grasses (e.g. creeping bluegrass, floren bluegrass) can tolerate lower levels of available N and will become more competitive in rundown pastures (Burrows 2001).

These changes may exacerbate the effects of rundown on pasture condition, but they do not cause rundown per-se.

1.3.3 Environmental impacts

Perennial sown grass pastures have major environmental benefits. Perennial grasses provide stable and productive vegetation that reduces deep drainage, sequesters carbon, provides food and habitat for wildlife, improves soil health and perhaps most importantly provides high levels of ground cover thereby reducing erosion and subsequently improving water quality (Johnson *et al.* 2008;

Silburn *et al.* 2009; Silburn *et al.* 2007). Australia's grazing industries have long struggled to balance grazier's and the community's expectations of high production and the need to maintain natural resources (McKeon *et al.* 2004; Pressland and Graham 1989). "Rundown" pastures contribute to over-utilisation of pastures, erosion and subsequent land degradation through:

- High expectations of long-term production. Very high initial production from sown grass pastures after planting can lead to un-realistically high expectations of their long-term productivity and attempts to maintain unsustainable stocking rates.
- Reduced pasture vigour and density leading to low ground cover and increased risk of erosion. Land degradation will occur unless grazing pressures are reduced in line with the reduction in forage production.
- Reduced resilience of pasture grasses. When N availability declines many sown grass species (e.g. Rhodes grass, green panic) become less competitive, less resilient to drought, less tolerant of grazing and subsequently die out (Jones *et al.* 1995). Ground cover is generally maintained when this change is gradual. However, if rundown pasture swards die out during drought conditions, the soil may be left with little ground cover and an increased risk of erosion until the paddock is recolonised by perennial grasses.

1.3.4 Economic impact

Reduced carrying capacities and reduced animal performance combine to dramatically reduce the economic returns from sown pastures as they age. Reductions in animal production per hectare of 50% undoubtedly have a severe impact on economic returns at the property and industry scale. Graziers consulted during this project suggested that:

- Returns are tight. There is a need to improve productivity to counter increasing input costs. Some graziers feel compelled by poor economic returns to increase stock numbers to unsustainable levels.
- Many of the current options to address productivity decline have marginal returns. However, these graziers recognised that doing nothing may be more expensive. For example, *"There's gotta be an answer…. We can't keep going down and down and down"*.
- Cash flow is important and returns from mitigating rundown may take several years to recoup costs.
- Increasing land values are intensifying agricultural production.

1.4 Process of pasture productivity decline

Productivity decline in well established sown grass pastures can be directly attributed to a reduction in the supply of available N in the soil. There is no measurable net loss of total soil N associated with rundown in extensive pastures, rather there is uptake of the available N by the pasture grasses and a reduced rate at which N is released from organic forms in the soil (Graham *et al.* 1981; Robertson *et al.* 1997). In these systems, the net loss of nutrients, including nitrogen, is very small.

1.4.1 Nitrogen losses in grass pastures

The amount of nitrogen exported through removal of animal products is small in extensive grazing situations (Radford *et al.* 2007). However, nitrogen can be lost from the pasture sward through:

- Erosion. Reduced pasture vigour and density can result in smaller tussocks with larger bare areas and lower ground cover thereby increasing erosion and nutrient loss (Cowie 1993);

- Nutrient redistribution (Dubeux *et al.* 2007). Grazing animals influence nutrient cycling through ingestion of pasture and excretion to soil, and therefore availability through redistribution within the pasture system. In warm climates, nutrients accumulate near shade areas and to a lesser extent around watering points. While total nitrogen levels of the pastures remain the same, N availability to pasture grasses is changed with higher levels of N in relatively small proportions of total land area; and
- Nutrient removal in harvested grain, hay and silage can be high in mixed farming systems. Each tonne of cereal grain contains approximately 20 kg of N and 3-4 kg of Phosphorus (P) which can lead to nutrient deficiencies and lost production in subsequent pastures (Bell *et al.* 2010).

Farming system studies have confirmed that nitrogen export through product removal under grazing is low relative to other agricultural land uses. Over 22 years "The Brigalow Catchment Study" in central Queensland reported N removal rates of 1.6 kg N/ha/yr for cattle grazing buffel grass pasture compared to 36.1 kg N/ha/yr in grain (Radford *et al.* 2007). Indeed, more nitrogen was lost in runoff from the catchments. In the first 5 years after clearing brigalow scrub, N removed in runoff water was 11.4 kg N/ha/yr for the cropping catchment and 3.4 kg N/ha/yr for the grazing catchment (Cowie 1993). The cleared grazing catchment recorded double the annual runoff measured in the remnant brigalow catchment, increasing the risk of erosion and transport of nutrients (Thornton *et al.* 2007). These losses of approximately 5 kg N/ha/yr under grazing did not contribute to a significant decline in measured Total Soil N. However, there was a dramatic decline in pasture productivity which was attributed to reduced N availability (Radford *et al.* 2007).

In summary, N availability has a much greater impact on pasture production than nutrient removal (Graham *et al.* 1981; Jones *et al.* 1995; Myers and Robbins 1991; Robertson *et al.* 1997). Graziers will ultimately need to replace the nutrients removed through beef production. However, the amounts are small and can be replaced through currently available practices. For example, P supplementation of stock is sufficient to replace the amount of P removed in animal products and legumes are capable of fixing many times the amount of N removed in animal products (Burrows 1991; Cameron 1996; Clarkson *et al.* 1987; Jones *et al.* 1996; Radford *et al.* 2007).

1.4.2 Nitrogen cycle

The largest pool of nitrogen (N) is the earth's atmosphere which is nearly 80% nitrogen. Nitrogen is often the first nutrient to limit pasture growth because atmospheric nitrogen is not directly available to plants, it is however available to nitrogen-fixing bacteria. Nitrogen cycles through organic and inorganic forms almost entirely through living organisms and soil organic matter (Figure 4).

Plants can only use the mineral forms of nitrogen in soil, mostly nitrate-N and to a lesser degree ammonium-N, that typically comprise up to 2% of the total N reserves in the soil (Harmsen and Kolenbrander 1965).The majority of soil nitrogen is in organic matter, which accumulates primarily from plant and animal materials falling on the soil surface and being incorporated by the soil fauna and flora. The large pool of organic matter is made available to plants when it is mineralised, firstly to ammonium and then nitrate, by soil microbes with some nitrogen being lost from the soil as gas in the form of nitrous oxides (Rosswall 1976).

In unfertilised pastures inputs of N can accrue from biological N fixation (symbiotic and asymbiotic) or in rainfall (Figure 4). Sources of N and indicative quantities of input for sown pastures are as follows:

- Pastures legumes can fix significant amounts of N in the right circumstances (Section 4.4.3) in a range from zero (with no legume present) to >100kg N/ha/yr with good legume growth (Peoples *et al.* 2001).
- Other symbiotic N fixation (e.g. lichens and rhizosphere endophytes) is capable of fixing small amounts (<10 kg N/ha/yr) (Nelson and Roth 2004; Unkovich and Baldock 2008).
- Asymbiotic fixation contributions of N is likely to be <10kg N/ha/yr and generally not of agronomic significance across most of Australia with higher rates possible in tropical high rainfall regions (Unkovich and Baldock 2008).
- Rainfall. Small amounts of mineral nitrogen can be added to the soil through rainfall with estimates in the range of <1 to <10 kg N/ha/yr(Ladd and Russell 1983; Nelson and Roth 2004).

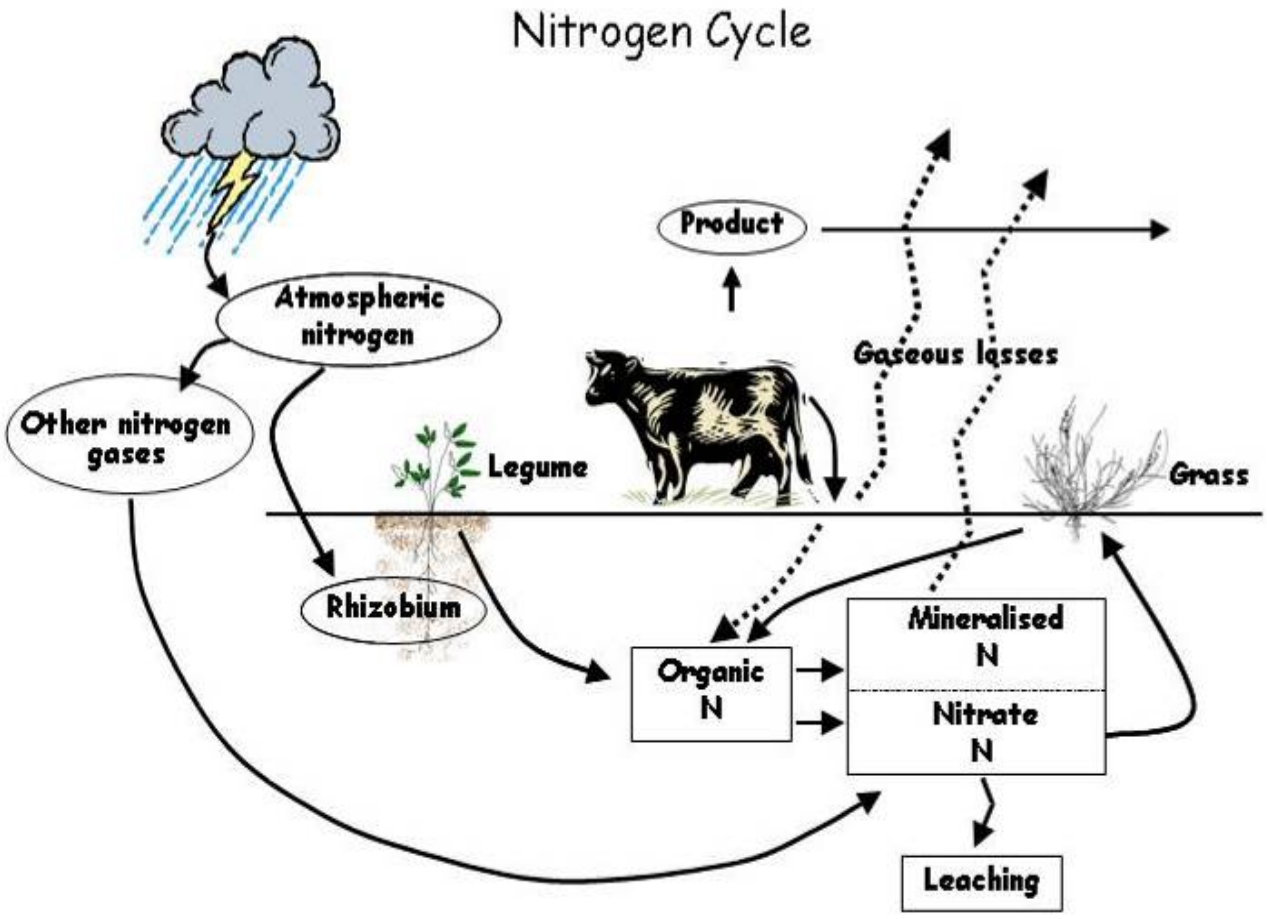

Figure 4: Flow of nitrogen in the soil from organic to mineral (inorganic) forms. Only mineral forms can be taken up by plant roots.

The productivity of sown grass pastures depends on the amount of available soil nitrogen and extent to which N cycling can maintain this level of nitrate (and ammonium) in the soil. The on-going

levels of available soil nitrate-N depend on concurrent processes that mineralise further organic matter to replenish available nitrogen, and immobilise available nitrogen when low quality organic matter (i.e. high in carbon and low in N) is added to the soil (Lawrence *et al.* 2009). The rate of N cycling and mineralisation are favoured by high soil organic matter levels, low C:N litter, large microbial populations and conditions that support greater microbial activity, namely warm and moist conditions (Jacobsen *et al.* 1992).

Clearing, burning and fallowing brigalow scrubs before establishing sown pastures dramatically accelerated the physical, chemical and microbial breakdown of vegetation and organic matter that had accumulated over millennia releasing large amounts of plant available nutrients (Table 2). Consequently, sown pastures were widely developed on soils with very high levels of available plant nutrients, for example nitrate-N levels of up to 300 kg/ha and total organic carbon levels up to 3.5% (D. Lawrence, unpublished soil test data). These soils can sustain a high level of available nitrogen and a massive initial 'flush' of production that lasts for many years. However, even on these fertile soils, pasture productivity will 'rundown' over time (Radford *et al.* 2007; Robbins *et al.* 1987; Robbins *et al.* 1986).

Table 2: Changes in soil chemical attributes with clearing and burning of brigalow scrubs (Lawrence *et al.* 1994b).

	Quantity (kg/ha)				
	Organic Carbon	Total N	Available N	Available P	Exchangeable K
Pre-clearing	23200	2280	9	13	200
Post-clearing	20450	2020	67	40	340
Change %	-12	-11	+690	+230	+75

Pasture productivity subsequently declines as there is a progressive reduction in the amount of N mineralised each year until an equilibrium is reached (Graham *et al.* 1981; Myers and Robbins 1991; Robbins *et al.* 1986). The clay soils of southern and central Queensland typically mineralise over 100 kg N/ha/yr when they are first fallowed (Dalal and Mayer 1987). However, as sown pasture grasses mature and become denser there are large amounts of litter from the pasture added to the soil and available nitrogen declines (Dalal *et al.* 2005). Increasing competition between the developing pasture and microbes means that net mineralisation and available soil nitrogen levels continue to decline. Comparative field measures of mineralisation in the top 10 cm of a red kandosol at St George from January to May 2004 increased from 12.5 kg N/ha under native mulga to 20.2 kg N/ha in a new buffel grass pasture, but decreased to 5.6 kg N/ha in a 20-year old buffel grass pasture (Mathers and Dalal 2004). These low soil nitrate-N levels have also been observed in older central Queensland buffel pastures (Graham *et al.* 1985) (Table 3), and soil testing in southern Queensland confirms that there is rarely more than 5 kg N/ha of available N in older buffel grass pastures (Lawrence, unpublished soil test data).

Table 3: Nitrogen content of soil (0-30cm) and plant pools in a 14 year old buffel grass pasture in central Queensland (Graham *et al.* 1985).

Component	Kg N/ha	Percent of total.
Grass tops	21	0.63
Grass litter	4	0.12
Grass root	207	6.17
Microbial biomass	152	4.53
Soil Mineral N	10	0.30
Soil Organic N	2960	88.25
Total	3354	

Several mechanisms contribute to reduced N cycling and subsequently lower available N for on-going production in sown grass pastures:

i. Stabilisation of N in soil organic matter and clay (Robertson *et al.* 1997). Soil organic matter levels increase if organic carbon is added to the soil at a faster rate than microbes break it down. Microbial activity will break down this coarse 'labile' organic material and mineralise any N excess to their needs. However, some N will also be 'locked away' or immobilised in humic carbon fractions that must be later mineralised over decades for the contained N to become available to plants. After repeated decomposition, a nutrient rich but 'resistant' carbon fraction develops that may take hundreds of years to decompose and mineralise N (Bell and Lawrence 2009).

ii. Immobilisation of N in plant litter (Robbins *et al.* 1989). Tropical C4 grasses have higher Carbon:Nitrogen (C:N) ratios than C3 grasses and produce large amounts of biomass resistant to decomposition. The amount of N in litter increases with pasture age which reduces the amount of N available for plant uptake. In a 16 year old green panic pasture, approximately 50% of plant N occurred in dead tissues (Robertson *et al.* 1993).

iii. Competition for available N between the pasture plant and soil microorganisms (Myers *et al.* 1986). Accumulation of root and litter residues with high C:N ratios results in a large microbial biomass which has a high demand for N and can compete with pasture plants for available N. For example, significant amounts of N are immobilised as dry grass and crop stubbles (with C:N ratios of up to 100:1) are decomposed and carbon respired. As organic matter decomposes it eventually forms nutrient rich, stable (resistant to decomposition) humic carbon complexes with C:N rations of approximately 12:1 (Bell and Lawrence 2009). Microbes may out-compete pasture grasses for available N in the short-term. However, the microbial biomass is dynamic and by the end of growing season the grass can accumulate dramatically more N than the microbial biomass (Graham *et al.* 1985; Robertson *et al.* 1997).

Experiments using ^{15}N labelled ammonium sulphate on green panic pastures have shown that the reduction in N availability and hence pasture productivity is due primarily to immobilisation of N in soil organic matter and clay; plant material; and to a lesser extent soil microbial biomass (Robertson *et al.* 1997).

1.4.3 Grass species differences

While grass species differ in the response to available N, they also affect N cycling through the amount and quality of the litter they produce (Jones *et al.* 1995; Robbins *et al.* 1989; Wedin and Tilman 1990). For example, C4 grasses produce large amounts of poor quality, high C:N ratio litter, that is resistant to decomposition (Dubeux *et al.* 2007). This effect is more severe as the pastures age, and their N content and quality decline to further reduce N cycling (Robbins *et al.* 1989).

In Minnesota (USA), monocultures of five locally abundant perennial grass species (both C3 and C4 species) established on initially identical soils resulted in a 10 fold difference in annual net nitrogen mineralisation rates by the third year (Wedin and Tilman 1990). The impact of commonly sown grasses on mineralisation in Australia has not been demonstrated, however grasses with higher C:N and root:shoot ratios may lead to greater reductions in N availability.

1.4.4 Productivity trends in grass/legume pastures

Grass/legume pastures have the potential to fix atmospheric nitrogen and therefore sustain higher levels of production than grass-only pastures. Nitrogen fixed by legumes in the pasture will improve feed quality and ultimately contribute more available nitrogen to grasses for dry matter production. However, the feasibility of developing and maintaining resilient and productive sown grass/legume pastures over long periods (e.g. >15-20 years) with few management inputs in northern Australia has been questioned (Walker *et al.* 1997).

There is little quantified information on the longer-term stability or resilience of sown grass/legume pastures or native pastures over-sown with legumes (Walker *et al.* 1997). However, there are several examples of reduced productivity, stability or resilience in legume/grass pastures (McIvor *et al.* 1996; Walker *et al.* 1997):

- Productivity decline after the establishment phase of leucaena/grass pastures has been reported (Radrizzani *et al.* 2007). The decline has been attributed to reduced supply of phosphorus and sulphur (Radrizzani *et al.* 2010);
- Legume dominance has been reported in grass pastures over-sown with stylos and round leaf cassia (McIvor *et al.* 1996; Miller and Stockwell 1991). Legume dominance can result in less resilient pastures (e.g. more prone to erosion) and lower production through reduced grass production. High legume content exposes animals in frost prone areas to severe feed shortages in cold, dry winters (Burrows 1991).
- Lack of persistence and production of pasture legumes with buffel grass pastures have been reported by graziers (Appendix 1). High legume content and dry matter production are required to fix large amounts of N and significantly increase grass growth. However, management practices that promote legume content (e.g. heavy grass utilisation in summer to promote medic establishment in southern Queensland) may increase the risk of feed shortages in subsequent dry winters (Clarkson *et al.* 1991).
- Over-grazing either the legume or grass component of pastures. For example, grasses have been grazed out in some stylo pastures and siratro has been grazed out of grass pastures (Quirk and McIvor 2005). Inadequate soil P is also commonly implicated in the legume component's decline.

Grass/legume pastures can be highly productive. However, these examples illustrate the need for good agronomy and grazing management to sustain productivity for long periods. Soil fertility,

especially nutrient management for the legume component, is a key consideration to establish and maintain productive grass/legume pastures.

1.4.5 Phosphorus and other nutrients

Legumes generally require more P and S than their companion grasses, therefore fertility management is important to maintain high levels of legume production and N fixation. In contrast to legume augmented pastures in southern Australia, fertilisers are rarely used on tropical pastures in northern Australia. The use of fertiliser to maintain productivity in sown grass/legume pastures is likely to become more important for pasture managers in northern Australia.

Phosphorus cycling in pasture systems is more complex than N cycling. Biological decomposition of organic matter contributes some P but most of the plant available P comes from mineral sources and depends on the P sorption potential of soils and the balance between strongly and weakly 'held' pools of phosphorus (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 cultivated but there is a decline as pasture ages. Figure 5 shows trends within 3 catchment areas at Brigalow Research Station. As P accumulated in plant material and soil organic matter, the more readily available Colwell bicarbonate P in the soil declined from the initial flush at clearing. While not shown, acid extractable P declined in a similar manner to bicarbonate P (C. Thornton *pers. comm*.). The cropping catchment has not had fertiliser applied and in comparison to the buffel grass catchment has higher levels of available P indicating that P availability declines under continuous pasture, while available P remains higher with cropping due to greater decomposition of organic matter.

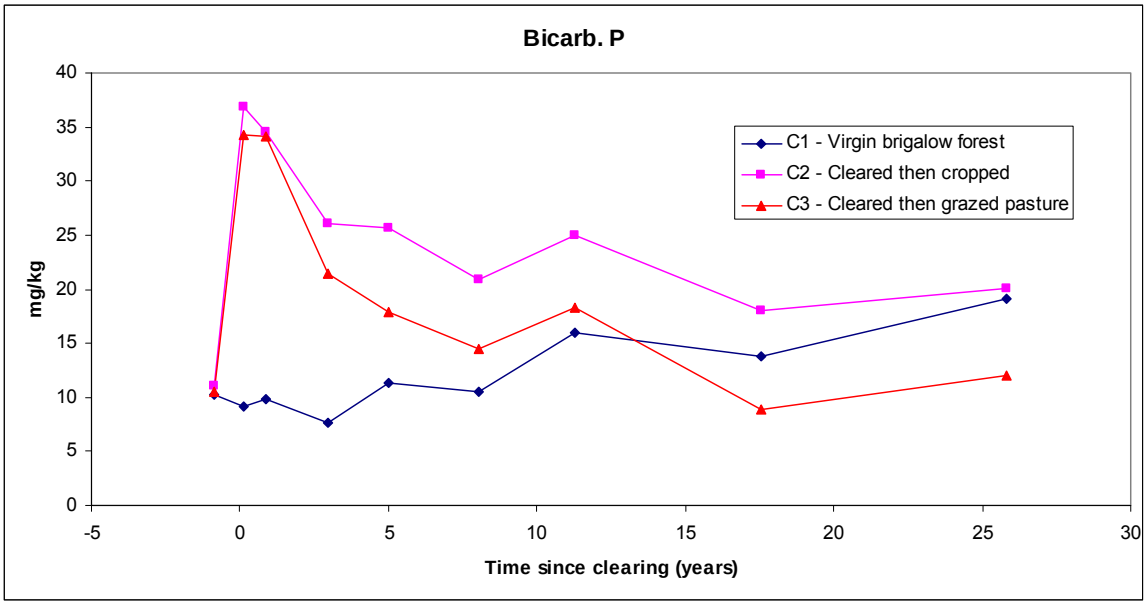

Figure 5: Phosphorus availability (bicarbonate P) over time (Thornton *et al.* 2010).

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 species. Consequently, P is more commonly a problem with the potential to reduce legume productivity and

persistence. Grass competition further restricts their productivity and persistence on low P soils because legumes generally require higher soil phosphorus levels than their associated grasses (Table 4).

On moderately fertile brigalow soils of southern and central Queensland, decline in P availability has occurred widely due to both removal in grain and other crop products and from "tie-up" in organic matter, reaching levels that restrict legume growth, e.g., < 15ppm. Recent unpublished studies of soil carbon on 100 sites across southern Queensland with a range of land uses and histories revealed Bicarbonate P levels (0-10 cm) as low as 3 ppm, with 50% of the sites below 15 ppm, and 25% below 10 ppm (unpublished data, D. Lawrence *pers. comm*.).

Table 4: Phosphorus requirements for maximum growth and persistence (Ahern *et al.* 1994).

Legume	P requirement (Colwell P, mg/kg)
Leucaena*	> 25
Seca stylo	> 8 (>3mg/kg for any growth)
Verano stylo	8-12
Siratro	10-14

(* S. Buck *pers. comm.*)

The amount of N fixed by legumes is directly related to their biomass production (Peoples *et al.* 1995). Improved nutrition, strategic grazing and other practices can increase legume growth and the amount of N fixed in grass/legume pastures, and such practices must become more widely used to sustain their positive impacts on productivity. However, this will require a better understanding of the costs and benefits of applied P to tropical grass/legume pastures.

1.5 Conclusion

It is clear that the decline in the productivity, or 'rundown', of sown grass pastures from their initial flush of high productivity is a major issue for graziers and industry across northern Australia. The problem is widely recognised by graziers and generally well understood by researchers. Progressive rundown in soil N availability to some new equilibrium of lowered productivity is an inevitable consequence of continuous grass-only pasture. Pasture legumes, mechanical renovation, and pasture-crop rotations have long been promoted as ways of reducing the impact of pasture 'rundown'. However, the degree to which these practices have been implemented in a cost-effective manner is uncertain, and it is highly likely that pasture 'run-down' continues to erode industry performance. Pasture rundown reduces pasture productivity, animal performance and farm profitability, while the risks of erosion and land degradation may be increased. This review was initiated to provide more reliable guidance on the impact of the issue, the extent to which practices are successfully reducing its impact, and priorities for additional extension and research efforts.

2 Project Objectives

Graziers in southern and central Queensland continue to be concerned about declining productivity in sown grass pastures. This concern is shared by Meat & Livestock Australia (MLA) and the Queensland government through the Department of Employment Economic Development and Innovation (DEEDI).

Research has documented this decline in productivity and identified the underlying cause to be a lack of available soil nitrogen as pastures age. However, the continuing decline and its impact on northern Australia's most widely sown species (buffel grass) suggests that current mitigation strategies and/or the way they are used on farms must be improved.

The review builds on past research. It includes more recent research findings and graziers' experiences to better understand the extent of the decline, and assess the impacts of mitigation options on commercial properties. Specifically, the project provides:

1. A concise overview of the primary causes, extent and economic impacts of sown pasture 'rundown'.
2. A review and evaluation of the mode-of-action and cost-effectiveness of options for abating the impact of sown pasture 'rundown', including those currently practiced and any others that have potential value.
3. An assessment of the technical and other (e.g. adoption) issues that constrain the cost-effective abatement of sown pasture 'rundown', and the likelihood of overcoming these constraints through additional research, development and extension.
4. The priority areas for future research, including the likely economic benefit to industry of pursuing these.

The findings of the review will support more informed investment R,D&E by MLA, DEEDI and other stakeholders across the red meat industries. It will help identify the best 'value propositions' for investment and provides recommendations for further targeted R,D&E activities.

3 Methodology

The review involved consultation with key groups within the grazing industries (graziers, researchers, seed companies and merchant resellers), literature review, spatial analysis, economic analysis and prioritisation of RD&E needs. Aspects of productivity decline in sown grass pastures have been studied in detail (e.g. process of rundown) while other aspects have received little attention (e.g. relative N fixation of commercially grown legumes) (Myers and Robbins 1991; Walker *et al.* 1997). This project builds on past and current industry supported projects, technical expertise across agencies and experiential knowledge of graziers and agri-business in reviewing the current state of knowledge of productivity decline.

The components of the review were:

1. Literature review. Scientific literature is referenced throughout this report.
2. Consultation with graziers, researchers, pasture seed industry and merchant resellers.
3. Spatial analysis of the current extent of buffel grass and potential area suitable for mitigation strategies.
4. Economic analysis of mitigation strategies at the farm and whole of industry scales.
5. Prioritisation of Research, Development and Extension needs.

3.1 Consultation

This project had a strong emphasis on consulting with key stakeholders to gain access to published and un-published information, experiential knowledge and to document the results of strategies currently being trialled or used by landholders and industry. The consultation process is summarised below.

3.1.1 Graziers

Graziers across southern and central Queensland were consulted to document their experiences with pasture productivity decline and mitigation strategies to address pasture rundown on their properties. During March and April 2010 six focus group meetings were held with graziers in southern and central Queensland to discuss productivity decline in sown pastures. Meetings were held in Moura, Rolleston, Clermont, Roma, Nindigully and Wandoan.

At the focus group meetings graziers discussed the following questions:

1. What's the extent of productivity decline?
    - How big a problem is it for your business?
    - How does it affect your business?
2. How do you manage productivity decline in sown pastures?
    - What has been tried?
    - What are the results?
    - What are the main reasons for success or failure?
3. What are the biggest limitations to overcoming productivity decline?
4. What RD&E is needed for the grazing industries to address productivity decline?
    - What would you like to try at home if you had the time and money?
    - What would you like MLA and DEEDI to do?

3.1.2 Seed industry

The seed industry was consulted via a semi-structured interview conducted by telephone. The initial questions asked were:

1. What is the extent of sown pasture or productivity rundown with your clients?
2. How does it affect the seed industry (your business) and your clients?
3. How do you advise clients to manage rundown in sown pastures?
4. What are your thoughts on the practicalities and impacts of perennial legumes?
5. What's the biggest limitation to overcoming rundown in Queensland pastures?

3.1.3 Researchers and extensionists

A workshop was held with key research and extension personnel to provide expert opinion and identify published and/or un-published sources of information. The key outputs from the workshop were expert opinion on:

- The likely pasture and animal response of pasture productivity decline and mitigation strategies. Level of knowledge and certainty of responses was also discussed.
- Identification of which land types support buffel grass pastures across Queensland.
- Legume suitability by land type across Queensland.
- Key knowledge gaps in scientific literature.
- R,D&E priorities for sown pasture productivity decline.

3.2 Spatial analysis

Spatial analysis was used to estimate the geographic extent of buffel grass pastures in Queensland, the area suited to mitigation strategies and regional sown pasture production.

3.2.1 Geographic extent of buffel grass pastures

Knowledge of the geographic extent of sown grass pastures is necessary to estimate the costs of productivity decline and the likely benefits from mitigation strategies. Previous authors have calculated that of the total area of sown pastures, 70% were sown with grass only and that buffel grass representing more than 75% of that area (Walker *et al.* 1997; Walker and Weston 1990). This project therefore decided to focus on improving the estimation of the area of buffel grass pastures in Queensland.

Improved estimation of the extent of buffel grass compared to previous estimations e.g. (Lawson *et al.* 2004; Weston *et al.* 1984) is now possible due to improved mapping. The extent of buffel grass map is based on the following linkages and assumptions:

- Buffel grass densities were linked to grazing land types (Whish 2010) by a panel of experts.
- The spatial extent of grazing land types have been mapped by linking the description to regional ecosystem mapping.
- Land use mapping was used to exclude those land uses which would exclude buffel grass pastures e.g. cropped land.
- Tree mapping was used to estimate the impact of tree competition on buffel grass density. Areas with 20-40% foliage projected cover (FPC) were reduced by one buffel dominance class (e.g. Dominant to Common), areas with >40% FPC were considered to not support buffel grass pastures.

- It is assumed that buffel has spread and established on land types it is adapted to. This assumption is supported by the observations of the experts involved in the researchers' workshop.

Descriptions of the spatial data sets used are provided in Appendix 4.

3.2.2 Area suited to mitigation strategies

Soil limitations were described for mitigation strategies (Table 5) and linked to land type descriptions. For suitability of leucaena and butterfly pea it is recognised that there is an interaction between climate and plant available water-holding capacity (PAWC) requirements. That is, a requirement for higher PAWC in drier environments to meet requirements for persistence and production. Similarly, there is interaction between clay content, soil structure and soil depth on PAWC, and therefore required rooting depths. The rooting depths required in drier districts that leucaena and butterfly pea are suited to was used for developing Table 5.

Table 5: Soil limitations for mitigation strategies.

Mitigation strategy	Soil Limitations
Supplements	None
Fertiliser (60 kg/N/ha)	None
Fertiliser (120 kg/N/ha)	None
High production Legume (butterfly pea, leucaena)	Fertile soils with rooting depth > 90cm for Butterfly pea and > 120cm for Leucaena. Suitability described by land type
Legume (medics, stylo, desmanthus)	Described by land type
Mechanical Renovation (Blade plough)	>60 cm to dispersible or impenetrable layers
Mechanical Renovation (Chisel plough)	>30 cm to dispersible or impenetrable layers
Short-term fallow (3 + months)	>50cm to dispersible or impenetrable layers
Herbicide	None

Legume suitability was described by land types (Appendix 5) and annual rainfall by region (Table 6). The suitability for mitigation strategies was then intersected with the buffel map described above to provide an estimate of the extent of land suitable for the different mitigation strategies.

Table 6: Rainfall requirements for legumes in different regions of Queensland.

Zone	Regions	Leucaena	Butterfly pea	Burgundy bean	Medics	Shrubby stylo	Caribbean stylo	Caatinga stylo	Desmanthus
Northern Queensland North of Charters Towers to Mt Isa	Northern Gulf, Southern Gulf, northern half of Burdekin	>800 mm	>750mm	Not well adapted	Does not grow	>600mm	>750mm	>750mm	>600mm
Central Queensland North of Isla Gorge, Carnarvon range	Fitzroy, Mitchell Grass Downs, Desert Uplands, Southern half of Burdekin (Belyando, Suttor)	550 - 800mm	>550mm	>600mm	Does not grow	>500mm	>600mm	>600mm	>500mm
Southern Queensland	Maranoa/Balonne, Border Rivers, Inland Burnett, Mulga, southern part of Fitzroy (Upper Dawson)	600 - 800mm	Not well adapted	>550mm	>450mm	Frost free areas, not well adapted or widely spread	Does not grow well	>550mm	>500mm

References: North Queensland was based primarily on un-published pasture evaluation trials (T. Hall *pers. comm.*); central and southern regions (Anonymous 2010; Collins and Grundy 2005; Dalzell *et al.* 2006; Gardiner *et al.* 2004; Gardiner and Swan 2008; Lambert and Graham 1996; Partridge *et al.* 2009; Partridge *et al.* 1996)

3.3 Economic analysis

A spreadsheet based pasture production and economics model was used to evaluate the benefits and costs associated with undertaking mitigation strategies at the farm level to address buffel grass pasture productivity decline. Four case study locations across Queensland (Moura, Glenmorgan, Clermont and Tambo) were selected to represent a range of production capabilities and model the effects of mitigation strategies on the production system. The mitigation strategies evaluated were:

- Dry season supplementation of stock.
- Fertiliser at two different rates (60 and 120 kg N/ha/yr).
- Mechanical renovations using three different methods – chisel plough, blade plough and a 3 month cultivated fallow with four cultivations.
- Leucaena established into cultivated strips (5 m cultivated, 3 m grass strips).
- Legumes established using four different techniques. The legumes were not specified although it is assumed they are well adapted to the location and in practice would most likely be medics, stylos and/or desmanthus. The establishment techniques were cultivated strips, herbicide strips, blade plough and short term fallow. The strip treatments assumed 5 m treated with herbicide or cultivation with 11 m grass strips.

A 'rundown buffel' scenario was developed for each region which was assumed to be the present state of sown buffel grass pastures (the 'base case') with productivity being constant over time (that is reduced N availability had resulted in a lower but stable equilibrium state of pasture productivity). Mitigation strategies were compared to the base case to derive a net economic benefit (or cost) of undertaking the mitigation. The results of the farm scale analyses were extrapolated to a regional scale (using the spatial analysis results) to estimate state-wide impacts of employing the selected mitigation strategies.

3.3.1 Pasture production, stocking rates and animal performance

Average annual pasture and animal production were described for high, medium and low fertility soils for the case study locations. Pasture production for rundown buffel grass was estimated through a combination of GRASP pasture growth models (Whish G. *pers. comm*.), back calculation from carrying capacity described in local consensus data reports (Clarke *et al.* 1992), other published sources (Dalzell *et al.* 2006; Middleton 2001; Partridge 1996) and expert opinion through consultation with researchers described in section 3.1.3. Individual animal performance was described as an average annual live weight gain and was estimated from published figures and expert opinion. Pasture production and animal performance for mitigation strategies were calculated from likely responses (from published sources and expert opinion) relative to rundown buffel grass production figures.

Stocking rates were calculated from pasture production estimates described above using an average annual forage budget methodology. Benchmark residual biomass at end of dry season for high, medium and low fertility soils for each location were calculated from published utilisation rates for land types at the case study locations. The stocking rates for mitigation strategies were calculated to achieve the same residual pasture biomass, that is stock numbers were increased to utilise the extra forage with the same end of dry season residual biomass. Forage for animal consumption was calculated as follows:

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

Benchmark utilisation rates and spoilage percentages used for pasture budgeting are shown in Table 7.

Table 7: Utilisation and spoilage rates used for forage budgeting. The utilisation rate was applied to rundown buffel grass DM production to calculate a benchmark residual biomass for use with mitigation strategies (adapted from Whish 2010).

Location	**Moura, Glenmorgan, Clermont**			**Tambo**		
Soil Fertility	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Utilisation rate	30%	25%	20%	25%	20%	15%
Spoilage	20%	15%	15%	20%	15%	15%

3.3.2 Property scale economic analysis

The economic analysis was based on a steer finishing enterprise where stock are purchased annually and finished to meet the "Jap Ox" market specifications (596 kg live weight, 310 kg carcase weight). Purchase weights were determined by working backwards using the required turn off weight (596 kg) and the calculated annual live weight gain for each scenario (Table 18). The livestock purchase price was based on a long term average for the Gracemere sales yards and the selling price based on a long-term average for the Dinmore meat processing plant. Freight and animal health costs were based on 2010 prices. Freight costs were calculated on the assumption that stock were purchased from the closest major saleyard and sold to the closest major abattoir.

Gross margins were calculated for high, medium and low fertility soils at each case study location for each mitigation strategy (as well as the base case), over a range of years (depending on how long the strategy was expected to have an impact on the production capacity of a pasture). For example, the 'blade plough' strategy had 9 gross margins calculated at each location:

3 fertility levels (L,M,H) x 3 different impact stages (Year 1, Years 2-5, years 6-7)
= 9 gross margins

The gross margin is equal to the annual income received from cattle sales, less the variable costs incurred by the operation (e.g. livestock purchase, health costs, freight and levies).

For the farm level analysis, expert opinion was consulted to estimate the percentage breakdown of low, medium and high fertility land sown with buffel, as well as the percentage of non-buffel pasture on a typical farm at each location. A representative farm size was also estimated (Table 8).

Table 8: Land type mix and size of case study properties which approximate a typical property for the respective district. Adapted from local consensus data (Clarke *et al.* 1992; Lawrence *et al.* 1994a)

Location	Size	High Fertility %	Medium Fertility %	Low fertility %	Non-buffel %
Moura	4 000 ha	20%	30%	20%	30%
Glenmorgan	3 000 ha	20%	20%	30%	30%
Clermont	15 000 ha	10%	20%	20%	50%
Tambo	20 000 ha	10%	10%	10%	70%

Annual gross margins for each mitigation strategy and the base case were aggregated at each location by summing the product of the gross margin for each fertility level, the percentage of farm area made up of the fertility level and total farm area:

$\sum$ (Gross Margin$_{(L,M,H,NB)}$ **x** % of land$_{(L,M,H,NB)}$ **x** Total farm area)

Where L = Low, M = Medium, H = High and NB = Non-buffel. The non-buffel area of the farm was assumed to be native pasture. The gross margin per Adult Equivalent (AE) for the non-buffel area was taken as $114.40/AE (Best 2009) and was assumed to be constant across locations. The figure is taken from a spear grass pasture production system and was adjusted to 2010 dollars. The stocking rate was adjusted for each case study to reflect the likely carrying capacity of non-buffel native pastures for each location (Table 9).

Table 9: Stocking rate (SR) and gross margins for native pastures for the case study properties (Best 2009).

Location	SR (ha/AE)	Gross Margin / ha
Moura	10	$11.44
Glenmorgan	12	$9.53
Clermont	15	$7.63
Tambo	25	$4.58

The impact of each mitigation strategy was measured over 30 years using the annual gross margins calculated for each strategy less the costs of mitigation and fixed costs. For simplicity, contract rates were used for planting, ploughing, spraying and cultivation. Fixed costs remained constant across strategies except for the fertiliser scenarios where increased depreciation was incurred due to ownership and use of a spreader. Because this mitigation strategy occurred annually, it was assumed a farmer would purchase a spreader and perform the operation themselves.

Mitigation was assumed to occur at different intervals depending on the strategy (e.g. chisel ploughing every 5 years, blade ploughing every 10 years, fertiliser annually). It should be noted that in years where the impact from a mitigation strategy was assumed to be negligible, the 'base case' gross margin figure was used. For example, the blade plough strategy was assumed to be implemented every 10 years, however it was assumed there would be no discernable impact in years 8-10 of each cycle, so the 'base case' gross margin figure was used in those years. The costs associated with implementing mitigation strategies are summarised in Table 10.

Table 10: Mitigation strategy costs.

Scenario	Description	Treatment Frequency	Cost
Rundown (Base case)	Assumed current scenario	N/A	N/A
Dry Season Supplement	50 days of supplement for Glenmorgan 100 days of supplement for Tambo and Moura 150 days of supplement for Clermont	Annual	12.5 cents per AE per day
Fertiliser (60kg/ha)	60kg of Nitrogen applied per ha (130 kg of Urea)	Annual	$102 per ha
Fertiliser (120kg/ha)	120kg of Nitrogen applied per ha (260 kg of Urea)	Annual	$188 per ha
Blade Plough	6 month destocking in treatment years, contract rate for ploughing	Every 10 years	$210 per ha
Chisel Plough	3 month destocking in treatment years, contract rate for ploughing	Every 5 years	$37 per ha
Cultivated Fallow	6 month destocking in treatment years, 4 x cultivation (contract rate)	Every 10 years	$170 per ha
Herbicide renovation	6 month destocking in treatment years, 2 aerial sprays of Roundup (2 L/ha)	Every 5 years	$46 per ha
Leucaena	2 x Ripper 2 x Offset disc 1 x Roundup (strips only, 1.5 L/ha) 1 x Spinnaker (strips only, 70 g/ha) 1 x Roundup (whole paddock – 1.5 L/ha) No stocking in year 1, only High and Medium soils are planted to leucaena.	Plant in year 1, maintenance trimming and fertiliser (100 kg/ha Superphosphate) every 5 years	$312 per ha - planting $149 per ha - maintenance
Legume – est. by Blade Plough	6 month destocking in year 1, contract rate for ploughing and planting	Plant in year 1	$250 / $224* per ha
Legume – est. by cultivated fallow	6 month destocking in year 1 4 x cultivation (contract rate) 25 kg/ha superphosphate on low fertility soils in year of establishment	Plant in year 1	Low Fert - $225 / $199* per ha
			Med & High Fert - $210 / $184* per ha
Legume – est. by cultivated strips	6 month destocking in year 1 2 x Ripper (strips only) 2 x Offset disc (strips only) 2 x Roundup (strips only, 1.5 L/ha) 1 x Spinnaker (strips only, 0.07 L/ha) 25 kg/ha superphosphate on low fertility soils in year of establishment	Plant in year 1	Low Fert - $105 / $97* per ha
			Med & High Fert - $90 / $82* per ha
Legume – est. by herbicide strips	6 month destocking in year 1 3 x Roundup (strips only, 1.5 L/ha) 1 x Spinnaker (strips only, 0.07 L/ha) 25 kg/ha superphosphate on low fertility soils in year of establishment	Plant in year 1	Low Fert - $74 / $66* per ha
			Med & High Fert - $60 / $52* per ha

* Prices for Glenmorgan. Legume is assumed to be a temperate legume for this location which are generally cheaper than tropical legumes

A discounted cash flow (DCF) investment analysis framework was used to compare the 'net present value' (NPV) of alternative mitigation strategies. The NPV is derived by discounting back all future cash flows (costs and income) at a given discount rate. For this analysis, a discount rate of 7% was used to represent the opportunity cost of the investment. The cash flows of the base case scenario (rundown buffel) were subtracted from the cash flows of each mitigation strategy to give a meaningful comparison of what the benefit (or cost) of a mitigation strategy was compared with what would have occurred in the absence of any mitigation. A negative NPV figure indicates that the mitigation strategy would result in a net cost to the farmer at the stated discount rate over 30 years.

Further, a benefit cost (B/C) ratio was calculated for each strategy. The B/C ratio is the ratio of the discounted benefits of the investment to the sum of the discounted costs over the 30 year investment period. It can be thought of as the return on investment for every dollar spent in present dollar value (i.e. for every dollar spent, how many dollars are returned). For the investment to be considered beneficial, a B/C ratio greater than 1 is required.

Sensitivity analysis was carried out on a number of assumptions. The NPV of each strategy was calculated at discount rates of 6% and 8% to test the robustness of the findings. The fertiliser strategies were expanded to test how results would change if application was only required every two and three years. Further, the percentage of land made up of each fertility level were altered to measure the effect on NPV.

3.3.3 Industry scale economic analysis

The industry scale economic analysis compared different rates of adoption of economically viable mitigation strategies to assumed current levels of adoption. The adoption rates modelled were 20, 40, 60 and 100% increases on current levels and adoption on all land that is suited to the mitigation strategy.

The NPV calculated at the property scale was extrapolated to the Queensland scale using the areas suitable for each mitigation strategy calculated by the spatial analysis. Only mitigation strategies that are technically (soil and climate) and economically (positive returns) feasible were extrapolated to the region and, subsequently, Queensland scale. The mitigation strategies that were modelled at the Queensland scale were:

- Legumes established in cultivated strips.
- Leucaena.
- Cultivated fallow.
- Blade plough.

The NPV's for mitigation strategies for the four case study locations were applied to land types in appropriate grazing land management (GLM) regions (Whish 2010). For example the NPV's for high fertility soils calculated for Moura were applied to high fertility land types across the Fitzroy and Inland Burnett GLM regions. The GLM regions that the case studies were applied to are shown in Table 11.

Table 11: Case study locations and the grazing land management (GLM) regions to which their economic returns were applied.

Case study location	GLM region.
Moura	Fitzroy, Inland Burnett, Darling Downs
Glenmorgan	Maranoa Balonne, Border Rivers
Clermont	Burdekin
Tambo	Desert uplands, Southern Gulf, Northern Gulf
Tambo – No suitable legume	Mulga, Mitchell Grass Downs, Channel Country

3.4 Research, Development and Extension priorities

R,D&E needs for addressing pasture productivity decline in grass pastures were identified from consultation with industry (graziers, researchers and pasture seed industry). Some of the R,D&E needs were tested through the spatial and economic analysis described above. Technical, social and economic drivers or constraints for mitigation options were identified. R,D&E needs were collated and prioritised with a panel of experts through considering:

- Potential value to industry
- Achievability for industry
- Cost of R,D&E to address the issue
- Ability to complete the R,D&E. This included consideration of organisational priorities, availability of skills or people to complete the project, weather etc
- Any other consideration that was deemed relevant.

4 Results and Discussion

4.1 Grazier consultation

Six Focus group meetings were held during March and April 2010 in Moura, Rolleston, Clermont, Roma, Nindigully and Wandoan. 95 producers were contacted and invited to meetings. 80 were interested and thought pasture productivity decline was an issue in buffel grass pastures. Forty-one landholders attended the 6 meetings with many unable to attend due to wet weather and flooding.

A full description of graziers' observations and opinions is presented in Appendix 1. The main observations from producers are described here.

4.1.1 Importance of buffel

Sown pastures were recognised as very important to maintain and improve production for the beef industry by improving the quality and quantity of feed for stock and extending the growing season. Buffel grass was recognised as being the most important sown pasture by all six focus groups, because of its:

1. Adaptation – Buffel grows on a variety of soil types and fertility levels across a wide range of rainfall environments and therefore covers a wide geographic area. Buffel is recognised as being the "only" sown pasture grass for drier areas. It has also been observed that buffel is spreading onto infertile soils and heavy clay soils previously thought to be unsuitable.
2. Persistence – Buffel has proven to be the most persistent sown pasture in much of Queensland. Many other species have been sown, but buffel is the one that survives and eventually dominates.
3. Drought tolerance – Buffel is identified as being the most drought tolerant sown grass in Queensland and has been observed to spread during dry years. Drought tolerance contributes to adaptability and persistence described earlier.
4. Grazing tolerance – Buffel is tolerant of heavy grazing once established and is one of the last good grasses to disappear when heavily grazed.
5. Competitiveness – Buffel is very competitive for moisture and nutrients. Buffel grass was described as having a massive root system that is more competitive than other grasses for water and nutrients. This competitiveness is good for competing with weeds but also makes it difficult to get other grasses or legumes to establish and persist.

4.1.2 Symptoms of rundown

Decline in pasture productivity was recognised as being a major problem in all areas. Symptoms described were:

1. Reduced pasture growth. The grass becomes lower, slower to grow and produces less bulk. Reduced dry matter production is the most important impact of pasture rundown for many producers as it reduces carrying capacity (see Table 12).
2. Changes in pasture density. On more fertile land types tussocks have reduced in size but in many cases have thickened into a "carpet of small tussocks". On low fertility soils large clumpy buffel tussocks can develop with very little ground cover or seedlings between the tussocks.
3. Nutrient deficiency symptoms of yellowing or reddening of leaves were described by all groups. A general yellowing of the plant was recognised as nitrogen deficiency by many

producers. Several graziers have noticed a red/orange/purple colouring along the margins of the leaves towards the end of the growing season after which very little grass grows even when more rain falls.

4. Reduced animal performance due to reduced feed quality. Graziers reported lower weight gains and increasing difficulty in meeting market specifications. However this may be off set or masked to some extent by improving production through better adapted cattle and increased use of supplements.
5. Pasture composition change. Changes in the mix of grass species was noted by all groups. Districts that were cleared and sown to pastures earlier reported a trend where Rhodes grass initially dominated, was replaced by green panic, and then become buffel grass dominated. The buffel grass in turn has been invaded by sabi grass and native grasses as the pastures age and rundown further. Rhodes grass and green panic were considered to cope with drought when first developed but died out during dry conditions once the pasture had been established for several years. More recently buffel grass has been sown initially and is being invaded by native grasses or sabi grass.

Table 12: Estimates of the carrying capacity since sown pastures were established (where current carrying capacity is described as a percentage of the carrying capacity when pastures are first established).

Focus group	Current carrying capacity	Comments
Moura	50-75%	For some landholders the best scrub country has reduced carrying capacity to levels similar to good forest country. Still declining.
Rolleston	50-75%	Still running down after the benefits of blade ploughing for sucker control.
Clermont	NA	Hard to put a figure on as pastures have recovered from drought, overgrazing and parthenium.
Roma	50-75%	Much of the western downs is still riding the benefits of clearing and blade ploughing but significant decline evident.
Nindigully	50%	Rundown buffel is still much more productive than the native species it has replaced on red soils (box, mulga country)
Wandoan	50%	50% reduction without renovation. If production is still running down it is now more gradual.

All groups have observed that rundown happens more quickly on lower fertility and lighter textured soils. Some groups thought that more fertile soils had a greater overall decline in productivity. Hard setting soils were considered to have a more severe problem of not only reduced pasture growth but also reduced infiltration once rundown had occurred due to lack of groundcover presumably due to grazing management not adapting to the reduced pasture growth.

All groups had observed that cropping, even if only immediately after clearing for sucker control, affected subsequent pasture production. Old cropping paddocks generally had poorer soil structure, lower nutrients (from removal in grain) and therefore poorer pasture growth.

4.1.3 Causes of rundown

Rainfall infiltration, nutrient cycling, over grazing and disease were all recognised as contributing to a decline in pasture production. However, views as to the relative importance of these causes differed within and between groups. Nutrient availability was less tangible than infiltration and runoff for many participants. Several participants attributed classic symptoms of nutrient deficiency to moisture stress.

Level of debt and enterprise size were also considered important to pasture productivity decline. Smaller properties and those with higher levels of debt are being forced to “run their country harder” to make ends meet.

4.1.4 Mitigation strategies used by graziers

Most producers who attended the focus group meeting indicated that pasture productivity decline had to be addressed to maintain profitability for their enterprise. Some producers believed it may not be currently economic to reinvigorate rundown pastures, but as productivity declines further it will reach a point where it pays to do something.

The mitigation strategies most widely used by graziers were:

- Live with rundown and accept lower production. In effect this is the most common strategy used with graziers reducing stocking rates to maintain land condition and animal performance through either not adopting or having poor results from other mitigation options. Other options under this strategy include buying more land, developing more land and supplementing cattle.
- Mechanical renovation ranging from single cultivations (e.g. chisel ploughs, ripping or blade ploughing) through to short term cropping or crop/pasture rotations. The most commonly used mechanical renovation treatment used has been blade ploughs which were primarily used for woody weed control with the side effect of stimulating the release of N from soil organic matter.
- Legumes for improved feed quality and nitrogen fixation. These benefits are recognised through improved land prices for established leucaena but not for other legumes. Producers reported mixed results from legumes with notable successes but also many failures. Many producers did not think legumes other than leucaena were a viable option with buffel grass due to its competitiveness despite notable examples to the contrary.

Other mitigation strategies discussed but not commonly used were:

- Fertiliser. No one in the groups routinely uses fertiliser on their pastures however several people have tried fertiliser on small areas.
- Spraying out of buffel grass has been used or observed by several graziers to provide a response similar to mechanical renovation.
- Fire. Some producers strongly supported the use of fire reporting greener buffel grass and better growth. Others were strongly against fire suggesting negative responses.
- Other grasses. Decline was observed to occur in all sown grass pastures however it was considered more of a problem with buffel as even when rundown it often maintains a monoculture, buffel tussocks take a long time to breakdown when cultivated compared to other grasses, it is difficult to establish other grasses due to its competitiveness and ground cover between tussocks is often low.
- Grazing management was thought to have some positive impacts on reducing rundown.

- Woody vegetation rotation where suckers are allowed to grow before being chained was thought to improve nutrient cycling by some participants.
- Slashing is thought to improve grass growth by some participants.
- Soil biology treatment – compost teas have been tried by a few participants with no visible response.

4.1.5 Limitations to addressing productivity decline

Landholders identified a range of limitations to addressing pasture productivity decline on their properties. These included:

- Economics. All mitigation strategies cost money in the short term with returns being considered marginal by some producers.
- Legume un-reliability. Legumes are difficult to establish with buffel. There are gaps in commercially proven legumes for many land types.
- Understanding about causes, costs and options for addressing productivity decline.
- Nutrient export and fertiliser cost especially in anticipation of increasing demand for fertiliser in the future.
- Having options for non-arable as well as arable land.

4.2 Seed industry consultation

Eleven seed industry and merchandising agronomists in Queensland were surveyed. Of the eleven interviewed, eight are specialist seed marketers and three are more general merchant/retailers who focus on cropping but also sell pastures seed and service some pasture inquiries in their main cropping activities.

All but one of the seed industry specialists believed that sown pasture decline was widespread, was most common or worse with buffel grass pastures but also occurs with other grasses. The dissenting view was that all pasture rundown and condition decline could be attributed to grazing management and remediated by rotational grazing.

The main points from the interviews are described here, with a comprehensive summary of the views and opinions expressed during the interviews in Appendix 9.2.

4.2.1 Effect on the pasture seed industry

There was a fairly pessimistic view about current trading conditions and the future of the pasture seed industry. While most seed industry reps believed that rundown was negatively affecting their business, they saw development restrictions (e.g. tree clearing legislation) and tough economic times as larger deterrents to sales of pasture seed. The merchandise/retailers were mostly focussed on cropping and did not see rundown as a major impact on their business other than reduced sales of animal health products from the lower stock numbers that properties could carry.

The combination of tough times, tree clearing and land development restrictions and pasture rundown means seed sales are becoming smaller and there were concerns about the future of the seed industry. The era of large scale clearing and land development with associated pasture establishment and high volume of seed sales is over. Export seed sales are also declining with the strong Australian dollar and reduced demand. A recent swing back to public pasture varieties (non

plant breeders rights protected lines) was also seen to be damaging some businesses in the seed industry as grazier bought less expensive seed from neighbours and other farmers.

Given the large area of rundown sown grass pastures and cropping lands there is a need for reliable supplies of sub-tropically adapted pasture seed. The views from and about the seed industry are of concern and present a serious challenge to continued production, supply and support of pasture species, in particular the legumes, that are critical for sustainable grazing and mixed farming systems across northern Australia in future.

4.2.2 Legumes

The seed industry believes that northern regions of Australia have benefitted from stylos that have helped to maintain pasture quality, while medic and other temperate legumes have been successful in southern Australia. The sown pastures of Queensland need more legumes as grasses still make up the majority of seed sales.

Everyone surveyed acknowledged the need to plant the right legume in the right situation (soil, climate, short or long term pasture). There was however considerable difference of opinion about how good different legume species were. Some of this may have been commercially-based with companies with variety rights claiming good results while competitors reported failures. Comments included:

- Desmanthus and caatinga stylo had polar responses ranging from being considered useful through to being complete failures. They were considered to be hard to establish with persistence and productivity being questioned by some. Their specific rhizobium requirements were considered a hindrance to their usefulness.
- Shrubby and Caribbean stylos were considered to be a success story for CQ and further north.
- Medics and vetches are useful in SQ however they are only productive in years with wet winters.
- Burgundy bean performs well as a ley legume, but does not persist in permanent pastures.
- Wynn cassia is good on acid sandy soils.
- Less legume options exist for drier inland areas.

4.2.3 Inoculation

While effective nodulation was considered important, views on inoculation varied. Inoculation is considered a waste of time in many situations by the seed industry as seed is surface sown and left in harsh conditions before rains arrive. As a consequence people sought better inoculation technology and ‘promiscuous’ legumes that could effectively use native Rhizobia.

Several people thought that legumes with specific rhizobium requirements were doomed to fail in extensive grazing situations. Others thought that legumes with specific requirements had formed effective nodules with native rhizobium.

4.2.4 Seed coatings

Seed coating is widespread in the pasture seed industry. It helps with ease of sowing through machinery and with applying ant treatments, inoculum etc. However, naked seed can provide greater numbers of viable seed per kilogram. The retailers provided strong evidence of a large shift

in attitude by graziers against seed coating. However, this is not reflected in the seed industry discussions with companies claiming better establishment with coated seed.

4.2.5 Investment in R,D & E

It is clear that money is tight in the pasture seed industry with businesses working on tight margins. The pasture seed market in northern Australia is considered to be small with many companies relying on export sales of seed. Several of those interviewed thought that investment in pasture R&D by the private sector was likely to remain small due to the domestic market being small with investment more likely to be in species identified to have potential in international markets.

4.3 Researcher consultation

Fourteen researchers and extension officers across DEEDI, CSIRO, UQ and QMDC attended workshops during the project. Other technical professionals were contacted during the project for specific questions, notably DERM soils and vegetation staff.

From consulting technical professionals it is clear that there are major gaps in scientific knowledge about sown pasture rundown and the likely impact of mitigation strategies across environments. Researchers consulted during the project clearly articulated that pasture and animal production responses to pasture rundown and mitigation strategies has not been measured in most situations. The pasture and economic modelling in this project relies more on expert opinion than measured data. The level of confidence in current level of understanding for different aspects of pasture productivity decline in buffel grass pastures is described in Table 13.

Table 13: Current state of knowledge for aspects of productivity decline in sown grass pasture and likely impact of mitigation strategies for addressing pasture rundown.

Issue/mitigation strategy	Confidence	Comments
Buffel grass model	??	GRASP modelling of buffel grass productivity was inconsistent and relies on few calibration sites with limited geographic spread. There is no pasture rundown model.
Acceptance of rundown	✓✓	Accepting lower pasture production and adjusting stock numbers to maintain animal performance is well demonstrated though not necessarily well understood by producers.
N fertiliser	✓ for response ? for residual effect	Buffel grass response to applied N has been demonstrated in some environments. The residual effect in subsequent years has not been well measured.
P & S requirements for legumes	?	P & S requirements for establishment, production and persistence of some legumes has been studied (e.g. leucaena), with less work on production and persistence on tropical legumes especially newer species (e.g. caatinga stylo).
Chisel plough	✓	Several research sites and commercial experience.
Short term fallow	✓	Well demonstrated in some locations.
Blade plough	✓ for sucker control and infiltration × for N cycling response	Widely accepted and adopted by industry. Effect on soil N and C dynamics not measured.
Herbicide renovation	××	Effect of herbicide application on N cycling and grass growth has not been measured
Legume establishment	? in buffel grass ✓✓ in cultivation ? rundown cultivation	Reliable establishment of legumes in drier environments especially in existing grass pastures has not been demonstrated.
Legume persistence	??	Grazing management, nutrition and climatic limits for newer legumes is not well demonstrated
Rhizobia establishment	×	Reliable establishment of rhizobia with small seeds, surface sown during summer with delayed germination needs work for legumes with specific rhizobium requirements.
N fixation	? Amount ? Impact on grass	Measured N fixation has been highly variable. The impact on grass production has not been widely measured. Impact on animal performance measured for a number of legumes.
Supplementation	✓ Northern areas ? Southern areas	Responses to supplementation are more reliable in northern areas due to extended dry seasons.
Animal performance	?	Animal performance in different regions with different mitigation strategies is not well known.
Economics	?	Economic performance of different mitigation strategies is not well demonstrated.

Legend: × - Not known; ? – Studied to some extent; ✓ - Well understood.

4.4 Overview of mitigation strategies

The reduction in productivity of sown grass pastures as they age is attributable to a reduction in the supply of available N in the soil following the flush in available N that occurs with initial clearing and/or cultivation. With age, more of the mineral N is re-incorporated back 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 therefore need to either:

- Increase the rate of N cycling. N 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 fertiliser or biological N fixation (i.e. legumes).
- Accept the reduction in pasture productivity and adjust management of other aspects of the farm business to maintain animal, environmental and economic performance.

Mitigation strategies described by graziers, seed industry and the research literature are described below.

4.4.1 Accept pasture rundown and manage with lower production

Rundown sown grass pasture represents, in effect, the “normal equilibrium condition” between soil type, climate and therefore decomposition rates and N supply to pasture (Burrows 1991). It may be more pragmatic and less risky to accept the reduced pasture production and quality and to adjust management accordingly (e.g. lower stocking rates) while seeking non-agronomic ways to increase animal performance (e.g. purchase more land, fencing and watering systems).

From focus group discussions (Appendix 1), it is clear that most producers have, in effect, accepted lower production through not adopting, or having poor results from other mitigation options. The extent to which this ‘acceptance’ has been a conscious and planned response has not been quantified however a range of views emerged through focus group discussions. Also, the extent to which appropriate changes in grazing management have occurred is unclear but some broad adjustment must have taken place to accommodate the reported reductions in reduced pasture growth.

The main options for maintaining animal and enterprise performance while accepting pasture rundown are:

- Reduce stocking rates to maintain land condition and animal performance. Individual animal performance can be maintained by reducing stocking rates thereby allowing the animals to select a better quality diet (Figure 3) (Burrows 1991; Radford *et al.* 2007).
- Supplement cattle to improve diet quality. Supplementation can increase live weight gains when pasture quality declines (McLennan *et al.* 1999). Responses to protein supplements are more reliable in more northerly districts due to the regular and protracted dry season. In southern Queensland the responses are negligible in average to good years but significant in dry years. Commercially the response to protein supplements varies from 0 – 500 g/head/day with 200 – 300 g/hd/day commonly being achieved (R. Sneath and R. Dixon *pers. comm*.).

- Develop another paddock. Clearing more land or controlling suckers has been a common approach for properties that are not fully developed. Land development opportunities have reduced due to tree clearing and regrowth management laws.
- Buy more land. Mitigation strategies cost money; there may be better returns to buy more land than to renovate pastures. In lower production areas the cost of pasture renovation options is a large percentage, or can be greater than, the value of the land.
- Re-sowing or management to promote the invasion of the pasture by other grasses that are more tolerant of lower N supply (e.g. promote native species to invade sown pastures).

4.4.2 Fertiliser

N fertilisers provide additional N to the pasture sward increasing both the soil available and total N, at least in the short term. As sown grass pasture rundown is primarily a response to reduced availability of N, rundown pastures respond dramatically in both quantity and quality to applied N fertiliser (Graham *et al.* 1985; Graham *et al.* 1981; Myers and Robbins 1991; Robbins 1984). Animal production is subsequently higher and on well drained soils in higher rainfall districts (e.g. wet tropical coast) has been shown to exceed grass legume pastures (Teitzel *et al.* 1991a).

Three rundown buffel grass (cv. Biloela) pastures near Moura with varying total N levels in central Queensland have been shown to grow an additional 30 kg of Dry Matter (DM) per hectare per kg of applied N with a straight line response to 120 kg N/ha/yr and maximum yields at approximately 240 kg N/ha/yr (Graham *et al.* 1981). Similarly strong responses to applied N fertiliser have been observed with green panic pasture with 200 – 250 kg/ha/yr of N per year being required to make a 5 year old pasture as productive as a 1 year old pasture (Robbins 1984). The studies described above were relatively short term (2-3yrs) and did not account for N re-cycling from year to year (i.e. the "residual effect" of applied fertiliser). When N fertiliser is applied annually, 100 kg N/ha/yr has been shown to maintain pasture production at a high level similar to young pastures (Jones *et al.* 1995).

N cycles through different forms in pastures. When ^{15}N-labelled ammonium sulphate was applied to green panic pasture, 32% of the ^{15}N was taken up by the plant, two thirds of which was released in the second season with ^{15}N being released from stabilised pools in subsequent years (Robertson *et al.* 1997). Jones *et al.* (1995) reported that Green Panic pastures that had a history of N fertiliser application maintained some response for 8 years subsequent to the last fertiliser application. The long term impacts of N fertiliser application and N re-cycling are not well understood. However it may mean that lower or less frequent N application may be possible that maintain high levels of production than what has been trialled.

Although rundown grass pastures respond dramatically to N fertiliser the cost is prohibitive in extensive pastures (Jones *et al.* 1995; Myers and Robbins 1991). However, N fertiliser usage may be viable, depending on fertiliser and animal prices, for high productivity pasture such as irrigated pastures, higher rainfall districts (e.g. 800 mm/yr in SQ, 1000mm/yr in more seasonal tropical districts) or for special purposes (e.g. seed production, or as part of a whole property feed base) (Teitzel *et al.* 1991a). None of the graziers consulted during this project routinely use N fertiliser on their pastures, however some have either trialled using fertiliser on small areas or used it for improved seed production.

In addition to poor returns there are technical constraints to the reliable use of fertiliser. Timing and amount of fertiliser need to be matched to seasonal conditions to maximise pasture response and

minimise losses. Timing of application can be difficult in the buffel grass lands due to seasonal variability, poor machinery access and large areas.

4.4.3 Legumes

Legumes can improve production on rundown pastures through biologically fixing atmospheric N and thereby improving diet quality directly and/or via the companion grass. However, the potential benefit of N-fixing legumes for their companion grasses needs to be put into perspective. In dry land pastures approximately 100 kg N/ha/yr is required to maintain production levels similar to young grass pastures, and extensive sown grass pastures legumes seldom fix anywhere near such amounts (Jones *et al.* 1995; Myers and Robbins 1991).

The amount of N fixed by legumes is influenced by a number of factors (Lloyd *et al.* 2007; Peoples *et al.* 1995) the most important being:

- Effective nodulation. Legumes differ in their rhizobia requirements with some legumes having specific requirements while others are promiscuous. Rhizobia differ in their ability to establish and persist in different environments especially in relation to soil pH and other properties. Generally where a legume has been grown for some time there will likely be enough indigenous rhizobia for nodulation. Beyond this generalisation it is difficult to predict situations where inoculation might not be necessary. Even the notion that it is unnecessary to inoculate promiscuous legumes in tropical soils may be flawed (Singleton *et al.* 1992). Introducing rhizobia with pasture legumes in the tropics is particularly challenging due to their generally small seed size and need for shallow or surface sowing on hot soils during summer.
- Available N in the soil. N fixation is energetically expensive therefore legumes tend not to fix much N if it is freely available in the soil. In rundown pastures N is in short supply and legumes are therefore stimulated to fix N. However, disturbance (e.g. cultivation) associated with legume establishment releases N from soil organic matter which promotes grass growth increasing competition which can reduce legume growth and therefore establishment and N fixation.
- Legume biomass production. N fixation is related to how much biomass legumes produce. Legume N fixation is approximately 2.5% of above-ground biomass production. N losses occur during decomposition with N contribution to companion grasses being approximately 1.2 – 1.5% of above ground biomass (Lloyd *et al.* 2007). Therefore factors that impact upon legume growth impact directly on N fixation. Important considerations for maximising legume production are:
    - Species/cultivar adaptation – using the most productive legume for the soil and environment.
    - Nutrition – legumes have higher requirements for many plant nutrients than companion grasses. Legume growth can be favoured by providing these nutrients while excluding N fertiliser.
    - Pests and diseases.
    - Legume content in the pasture. To fix large amounts of N, legumes need to be a significant percentage of pasture composition. Initial establishment, grazing management (timing and intensity) and nutrition are important for maintaining high legume content in pastures.

For the reasons outlined above, the amount of N fixed by legumes varies from negligible to very large, some examples include:

- Medics can average 3,500 kg DM/ha returning an average of 42 kg N/ha/yr to following crops (with a range of 0 - 120kg N/ha/yr) (Clarkson *et al.* 1987).
- Stylos average 30 – 80kg N/ha/yr to following crops (Cameron 1996; Jones *et al.* 1996).
- Leucaena
    - Fix 75 – 150 kg N/ha/yr (Dalzell *et al.* 2006).
    - CQ average yields are estimated to be approximately 2500 kg DM/ha/yr (Clem *et al.* 1993; Radrizzani *et al.* 2010), therefore about 63 kg N fixed, and 38 kg N/ha/yr to the companion grass (Lloyd *et al.* 2007).

The other benefit from legumes, and likely to have the biggest impact, is through improving diet quality and improved animal production per head and, in some cases, per hectare. Examples of the likely benefits from legumes for individual animal performance are:

- Stylos: Average 30 - 60 kg/hd/yr extra, 0 – 100 kg/hd/yr range (Hall & Glatzle 2004)
- Leucaena: 100 – 150 kg/hd/yr extra (Dalzell *et al.* 2006).

Despite the benefits described above, adoption of legumes in sown grass pastures by graziers has not been extensive and performance has been mixed (Appendix 1). Producers consulted during this project reported mixed results from legumes with successes but also many failures. Many producers in focus group discussions did not think legumes other than leucaena were a viable option with buffel grass due to its competitiveness despite notable examples to the contrary described by other participants. Most producers thought legumes were either not widespread or not as widespread as they should be in their district.

4.4.4 Mechanical renovation

Cultivation can be effective at improving productivity of rundown grass pastures while in other circumstances it has reduced production or resulted in little difference. Results are dependent on the intensity of renovation, the relative fertility of the soil, how run-down the pasture is, and seasonal conditions after renovation (Myers and Robbins 1991).

In Queensland, renovation by graziers appears to have been mainly as a consequence of mechanical control of woody regrowth, e.g. by blade ploughing (Appendix 1). Mechanical renovation solely for improving grass growth through stimulating N cycling appears to be not widely practiced. Where there is deliberate practice of renovation, the most commonly used approaches or implements used are:

- Blade ploughs and cutter bars
- Single cultivation e.g. Deep rippers, chisel ploughs, disc ploughs.
- Short fallows using several cultivations

Blade plough and cutter bars

The widespread use of blade ploughs for controlling regrowth, particularly in the brigalow belt, has effectively meant that large areas of sown grass pasture have been renovated. Graziers consulted during this project reported widespread use of blade ploughs for controlling regrowth and renovating degraded pastures (e.g. scalds). Renovating pastures and the opportunity to establish new pasture species is considered a bonus. Blade ploughs cause severe disturbance leaving large clods and very rough surfaces for many years after treatment. Some key points about blade ploughing from commercial experience include:

- It's expensive. Costs varied from $180/ha - $250/ha. Some people are using blade ploughs for pasture renovation however its primary use is for controlling suckers or breaking up scalded areas. Most participants saw blade ploughing as an expensive option for pasture renovation alone.
- Pastures post blade ploughing produce better weight gains and can run more cattle. However the size of these improvements diminishes with repeated blade ploughing.
- Blade ploughing better soils will give a response for 10 – 15 years. On hard setting lighter soils the benefit lasts for a shorter period. Blade ploughing was generally seen as having a longer term response than ripping or chisel ploughing especially for infiltration benefits.
- Provides an opportunity to establish legumes and other grasses, however blade ploughs are not a good way of sowing pastures. Blade ploughs produce a poor seed bed with very rough soil surface condition. Large clods result in seed being buried too deep, poor soil to seed contact and if controlling suckers long periods from sowing till germinating rain can be expected.
- Can cause problems if the plough goes too deep on soils with dispersive layers.
- Can be very effective on clay pans or scalded areas.
- Blade ploughed country is worth more per hectare.

Improved pasture growth after blade ploughing in many instances reflects responses to both water availability (less competition from suckers, increased infiltration on hard setting soils) and N cycling. N and water dynamics after blade ploughing are not well understood (researchers workshop).

Single cultivation

Responses to single cultivations are variable with positive responses in some instances (Catchpoole 1984), no difference (Graham *et al.* 1985) or negative in others (Grof *et al.* 1969). Graziers consulted during this project also reported mixed results. Comments included:

- Produces results in drier years with better infiltration, more and greener grass. In wetter years several graziers have noticed no difference between cultivated and un-cultivated areas.
- More severe disturbance produces a greater response. Offset discs or disc ploughs were considered to produce a better response by some producers as the process turns the root mass and soil over which kills most buffel plants.
- Cultivation provides an opportunity to spread legume and grass seed.

Based on these results it would appear that single cultivation approaches are only reliable and effective where the soil has set hard with poor infiltration and land condition is poor.

Short fallows

Short term fallows of 3 – 6 months duration with several cultivations that break up and kill the majority of the pasture sward have been shown to be effective in renovating rundown pastures and improving pasture growth by approximately 50% (Graham *et al.* 1985). Other benefits reported by graziers include:

- Short term fallowing allows forage crops to be used in the enterprise before re-establishing pasture.
- Short term cropping was seen by many as the most reliable way of establishing legumes.

4.4.5 Crop/pasture rotations

Ley farming can be productive, sustainable and provide a greater hedge against climatic and economic risks than either grazing or cropping alone (Lloyd *et al.* 1991). Using rotations of crops and pastures can benefit both the crop and pasture as the crop takes advantage of organic matter accumulated under the pasture phase and the pasture takes advantage of N released during cultivation (Myers and Robbins 1991). There are significant technical, economic and social challenges to successfully implementing ley farming systems in sub-tropical and tropical Australia (Lloyd *et al.* 2007; Singh *et al.* 2009), examples include:

- Transitioning from crops to pastures and pastures to crops. Establishment of pasture phases is unreliable. Pastures phases can cause difficulties to following crops (e.g. dry soil profile, pasture plants as weeds).
- Relative economics of grain compared to grazing animals.
- High degree of management skill required to successfully manage a diverse farming system.
- Farmers perception of poor economic returns from ley pastures.

Several producers consulted during this project use crop pasture rotations, however the majority either managed their cropping country separately to their grazing areas or were focused on cattle production with little if any cropping. Views ranged widely in relation to crop/pasture rotations from being useful to damaging soil health. Key points included:

- Benefits for subsequent crops. There were mixed results ranging from:
  - Dramatic improvement in crop production.
  - Poorer first crop after pastures with lower yields and/or protein levels but subsequent crops performed well.
  - No improvement in subsequent crop performance.
- Short term fallowing and cropping allows forage crops to be used in a grazing enterprise.
- Short term cropping was seen by many as the most reliable way of establishing legumes.
- Fallowing for crops releases nutrients from soil organic matter that was built up during the pasture phase. Any fertiliser that is used for cropping is subsequently available to the pasture.
- Cropping was seen by many as exporting too many nutrients and degrading soil structure. A number of people noted that land was often cropped until cropping becomes unreliable, and then returned to pasture. In this situation, pastures perform poorly.
- Relative economics between grain, sheep and cattle production. When grain prices are high there is an opportunity to put better country back to cropping for a few years to improve income in the short term with the added benefit of fixing pasture productivity decline. However if cropping continues for long periods, organic matter and nutrients are depleted and subsequent pastures perform poorly.

4.4.6 Herbicide renovation

A few producers have used herbicides to renovate grass pastures (Thompson and Thompson 2009). No references were found in the scientific literature about the results of using herbicide to renovate tropical grass pastures.

Of the producers consulted during this project a few have sprayed buffel out using Roundup™ with one example of using Spray Seed™. Most reported improved greenness and productivity after spraying. Results relied on killing a large percentage of mature plants and having a good soil seed bank for the buffel to re-establish. Spraying out before forage cropping or establishing legumes was seen as a viable option by some participants if machinery could cope with the buffel tussocks.

In southern Queensland, spraying out has been used to manage medics by a few people. If there are already medics in the paddock spraying out in summer to allow moisture storage and to reduce shading can be effective in promoting medic growth. Alternatively spraying out to store moisture followed by some cultivation was seen by some as a useful way of establishing medics.

4.4.7 Grazing management

Higher stocking rates increase the proportion of forage consumed by livestock and therefore increases the amount of nutrient cycled to the soil through excreta relative to litter. Although excreta return nutrients to the soil quicker relative to litter, there are also greater losses (e.g. through volatilisation) (Dubeux *et al.* 2007). Although wet season spelling has been shown to improve land condition, the effect if any on N availability does not appear to have been measured.

All grazier groups involved in the project discussed the importance of sustainable grazing management and identified overgrazing as contributing to pasture productivity decline. Spelling to allow pasture recovery was considered to be good management by all groups with most people having some level of spelling. Many participants use some form of rotational grazing with some using cell grazing. Participants reported seeing changes in pasture composition with more grasses other than buffel in paddocks, especially green panic, native grasses and legumes after changing to a rotational grazing system. However reviews of grazing experiments have concluded that there is little (or no) difference on land condition or animal performance between grazing systems (Briske *et al.* 2008).

Heavy grazing followed by spelling was seen by several participants as being useful for improving greenness and productivity of buffel grass. The heavy grazing was thought to force buffel to reshoot thereby mobilising nutrients within the plant and to promote nutrient cycling through trampling and dung. Heavy herd and hoof impact during wet weather has been observed by some producers to improve buffel productivity e.g. in cells, laneways or holding paddocks.

4.4.8 Fire

Annual burning did not improve pasture yield in buffel grass pastures in CQ (Graham *et al.* 1985). Graziers had mixed comments about using fire with buffel grass with some people supporting the use of fire reporting greener grass, better grass growth depending on the following season, better animal performance and promoting more tussocks and shoots. Others were strongly against using fire seeing it as a waste of a forage resource, risky if the season turns dry, reducing ground cover

thereby increasing erosion, scorching the soil surface as buffel burns hotter than native grasses and promoting weeds like pimelea.

4.4.9 Other grasses

All pasture grasses, including native species, will produce more dry matter with higher levels of available N present shortly after establishment with productivity declining over time (Robbins and Bushell 1985). Introduced pasture grasses (especially early introductions) were selected for high growth potential in favourable environments and are highly responsive to N availability, however their persistence and productivity compared to other grasses declines with reducing N availability (Burrows 2001). Although all grasses suffer from pasture rundown, native grasses and some introduced grasses are better adapted to lower N availability (Table 14). Although some grasses are better able to persist with low available N, their productivity in low N situations is still greatly reduced.

Table 14: Broad relative rating of pasture grasses nitrogen requirements for persistence, reproduction and growth based on qualitative observations (Peck and Chamberlain 2001). This table attempts to give a relative rating for plants growing on soils and climates they are adapted to.

N requirement	Pasture grass
Highest	Silk sorghum, forage sorghum
	Green panic, purple pigeon, Rhodes grass
	Buffel, bambatsi panic
	Digitaria spp., Sabi grass
	Astrebla spp., Dichanthium spp., Bothriochloa spp., Heteropogon spp.
Lowest	Spinifex, *Aristida spp.*

4.4.10 Other options

There were other options discussed during the project, however the effect of these treatments is either unknown or considered small. Options discussed were:

- Slashing. A few people have slashed buffel around house yards, sheds etc. They have observed slashed buffel pastures to have more tussocks and to be greener.
- Rotations of trees and shrubs. The role of native trees and shrubs in nutrient cycling was mentioned by several graziers, brigalow as a legume was also mentioned. Having a cycle where suckers were allowed to grow to a moderate height before being chained and allowed to re-grow or alternatively leaving strips of suckers was seen as a useful way of promoting nutrient recycling and N fixation if suckers are leguminous. However with current vegetation management laws and uncertainty with future legislation, most producers saw these options as risky to their long term property viability. Although trees and shrubs can have positive benefits to associated grasses there are competitive effects (i.e. competition for moisture, nutrients and light) which results in a net decline in pasture production with increasing tree or shrub cover without providing improvements in diet quality (Burrows *et al.* 1988a; Scanlan

1991; Scanlan and Burrows 1990). No graziers in the focus groups were managing trees for their nutrient cycling attributes.

- Biological treatments. A few people were interested in using compost or compost teas for improving nutrient cycling and improving pasture growth. A few participants had tried using compost teas but had seen no response (either visually or in pasture yield or grain yield).

4.5 Pasture and animal production responses to mitigation strategies

Pasture and animal production responses were developed for twelve mitigation strategies across four example properties. Pasture, animal and economic responses were considered relative to "rundown buffel" pastures. The mitigation strategies were:

- Protein supplementation of cattle.
- Three mechanical renovation options – blade plough every 10 years, chisel plough every 5 years and short term fallows (4 cultivations over 4 months) every 10 years.
- Two nitrogen fertiliser rates (60 and 120 kg N/ha/yr) applied annually.
- Five legume options – leucaena established in cultivated strips, other legumes established by either blade plough, cultivated fallow, cultivated strips or herbicide strips.

Most graziers consulted during the review use low cost, low reliability sowing methods when trying to establish legumes into existing grass pastures which commonly results in failures. For the purposes of the production analysis review, only establishment techniques that had a high likelihood of success in most years were considered (see Table 23).

4.5.1 Pasture production

Average annual pasture production for rundown buffel grass at each case study location was determined from GRASP modelling (G. Whish *pers. comm*.) and other sources (e.g. Local Consensus Data, Grazier Guides) (Clarke *et al.* 1992; Partridge 1996). Benchmark residual biomass for high, medium and low fertility soils for each location were calculated from published utilisation rates for land types at the case study locations (Whish 2010). Stocking rates were calculated from pasture production estimates described above using a forage budget methodology (Table 15). The stocking rates for mitigation strategies were calculated to achieve the same residual pasture biomass, that is stock numbers were increased to utilise the extra forage with the same end of dry season residual biomass. Pasture production for mitigation strategies was determined as a function of the rundown buffel baseline as described in Table 16.

Table 15: Average annual pasture production for 'rundown' buffel grass pastures at four locations in Queensland. Utilisation rates were used to calculate stocking rates and end of dry season residual biomass. Spoilage was estimated at 20% for high fertility soils and 15% for medium and low fertility.

Location	Moura			Glenmorgan			Clermont			Tambo		
Soil Fertility	**High**	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Rundown buffel (kg DM/ha/yr)	5000	4000	3000	4500	3500	2500	4500	3500	2500	3000	2000	1500
Utilisation rate	30%	25%	20%	30%	25%	20%	30%	25%	20%	25%	20%	15%
Residual (kg DM/ha/yr)	2500	2400	1950	2250	2100	1625	2250	2100	1625	1650	1300	1095
Stocking rate (AE/ha)	0.41	0.27	0.16	0.37	0.24	0.14	0.37	0.24	0.14	0.21	0.11	0.06
Stocking rate (ha/AE)	2.43	3.65	6.08	2.70	4.17	7.30	2.70	4.17	7.30	4.87	9.13	16.22

Table 16: Assumed rates of average annual pasture production, as a percentage of that for rundown buffel grass pasture, for environments at Moura, Glenmorgan, Clermont and Tambo. (Confidence ratings H – high, M – medium, L – low)

Mitigation Strategy	Average annual pasture production			Confidence	References and comments
Soil fertility	**High**	**Medium**	**Low**		
Rundown buffel (RB)	100%			H	Pasture production described in Table 15.
Initial buffel	200%			H	(Burrows 1991; Middleton 2001)
Supplements	100%			H	(McLennan *et al.* 1999)
Fertiliser (60 kg N/ha/yr)	Response rate of 30 kg DM/ha/yr for each kg/ha of N applied. (RB + (60 x 30)			MH	(Graham *et al.* 1981; Robbins 1984) Trials at limited locations.
Fertiliser (120 kg N/ha/yr)	Response rate of 30 kg DM/ha/yr for each kg/ha of N applied RB + (60 x 30)		Response rate of 25 kg DM/ha/yr	MH	(Graham *et al.* 1981; Robbins 1984) Trials at limited locations. Other nutrients assumed to be limiting with high fertiliser rates on low fertility soils.
Blade plough	125% years 1-5 115% years 6-7 100% year 8-10		125% years 1-5 110% years 6-7 100% year 8-10	ML	Estimated relative to chisel plough and short term fallow. Hard to separate N cycling effect from sucker control.
Chisel plough	115% year 1 105% year 2-3			M	(Catchpoole 1984; Graham *et al.* 1985; Grof *et al.* 1969), Responses from single cultivations are variable.
Short term fallow	150% years 1-3 115% years 4-6		140% years 1-3 110% years 4-6	MH	(Graham *et al.* 1985) Maximises mineralisation from soil organic matter and therefore larger effect than other renovation options.
Herbicide renovation	125% year 1 115% year 2-3			L	(Thompson and Thompson 2009) Pasture response not measured.
Leucaena*	75 kg N/ha/yr supplied to grass. RB + (75 x 30)	60 kg N/ha/yr supplied to grass. RB + (60 x 30)		M	(Clem *et al.* 1993; Dalzell *et al.* 2006; Radrizzani *et al.* 2010). N cycling from legume to pasture grass difficult to measure.
Legumes* (Clermont, Glenmorgan & Moura)	50 kg N/ha/yr supplied to grass. RB + (50 x 30)	40 kg N/ha/yr supplied to grass. RB + (40 x 30)	20 kg N/ha/yr supplied to grass. RB + (20 x 30)	ML	(Cameron 1996; Clarkson *et al.* 1987; Jones *et al.* 1996) Reliable estimates for medics, less reliable for tropical species.
Legumes* (Tambo)	30 kg N/ha/yr supplied to grass. RB + (30 x 30)	20 kg N/ha/yr supplied to grass. RB + (20 x 30)	15 kg N/ha/yr supplied to grass. RB + (15 x 30)	L	(Cameron 1996; Clarkson *et al.* 1987; Jones *et al.* 1996)

* Leucaena and legume figures are for fully established pasture. (NB legume production relative to rundown is lower at Tambo due to harsher growing conditions and leucaena is considered unsuitable, leucaena is considered unsuitable with low fertility at all other locations).

When establishing legumes there can be benefits to the companion grasses from the mechanical disturbance as well as trade offs to production from spelling requirements to allow establishing pastures to mature and set seed. Legumes require several years to reach sufficient numbers to contribute a large percentage of biomass production and therefore diet of grazing animals. Assumptions for legume establishment periods, spelling requirements and time required to achieve stocking performance improvements for the different legume establishment options are described in Table 17.

Table 17: Legume establishment periods, spelling requirements and production levels for different establishment techniques used in production and economic modelling.

Establishment method	Year	Spell	Pasture and animal production levels
Leucaena (cultivated strips)	1	12 month	No stock in the year of establishment.
	2	6 month	Pasture and animal production halved.
	3+	3 month	Leucaena destocked during winter.
Legume - Blade plough	1	6 month	Production reflects renovation effect only.
	2 - 5		Production reflects renovation effect only (Table 16 and 18).
	6 - 7		Production reflects renovation effect only (Table 16 and 18).
	8 - 9		Grass production at rundown levels. Legume established sufficiently to improve diet quality.
	10+		Pasture and animal production of fully established pasture.
Legume - Short term fallow	1	6 month	Production reflects renovation effect only.
	2 - 3		Production reflects renovation effect only.
	4 - 5		Pasture production at renovation levels. Animal performance improved from legume in diet.
	6+		Pasture and animal production of fully established levels.
Legume - Cultivated strips	1	6 month	Production at rundown buffel levels.
	2	3 month	Pasture production at rundown buffel levels. Animal performance improved from legume in diet.
	3 - 4		Stocking rates as for rundown buffel grass. Animal performance improved from legume in diet.
	5+		Pasture and animal production of fully established levels.
Legume - Herbicide strips	1 – 2	6 month	Production at rundown buffel levels.
	3 – 4	3 month	Production at rundown buffel levels.
	5 – 6	3 month	Stocking rates as for rundown buffel grass. Animal performance improved from legume in diet.
	7+		Pasture and animal production of fully established levels.

Pastures also require spelling after mechanical or herbicide renovation to allow grasses to re-establish. Pasture spelling was assumed to only be required in the first year after renovation for the following periods:

- Blade plough – 6 months
- Chisel plough – 3 months
- Short term fallow – 6 months
- Herbicide renovation – 6 months

4.5.2 Animal production

Animal production is based on published figures and expert opinion and is summarised in Table 18.

Cattle live weight gains were assumed to be similar across all case study locations given similar soil fertilities for rundown buffel grass, fertiliser, mechanical and herbicide renovation. Animal performance was adjusted for legume options in different locations and soil fertilities to reflect the expected legume growth potential. Animal performance with the use of supplements was adjusted for different districts.

Table 18: Average annual cattle live weight gains for 'rundown' buffel grass and for each mitigation strategy. Animal performance for mitigation strategies is expressed as kg live weight gain benefit compared to rundown buffel. Leucaena and legume figures are for fully established pasture.

Mitigation Strategy	Average annual live weight gain (kg/hd/yr)			Confidence	References and comments
Soil Fertility	**High**	**Medium**	**Low**		
Rundown buffel (RB)	160	150	140	MH	(Burrows 1991; Middleton 2001; Myers and Robbins 1991; Rudder *et al.* 1982)
Initial buffel	+ 40		+ 30	M	(Burrows 1991; Middleton 2001; Myers and Robbins 1991; Rudder *et al.* 1982)
Supplements (Clermont)	0.2 kg/hd/day for 150 days. Compensatory growth of 50% (RB + (0.2 x 150)) x 50%			MH	(McLennan *et al.* 1999) (R. Sneath and R. Dixon *pers. comm.*)
Supplements (Tambo and Moura)	0.2 kg/hd/day for 100 days. Compensatory growth of 50% (RB + (0.2 x 100)) x 50%			MH	Responses to supplements lower and less often in more southerly areas due to winter rain.
Supplements (Glenmorgan)	0.2 kg/hd/day for 50 days. Compensatory growth of 50% (RB + (0.2 x 50)) x 50%			MH	As Above.
Fertiliser (60 kg N/ha/yr)	+ 20			M	(Teitzel *et al.* 1991a; Teitzel *et al.* 1991b)
Fertiliser (120 kg N/ha/yr)	+30			M	As above.
Blade plough	+ 30 years 1-5		+ 20 years 1-5	ML	
Chisel plough	+15 year 1			ML	
Short term fallow	+ 30 years 1-3		+ 20 years 1-3	ML	
Herbicide renovation	+ 30 year 1		+ 20 year 1	L	(Thompson and Thompson 2009) Animal performance not measured.
Leucaena* (Moura, Clermont)	+ 110	+ 70		MH	(Dalzell *et al.* 2006); S. Buck *pers. comm.*
Leucaena* (Glenmorgan)	+ 90	+ 50		M	As above. Animal response lower due to shorter growing season. Confidence lower due to less trials in SQ.
Legumes	+ 60	+ 50	+ 40	MH	(Hall *et al.* 2004; Middleton 2001; Partridge *et al.* 1996)

(* leucaena is considered unsuitable at Tambo and on low fertility soils at all other locations).

4.6 Property scale economics of mitigation strategies

4.6.1 Economic returns for case study properties

NPV and B/C ratios over a 30 year period for mitigation strategies in the four case study locations are shown in Figure 6 and Appendix 3. Returns show a similar pattern for Moura, Clermont and Glenmorgan while Tambo shows much lower returns across all mitigation strategies.

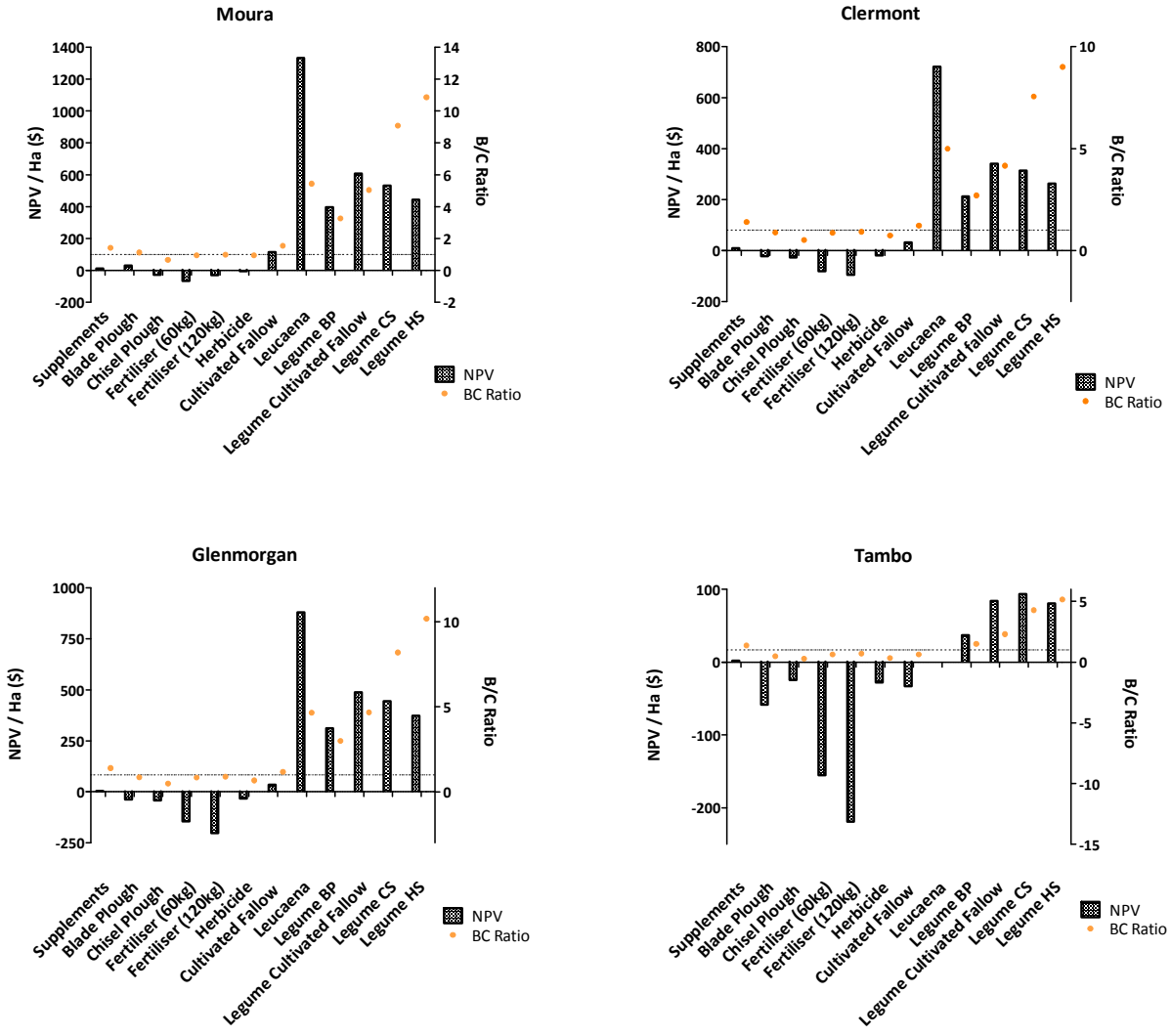

Figure 6: NPV and B/C ratios for rundown mitigation strategies at Moura, Clermont, Glenmorgan and Tambo. The dotted line represents a B/C ratio of 1, i.e. the "break even" point. (Codes for legume establishment: BP – blade plough; CS – cultivated strip; HS – herbicide strip)

Legumes (including leucaena) provided the highest NPV and B/C ratios in all districts. Leucaena produced the highest NPV for the districts it is suited to; that is Moura, Clermont and Glenmorgan, however other legumes established by cultivated strips and herbicide strips had a higher B/C ratio. The higher B/C ratio is due to lower costs incurred during establishment, while the higher production assumed for leucaena provides it with a higher NPV in the long term.

The method of legume establishment affected the long term returns through costs incurred during establishment and time required to reach full production. Cultivated fallows provided the quickest time to full production of the legume establishment options and subsequently the highest NPV (except for Tambo where the cultivated strip establishment gave the highest returns). Although reliable, but lower cost, establishment techniques provided lower NPV's, they did provide a higher B/C ratio due to less expenses being incurred initially. Blade ploughs were the highest cost, lowest B/C and lowest NPV legume establishment option. Blade ploughs are good for sucker control, however for renovating pastures or establishing legumes they are not an economically or agronomically sensible option.

Of the mechanical renovation methods used only cultivated fallows showed positive returns at the property scale at Moura, Clermont and Glenmorgan whilst the blade plough strategy produced a positive NPV at Moura (due to the greater area of high fertility soil and higher pasture production). No cultivation treatments produced positive returns at Tambo.

Differences between districts reflect variations in:

- Pasture productivity (climate). Moura has the highest baseline pasture production (rundown buffel) being 4000 kg DM/ha/yr for medium fertility soils, Glenmorgan and Clermont had 3500 kg DM/ha/yr with Tambo having the lowest at 2000 kg DM/ha/yr (Table 14).
- Land type mix which affects both production response and area suited to leucaena (only high and medium fertility soils). The percentage of land area that is high or medium fertility soils were 50, 40, 30 and 20% for Moura, Glenmorgan, Clermont and Tambo respectively (Table 8).
- Property size. Sizes are Moura – 4000ha; Glenmorgan – 3000ha; Clermont – 15,000ha; Tambo – 20,000ha. Combined with land type mix, property size influences the area suited to different mitigation strategies and their respective production levels.
- Production costs (e.g. transport distance to market).

From the economic analysis it is clear that legumes, if established successfully and managed well, will likely provide the best economic returns for mitigating rundown buffel grass pastures. However it is not as clear about which legume is the "best". Although leucaena provides higher NPV's on fertile land types the other legumes can provide higher B/C ratios depending on the establishment method. From an economics point of view leucaena may be a better option for those with high fertility soils who can afford the establishment cost while the other legumes may be a better option where leucaena is marginally adapted, where low cash flow precludes expensive establishment or with lower fertility soils.

4.6.2 Mechanical renovation, fertiliser and herbicides

Cumulative returns for mechanical renovation, fertiliser and herbicides for Glenmorgan is shown in Figure 7. Relative to those for Glenmorgan, returns are similar at Clermont, slightly higher at Moura and lower at Tambo. The “saw tooth” pattern with mechanical renovation is due to re-treatments.

Of the mechanical renovation and fertiliser options, the 3 month fallow showed positive returns at Moura, Clermont and Glenmorgan. The blade plough option showed positive returns only at Moura, whilst no mechanical renovation options gave positive returns at Tambo. Supplements provide small positive returns at all locations.

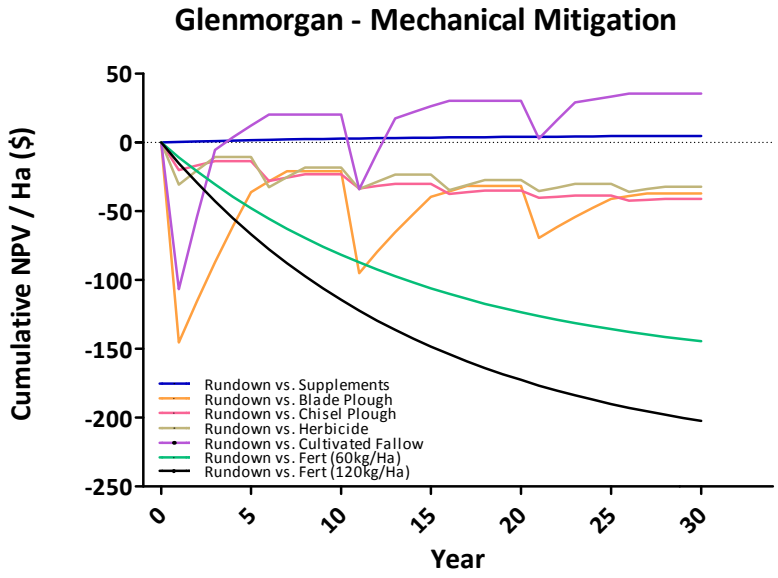

Figure 7: Cumulative returns from pasture renovation treatments.

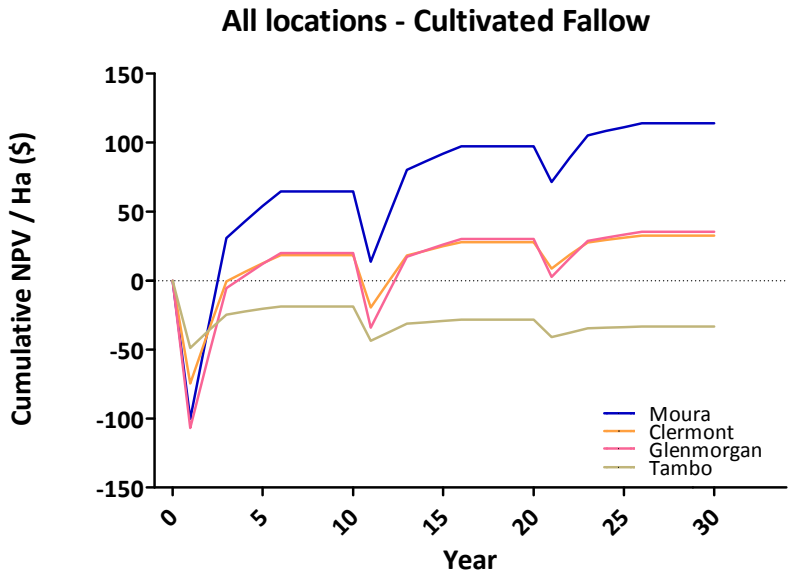

Figure 8: Cumulative returns from mechanical renovation for case study properties.

Cultivated fallows provided the best returns of the mechanical renovation strategies and provide positive returns at Moura, Glenmorgan and Clermont (Fig. 8). Returns were not positive at Tambo due to lower pasture production levels reflecting a harsher environment and a smaller percentage of high and medium fertility soils. Moura shows the best returns from cultivated fallows reflecting a better environment for growing buffel grass and a higher percentage of fertile soils.

Although cultivated fallows provide positive returns they are not providing high levels of return relative to legume options and are therefore unlikely to be widely adopted for renovating buffel grass pastures. Where they are used to incorporate forage crops they may provide benefits in providing additional forage including during times of the year that may have low quality and quantity forage from buffel grass alone (Moore *et al.* 2009). Alternatively the cultivated fallow option may allow transitioning into grain cropping which provides benefits in renovating buffel as well as improved soil health for subsequent crops (Myers and Robbins 1991).

Fertiliser sensitivity analysis

Fertiliser applied annually showed negative returns at all locations. However, N cycles through various forms in pasture and the long term impacts of N fertiliser application and N re-cycling are not well understood. N re-cycling may mean that lower and/or less frequent N applications may be adequate to maintain production at high levels. To test the sensitivity of economic returns to assumed residual impacts of applied N, economic returns were calculated with the assumption that similar yields may be achieved with application rates every second or third year (Figure 9).

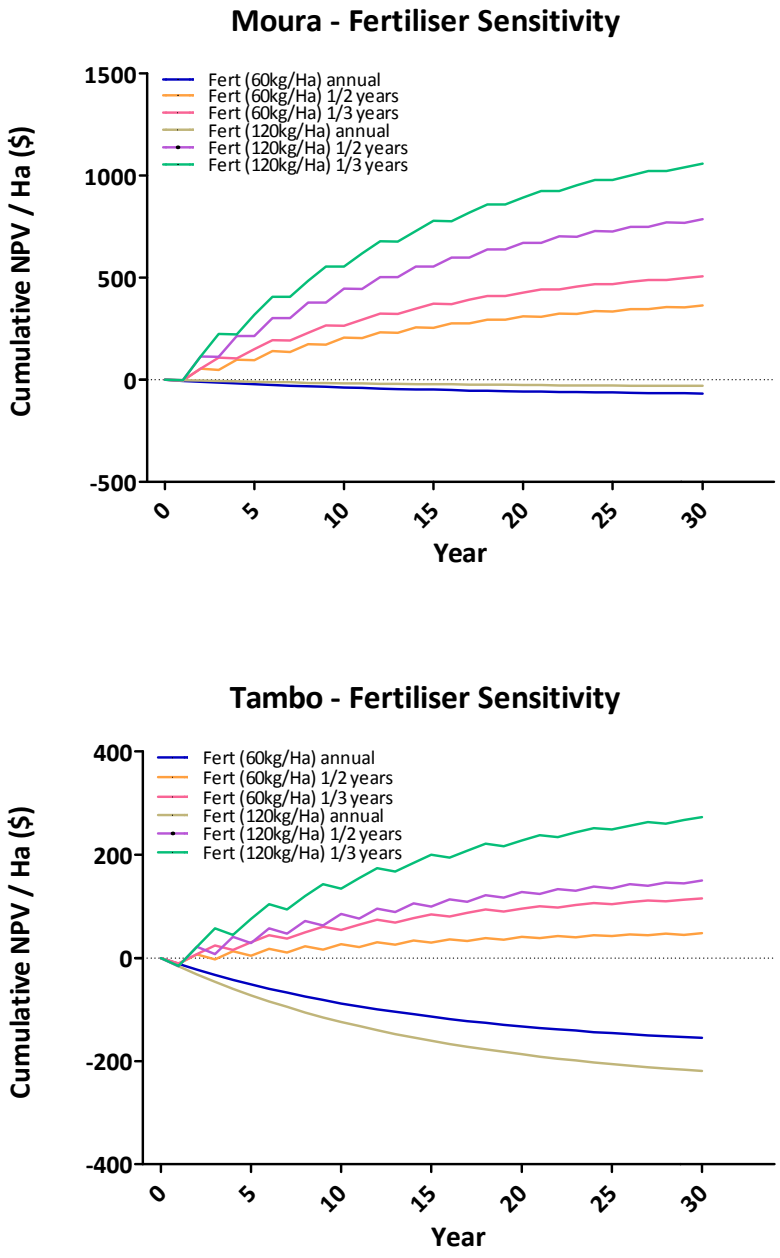

Figure 9: Cumulative NPV with N fertiliser assuming 30 kg DM/ha/yr per kg of N from different fertilising frequencies for Moura and Tambo case study properties.

For Moura, substantial positive returns accrued where a large residual impact of applied N was assumed (meaning that fertiliser could be applied less frequently). However at Tambo (where the

non-buffel percentage of land is assumed to be 70%), a much smaller benefit was derived from applying fertiliser to targeted areas, though returns are still positive.

This analysis supports the conclusions of previous authors that N fertiliser can be viable on higher production pastures (higher rainfall, irrigation, higher fertility) or special purpose pastures (e.g. seed production, relieving grazing pressure on other parts of the property) (Teitzel *et al.* 1991a). The analysis also suggests that if repeated N fertiliser application results in an accumulation of total soil N, increased N mineralisation and therefore increase N availability as suggested by the work of Jones *et. al.* (1995), that N fertiliser use would be an economically viable option. Broad acre application of N fertiliser to buffel grass pastures would present technical challenges (e.g. to reduce volatilisation losses and manage seasonal variability). However, N fertiliser application, especially on more productive land types, warrants investigating further to test whether it is technically and economically feasible.

4.6.3 Legumes

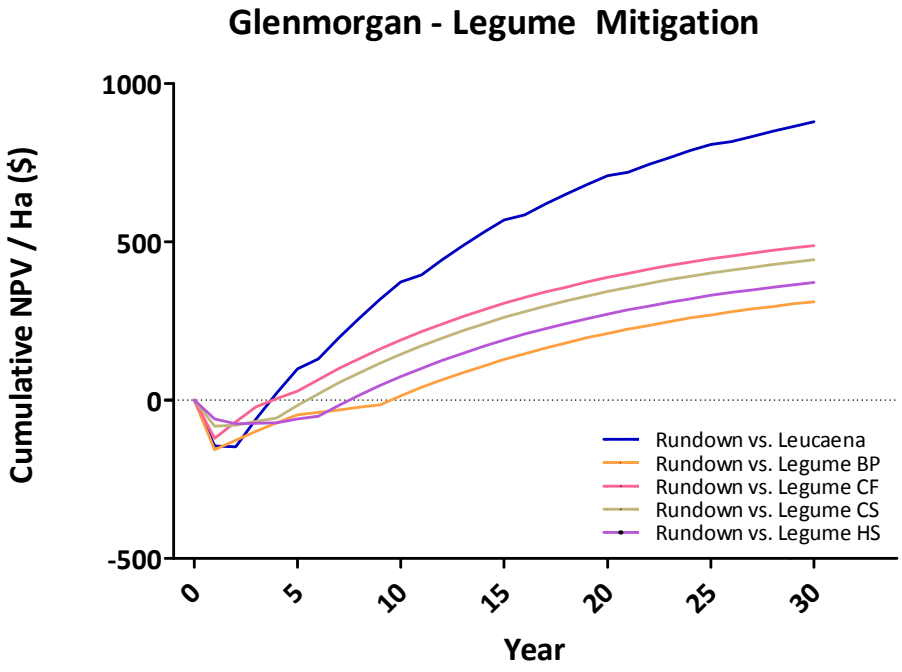

Figure 10: Cumulative returns from establishing legumes in rundown buffel grass pastures at Glenmorgan.

All legume treatments provided positive economic returns across all locations (Figure 10). The effect of speed of establishment and reaching full production (as described in Table 17) is shown in the graphs and is demonstrated by the time it takes to break even. Leucaena provides the greatest economic returns (in NPV terms) and is a proven reliable technology where it is adapted.

Cultivated fallows provide the quickest establishment of legumes, shortest break even period and highest NPV in the long term; however it is more expensive than cultivated or herbicide strips. Establishment in cultivated or herbicide strips in buffel grass pastures has not been commercially demonstrated (other than leucaena) however it does allow for accumulation of soil water and weed control resulting in reliable legume establishment at reduced costs. If time periods to reach full establishment for legumes established in strips could be reduced to being similar to clear fallow it would be clearly more economically effective. It is likely that management would need to be adjusted when establishing legumes in strips as stock may concentrate and over graze the strip, thereby reducing seed set and subsequent thickening of the legume. The legume also has a greater distance to spread to colonise the whole pasture (Cook *et al.* 1993a).

The difference between leucaena and the other legume options may be able to be reduced with better establishment and better grazing management especially if some of the newer legumes for clay soils (caatinga stylo, desmanthus, butterfly pea) prove to be as commercially successful as they have been in trials.

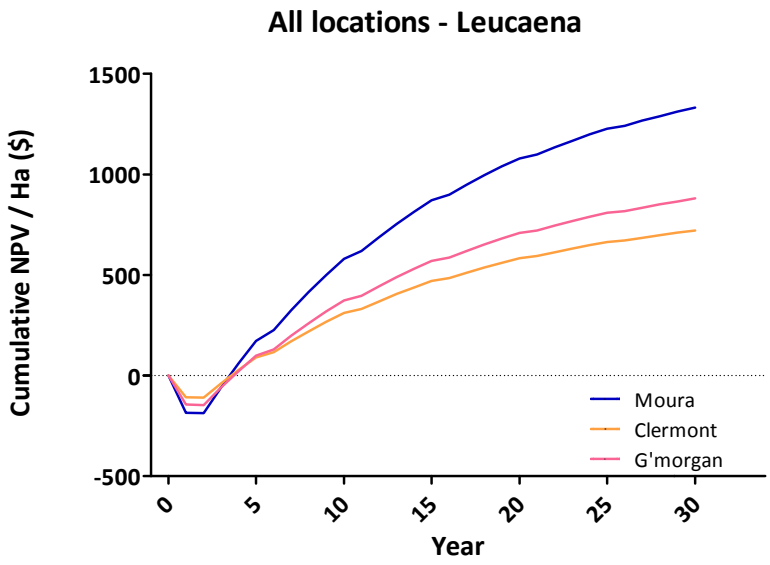

Figure 11: Cumulative returns from leucaena establishment for case study properties.

Of the legumes considered, leucaena provided the highest NPV, however it is not suited to drier areas such as Tambo. Moura shows the best returns from leucaena reflecting a better environment for growing leucaena grass pastures and a higher percentage of fertile soils (Figure 11). Although leucaena production is higher at Clermont than Glenmorgan the returns are lower which reflects the higher percentage of fertile land types on the Glenmorgan case study property.

Legumes other than leucaena, such as stylos and medics, produced the second highest NPV and depending on establishment method the highest B/C ratios. For the purpose of comparing case

study properties, the returns from legumes established using cultivated strips are shown in Figure 12. Moura shows the best returns from legumes reflecting a better environment for growing legume grass pastures and a higher percentage of fertile soils. Although legume production is considered to be the same at Clermont and Glenmorgan the returns are higher at Glenmorgan reflecting the higher percentage of fertile land types and lower establishment costs as medic seed is generally less expensive than stylo.

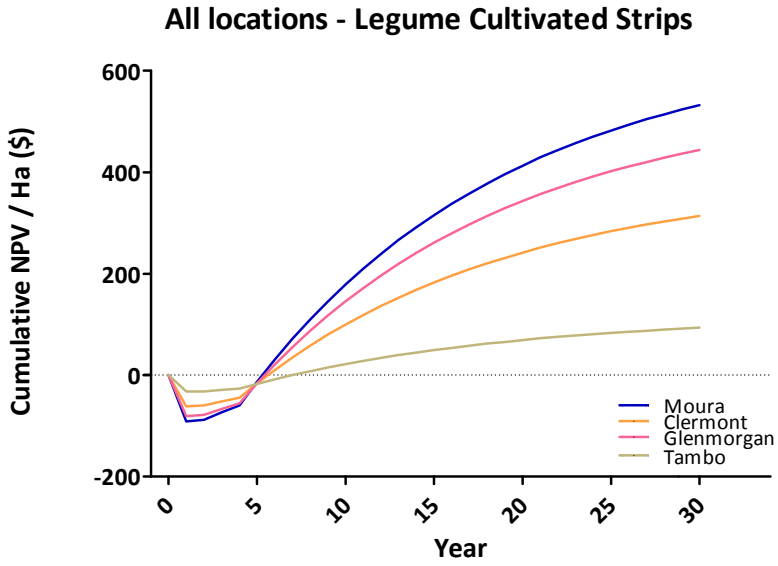

Figure 12: Cumulative returns from legumes established in cultivated strips for case study properties.

4.6.4 Mechanical renovation with and without legumes

Mechanical renovation using blade ploughs is common in the industry especially where suckers are being controlled. Cultivated fallows and single cultivations are used by some graziers to renovate pastures. However the economic return from mechanical renovation of rundown buffel grass pastures is marginal (Figure 13). Mechanical renovation does disturb the mature pasture plants and thereby reduces competition and provides an opportunity to establish legumes. Economic returns from establishing a legume when mechanically renovating a pasture far out-perform mechanical renovation alone.

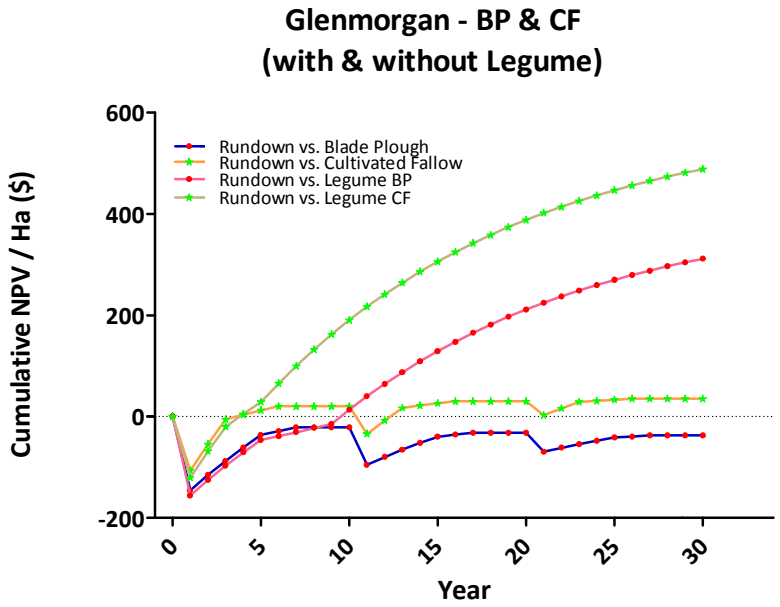

Figure 13: Cumulative returns from mechanical renovation with and without legume establishment. BP – blade plough; CF – cultivated fallow.

4.6.5 Land type impact on economic returns

Land type fertility has a large impact on pasture production, animal performance and therefore economic returns. The economic analysis for this project used example properties that approximate "average properties" in different locations of Queensland to estimate whole property returns from mitigating buffel grass rundown. However every property has a different land type mix. While whole property returns are important, it is also important to understand likely returns by land type fertility for each hectare treated when considering mitigation options at the paddock scale. Tables 19 and 20 show estimates of economic returns as affected by soil fertility for the hypothetical case study properties at Glenmorgan and Clermont, respectively.

Table 19: Glenmorgan economic returns for selected mitigation strategies assuming the whole property was one soil fertility. These values approximate returns that could be expect for individual paddocks of uniform land type.

Mitigation	NPV/ha (7%)			B/C Ratio (7%)		
Soil Fertility	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Leucaena	-	$1,391	$3,006	-	3.31	5.99
Legume CS	$260	$726	$1,104	3.69	9.85	14.46
Cultivated Fallow	-$106	$107	$228	0.65	1.36	1.76
Legume CF	$253	$816	$1,248	2.27	5.43	7.78

Table 20: Clermont economic returns for selected mitigation strategies assuming the whole property was one soil fertility. These values approximate returns that could be expect for individual paddocks of uniform land type.

Mitigation	NPV/ha (7%)			B/C Ratio (7%)		
Soil Fertility	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Leucaena	-	$1,806	$3,601	-	4.00	6.98
Legume CS	$264	$742	$1,125	3.53	9.24	13.49
Cultivated Fallow	-$94	$129	$255	0.69	1.43	1.85
Legume CF	$245	$825	$1,265	2.09	4.93	7.02

For both Glenmorgan and Clermont it is more profitable to mitigate rundown on higher fertility land types. Cultivated fallows provide positive economic returns only on medium and high fertility land types. Leucaena provides a larger NPV, but lower B/C ratio, than other legumes on medium and high fertility soils. As generally found with analysis of land clearing and pasture development in the past (e.g. Burrows *et al.* 1988b), the more fertile soils provide the highest returns to investment. From an economic point of view it would be recommended to treat the most fertile soil types on a property first (assuming, of course, that reliable and proven technologies are available for all soil types to produce the assumed benefits used in the analysis).

Due to the different economic returns for different soil fertilities, whole of property returns change with different land type mixes. A range of land type mixes (Table 19) were modelled to demonstrate the impact of land type mix on whole of property returns for legume mitigation strategies (Figure 14).

Table 21: Scenarios of different ratio's of land types.

Scenario	High fertility %	Medium fertility %	Low fertility %	Non-buffel %
1	40%	40%	10%	10%
2	10%	40%	40%	10%
3	0%	20%	40%	40%
4	0%	10%	40%	50%
5	0%	0%	20%	80%

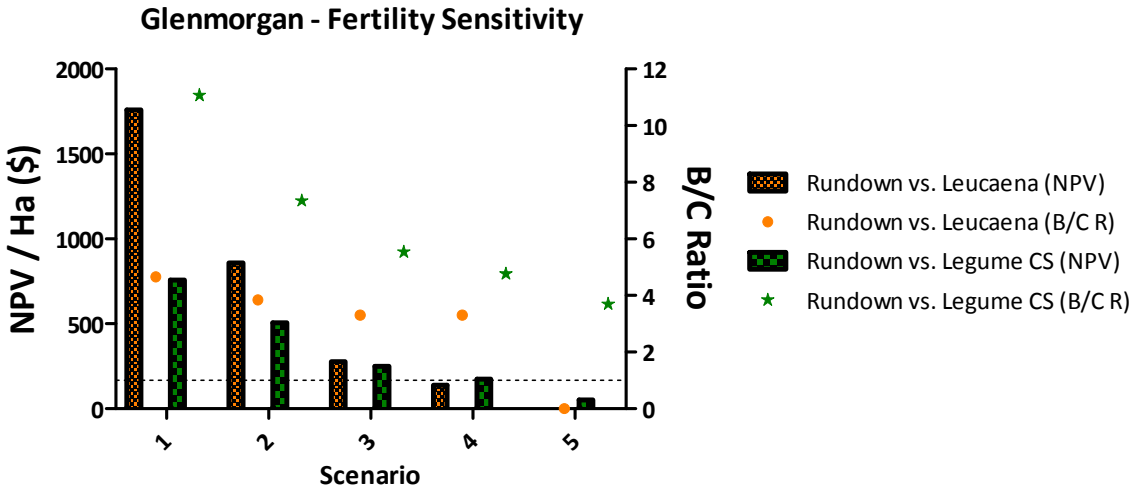

Figure 14: Changes in Net Present Value (NPV)and Benefit/Cost ratios(B/C R) for the different scenarios of land type fertilities described in Table 19 at Glenmorgan. (CS – Legumes established using cultivated strips).

As the percentage of high and medium fertility land types on a property decreases:

- The NPV and B/C ratio for all legumes decreases.
- The differences in NPV and B/C between legumes and leucaena decreases.

As land type mix changes it would appear that the rule of thumb of “planting what is best suited to the area and land type” holds true from both the returns per hectare and returns at the property scale perspective. The greatest benefit from leucaena accrues on high fertility soils with the differences being less on medium fertility soils, however the other legumes provide a greater B/C ratio which may make them a better option if cash flow is tight.

The analysis above also suggests that as the land type mix of a property shifts towards greater areas of buffel grass on low fertility soils or native pastures the return at the whole farm level from mitigating rundown reduces. However the economic analysis assumed a buying and selling operation. If the property was a breeding and fattening enterprise with different stock classes on different land types, then impacts of improving the productivity of relatively small areas of rundown sown grass pastures in “finishing paddocks” may have a larger impact on whole farm economics.

4.6.6 Economic conclusions

The economic analysis strongly suggest that legumes are the most promising mitigation option for large areas of buffel grass pastures. Higher production pastures (higher rainfall and higher fertility soils) provide the highest returns. Developing more fertile land types on a property first will therefore provide better returns. Similarly at the industry scale, investment into higher production districts is likely to provide greatest returns.

Mechanical renovation appears viable only for high production buffel pastures (higher rainfall districts and higher fertility soils) with cultivated fallows providing the best returns. However returns from mechanical renovation are improved significantly if they are used to establish legumes.

Nitrogen fertiliser was not viable at any location were no residual impact of N cycling to subsequent years is assumed. However, where repeated N fertiliser application is assumed to influence N cycling and therefore availability to producing a similar response with applications every second year the economic returns improve dramatically to be similar to legumes. The analysis suggests that N fertiliser can be viable on higher production pastures (higher rainfall, irrigation, higher fertility) or special purpose pastures (e.g. seed production, relieving grazing pressure on other parts of the property, finishing paddock). N fertiliser application, especially on more productive land types, maybe worth investigating further to test technical feasibility.

None of the mitigation options appear to be viable for the lower production buffel pastures of far western Queensland.

4.7 Limitations to addressing pasture productivity decline

For the mitigation strategies described above it is important to consider limitations, critical success factors and knowledge gaps. For the purposes of this project it was decided to model pasture productivity and economic performance of mitigation strategies that appear to have some impact as inferred from trials and/or as implied from observations by producers and researchers. The limitations, critical success factors and key knowledge for the main mitigation strategies that may be effective for commercial application are described in Table 22.

Table 22: Technical, social and economic considerations that may influence the adoption of mitigation strategies used to address pasture rundown in buffel grass pastures.

Mitigation Strategy	Constraints / Drivers / Questions		
	Technical	**Social**	**Economic**
Initial buffel	Unrealistic in the long term.	Creates high expectation of production potential of sown pastures.	Returns not sustainable as N availability declines, returning to more 'normal' levels.
Rundown buffel	Will production remain stable or will it decline further? What are the differences in rate and degree of rundown in different climates and soils?	Acceptance – rundown buffel is what people have to manage. Desire to increase productivity, as opposed to managing a declining trend.	Lower returns with a question of whether production will decline further. Reduced productivity on smaller properties affects viability.
Protein supplements	Lower response and less reliable in SQ. Phosphorus needs to be considered as well on soils <8ppm, with buffel growing on soils to 6ppm.	Industry accepted practice with wide use of dry season protein supplements.	Supply and cost varies widely.
Nitrogen fertiliser	Residual effect of N not quantified, N cycling in system should increase. Potentially high losses from volatilisation. Limitations of effectiveness not defined. How repeatable are the responses to N fertiliser – how big an impact from: ▪ seasonal variability ▪ soils ▪ application methods ▪ relationship to other nutrients (e.g. P, S)	Land owners are reluctant to use fertiliser on pasture at all let alone frequently or regularly. May be useful to demonstrate what is possible.	Expensive. Poor and unreliable returns (perceived and/or real).

Mitigation Strategy	Constraints / Drivers / Questions		
	Technical	**Social**	**Economic**
Mechanical renovation (Blade plough)	Sucker control method – pasture renovation is a secondary consideration. Hard to separate the effects of sucker control, water infiltration and N cycling. Length of response not known. Effect of repeated blade ploughing not known. Not suited on shallow or dispersive soils. Provides an opportunity to establish legumes but is a very rough seed bed.	Widely used. Highly regarded. Large disturbance provides a feeling of "doing something" to address the problem.	Expensive if primarily for stimulation of N availability.
Mechanical renovation (Chisel plough)	Questionable whether there is enough disturbance to release sufficient N for a grass response. Water versus N response hard to separate. Different results in different years. Provides some opportunity for legume establishment. Trial responses were variable, it is likely that commercial responses are the same.	Graziers do use this approach. Provides a visual response. Provides a feeling of doing something.	Little DM response and therefore questionable economics.
Short-term fallow (3 + months)	Greatest disturbance to buffel plants and soil organic matter and therefore biggest release of N. N dynamics in different soils – does it need applied N (fertiliser) to overcome high C:N ratio in litter to stimulate decomposition of organic matter in some situations. Rotation with cropping is a viable option. Provides good opportunity to establish legumes.	No stock in paddock – need to sell the benefits to get producers to take paddock out of production.	Loss of production for a period.

Mitigation Strategy	Constraints / Drivers / Questions		
	Technical	**Social**	**Economic**
Herbicide	DM and pasture quality responses have not been measured – is the response as great but slower than mechanical renovation? Timing more difficult than mechanical renovation as need actively growing grass. N dynamics not understood – may need applied N (fertiliser) to overcome high C:N ratio in litter to stimulate decomposition of organic matter.	Perceived environmental risk of using herbicides to waterways, remnant vegetation and wildlife.	Cheap compared to mechanical renovation.
Legume - General	Long term persistence on low P & S soils. Fertiliser requirements. Seed availability and supply. Reliable establishment. Grazing management for establishment & long term persistence not well defined. Rhizobium establishment and effectiveness for "newer" legumes. N fixation rates and cycling not widely measured. Animal performance from desmanthus not demonstrated. Resistance to selective herbicides. Limited potential for future development of new varieties. Adaptation limits not well understood.	Wide commercial success is lacking. Need demonstration and support to show what is possible and how to do it. Most persistent and productive legume is not necessarily the most promoted or sold.	Comparative productivity between legume options not defined. Comparative costs, returns and reliability of establishment techniques not well measured. Loss of production and therefore cash flow during establishment.
Leucaena	Production decline overtime needs further investigation. P & S requirements long term. Climate and soil constraints in relation to production and economic returns for "new" areas. Production relative to other legumes in SQ not well known or demonstrated.	High production expectations. Proven technology in some environments. High expectations have led to planting on unsuitable soils. Active support network of researchers and producers.	High initial cost, high returns long term where well adapted therefore higher risk from failures. Comparative economics with other legume option not well understood especially in SQ with lower temperature, poorer soils and less summer rain.
Legume - Established with blade plough	Small seeds, big clods. Timing in the season – long time till germination and implications for survival of rhizobia. Establishment success rate uncertain.	Widely used and highly regarded for suckers and scalds. Legume introduction is secondary but this is one of the most widely used approaches to establishment.	Expensive if primarily used for renovation and legume establishment.

Mitigation Strategy	Constraints / Drivers / Questions		
	Technical	**Social**	**Economic**
Legume - Established with short-term fallow (3 + months)	Most reliable commercial establishment technique. Is 3 months enough to store moisture and kill enough soil seed bank to provide legumes a chance to establish?	No stock in paddock – need to sell the benefits to get producers to take paddock out of production.	Opportunity cost of destocking whole paddock during cultivation and pasture establishment.
Legume - Established in 5m cultivated strips with 16m centres.	Proven reliable technique with leucaena. Legume tolerance to Spinnaker? Residual herbicide option to handle more stubble. Time to spread from strips for both legume and rhizobium. Grazing management for legumes in strips.	Not commercially used.	Expensive with the number of cultivations required for Spinnaker to work effectively.
Legume - Established in 5m herbicide strips with 16m centres.	Reliability not demonstrated. Zero till approaches are highly successful in dry land cropping, their use with pasture legume establishment has not been tested.	Not commercially used.	Lower cost approach to establish legumes than cultivated strips, but may have similar reliability.

4.7.1 Limitations of legumes for addressing pasture rundown

Leucaena technology has been extensively researched and developed over many years to the point that it is reliable and effective. Other legume options (e.g. desmanthus, caatinga stylo) for the buffel grass pastures of northern Australia have not had similar levels of development and are relatively speaking un-developed technologies. Shrubby and Caribbean stylos have proven to be effective in monsoonal and coastal regions however the same establishment and management techniques have proven to be in-effective in buffel pastures (Appendix 1). Key constraints of currently available legumes (other than leucaena) for addressing pasture rundown (as identified by producers, seed industry and researchers) included:

- Difficulty in establishment.
- Long-term persistence.
- Adaptation for the variety of soils, climates and sown grass species.
- Amount of nitrogen fixation.
- Establishing and maintaining adequate rhizobium populations.
- Production – the amount of legume dry matter production has varied widely.

Some of the newer legumes need management packages developed if they are to be commercially successful. Desmanthus and caatinga stylo have performed well on clay soils and cool areas in trials, however commercial results have been mixed. Wider adoption of caatinga stylo and desmanthus have been hindered by technical issues such as seed quality, specific rhizobia requirements, reliable establishment, and management practices to promote persistence. Several people in the seed industry suggest that because of these technical issues (especially specific

rhizobia requirements) that they are doomed to fail as legumes for wide scale adoption in northern Australia.

Some of the newer legumes offer potential to extend the range of land types and climates that it is possible to establish productive legume infused sown pastures. Industry faces two possibilities with regards to "newer" legumes for permanent pasture in the buffel regions of northern Australia:

1. The new alternative legumes are not well enough adapted and/or have technical issues that cannot be overcome, or
2. New alternative legumes are well enough adapted but have technical issues that can be overcome.

If these legumes are to be more widely adopted and successful in addressing pasture rundown the issues described above need to be prioritized and addressed.

4.7.1.1 Legume establishment in sown grass pastures

A major constraint to the successful use of legumes in sown grass pastures is the lack of establishment reliability. Although good establishment is recognised as critical to the long term persistence of legumes, many producers don't think they can afford to use more expensive establishment techniques and not graze to allow establishment. A focus on establishment difficulties and negative short term economic returns by producers needs to be balanced with the opportunities of higher production of legume grass pastures demonstrated by research.

Commercially, legumes have not established reliably in sown grass pastures. However most producers are using low-cost and low-reliability establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire or chaining) or severe soil disturbance and a rough seed bed behind a blade plough. In the vernacular of producers, pasture legumes are very seldom "sown", rather they are "chucked out", "hurled out", "woofed out", "spewed out" and "thrown out" of planes or dozers. Small seeded pasture legumes with weak seedlings are unable to complete with established grasses. In the black spear grass zone of central and southern Queensland, surface sowing has been shown to be unreliable (80% failure); it is likely that buffel grass pastures in lower rainfall areas have even higher failure rates (Cook *et al.* 1992; Cook *et al.* 1993b).

Competition from existing vegetation and weeds often limits pasture seedling survival. It is not that competition *per se* that kills seedlings; rather competition from existing vegetation may restrict growth to such an extent that seedlings subsequently die from moisture stress, temperature stress or acute nutrient deficiency. Survival depends on plant size when stress is encountered. Well established pasture grasses with large root systems are clearly better able to cope with nutrient and moisture stress then establishing legume seedlings (Cook *et al.* 1993a; Cook *et al.* 1993b).

In environments characterised by high levels of evapo-transpiration over summer, the amount and distribution of rainfall following sowing have a major influence on pasture establishment. Survival and growth of seedlings is also severely influenced by competition from existing pasture plants and weeds. Fallowing, sowing and weed control methods similar to those used in dry land cropping which control plant competition and facilitate soil moisture storage partially reduce the effects of variable rainfall on pasture establishment (Cook *et al.* 1993a; Cook *et al.* 1993b). Only when establishing leucaena, does industry routinely use "cropping methods" for establishment. The willingness to used improved agronomy when establishing leucaena probably reflects it being a

mature technology and the perception that it's persistence and productivity warrant the additional effort and cost.

In addition to competition for moisture and nutrients described above, buffel grass has also been shown to release allelopathic chemicals that reduce germination and seedling growth of some plants including a species of desmanthus (Cheam 1984a; b; c; Nurdin and Fulbright 1990). Buffel's allelopathic characteristics may impact upon legume establishment and warrant further investigation.

Table 23: Indicative time periods for establishment of legumes with grass pastures. Animal response refers to the time period before dietary quality is improved relative to grass only pastures. Grass response refers to the time period before biological N fixation by the legumes contributes to increased N availability relative to grass only pastures.

Technique	Animal response (Yrs)	Grass response (Yrs)	Reliability	Cost assumptions	Comments
Full cultivation	2	5	High	2 offset discs, 2 chisel plough whole area	Proven reliable establishment if good weed control and stored moisture.
5m cultivated strips, 11 m grass (16m centres) with high input	1 - 2	7	High	2 offset discs, 2 chisel plough, 2 roundup, 1 spinnaker to 5m strip	Proven reliable technique with leucaena. Legume recruitment allows wider rows. Spinnaker provides good weed control.
5m cultivated strips, 11 m grass (16m centres) with moderate input	2 - 3	7	Medium – High	2 offset discs, 2 roundup, 1 spinnaker to 5m strip	Less cultivation and greater use of herbicides may result in more stubble cover and less effective Spinnaker treatment.
5m herbicide strips, 11 m grass (16m centres) with low input	3 - 4	8 – 10	Medium – High	3 roundups (2 to kill grass, one @ plant)	Zero till approach to storing soil moisture. Timeliness required for herbicide treatment as grass must be actively growing.
5m herbicide strips, 11 m grass (16m centres) with very low input	7 - 10	15	Medium	1 Roundup @ plant	Approximates a "band seeding" approach. Does not involve storing sub-soil moisture and is therefore less reliable then treatments above especially in drier areas or years.
5% of area fully cultivated and fenced	Very slow	> 25	High in small area Low in rest of paddock	2 offset, 2 chisel, 1 spinnaker	Rate of spread of legume critical to long term success. Allows observation of legume productivity potential.
Broadcast after minimal or no disturbance (e.g. fire)	Only successful in some years	Only successful in some years	Very low	Broadcast from plane or ground rig.	Relies on follow up rain without excessive grass competition. If applied each year would eventually get the right conditions. Very un-reliable in buffel grass regions.
Seed in molasses	Very slow	> 25	Very Low	Seed and molasses.	Requires long term use to allow sufficient seed to be spread in the paddock.

The reliability and length of time it takes for legume/grass pastures to reach full production in turn affects economic returns. Indicative time periods to reach full production in terms of feed quality for the grazing animal and N fixation to supply N to the companion grasses are described in Table 23.

Due to their ability to biologically fix atmospheric N, legumes have a competitive advantage over grasses when N availability limits grass growth. Cultivation during or preceding sowing promotes the breakdown of organic matter and release of N, especially on fertile soils, which competitively favours grasses over legumes. Minimal disturbance of the soil through using zero till technique for sowing to avoid mineralising N may competitively favour establishing legume seeds through reducing grass and weed growth (Cook *et al.* 1993b).

4.7.1.2 Legume persistence

Even where legumes have established, few species have persisted long term. Plant nutrition is likely to be contributing to poor commercial performance on poorer soils and old cultivations as there is very limited use of fertilizer by graziers in northern Australia. Legumes have higher requirements for P than grasses and P availability declines as pastures age which may limit legume persistence (Figure 5).

Grazing management (timing and intensity) to promote legume content has been shown to be critical for legumes. Generally the industry in northern Australia has relied on grazing tolerant legumes such as stylos rather than adjusting management to promote legume content. Adoption of more intensive grazing management systems has increased in recent times and management has been adjusted for leucaena/grass pastures. In the future there may be greater adoption of grazing systems that promote higher legume content in legume/grass pastures.

4.7.1.3 Legume adaptation

A large number of legume species have been released for commercial use in northern Australia which are adapted to a wide range of soils and environments. More than 70 tropical legume cultivars have been officially released by government agencies in Australia, although only a relatively small number (<10) have made a significant impact on the pastoral industry (Shelton *et al.* 2005). Industry reviews have concluded that for most areas which are not constrained by low rainfall (e.g. Mitchell grass region) (Quirk 2011; Walker *et al.* 1997):

- There is an adequate range of grasses and legumes available and therefore no high priority area for new cultivar development,
- There is decreasing likelihood of finding plants that are better than those either already released or already under evaluation.
- However there needs to be further work on solving technical issues with some of the more recently released legumes.

Producer's experiences in southern and central Queensland with commercially available legumes is summarised in Appendix 1. Producers and seed industry surveyed during this project identified gaps in commercially-proven, widely-adapted legumes for different soils or environments:

- For central Queensland - Stylos and Wynn Cassia have performed on light textured (loams and sands) soils. There has been a gap in hardy legumes for clay soils. The only widely proven, persistent legume on clay soils is leucaena but it is not suitable for all soils or enterprises and is recognised as a weed in some situations. Butterfly pea and burgundy bean are considered to perform well as short term pastures.

- Southern Queensland – Medics are widely spread on many land types but rely on winter rain in years without too much grass cover. There are no widely planted, commercially proven, summer legumes for any land types. Southern Queensland is particularly challenging as it is cool with a short growing season for tropical legumes while winter rainfall and temperatures in spring is marginal for medics.

Caatinga stylo, desmanthus and leucaena may fill a large part of the gaps identified above, however they have not consistently performed well commercially. Many of the failures have likely been due to poor initial establishment, however in other instances they have either not persisted, spread or produced. There remain unresolved technical issues to ensure these newer legumes fill the gap in legume adaptation for clay soils and southern areas. Unless caatinga stylo and desmanthus prove commercially successful, there remains a gap in adapted legumes for clay soils in the sub-tropics.

4.7.1.4 Nitrogen fixation

The amount of N fixed is the main impact legumes have on the productivity of companion grasses. N fixation is influenced by several factors as described in Section 4.4.3. The benefit that N-fixing legumes provide to companion grasses needs to be put into perspective as they seldom fix enough N to completely prevent pasture rundown. Graziers therefore need to have realistic expectations of legume production in their environment when assessing the success of legume augmentation on sown grass pastures.

4.7.1.5 Rhizobium establishment

Introducing rhizobia with pasture legumes in the tropics is particularly challenging due to their generally small seed size and associated need for shallow or surface sowing on hot soils during summer. Improved methods of establishing and maintaining rhizobium populations are required especially for summer growing legumes with specific requirements. Improved strains of rhizobia may be required, for example additional strains of rhizobia for caatinga stylo have proven more effective than the commercial strain in pot trials but require field testing (Date 2010). Alternatively legumes with promiscuous characteristics that can effectively use native rhizobia are required.

4.7.1.6 Production

The amount of legume dry matter production measured or observed has varied widely with good bulk in some situations and not others. Inadequate soil fertility, especially phosphorus is likely to have caused poor legume growth in many situations. Successful inoculation of legumes with appropriate stains of rhizobia are required for high levels of production (Peoples *et al.* 1995) which may explain some of the variability in commercial experience with caatinga stylo and desmanthus. In other situations the reason for poor performance is not known.

4.8 Research, development and extension needs identified during consultation

Research, Development and Extension (R,D&E) needs for addressing pasture productivity decline in grass pastures were identified from consultation with industry (graziers, researchers and pasture seed industry), review of literature and modelling (spatial, pasture production and economics). The consistent message from those consulted is there are a number of issues that need addressing, however there was not a clear consensus of the highest priorities.

4.8.1 Improved understanding of the impact of productivity decline.

A greater understanding and quantification of pasture productivity decline across environments and management strategies is required by industry. There is also a need to improve the packaging and delivery of information to pasture managers.

Pasture productivity decline has been intensively studied in limited locations; there has been little quantification across a range of environments. Gaps in knowledge include:

- Effect of rainfall seasonality. Does pasture rundown, especially in buffel grass pastures, occur to the same extent in seasonally dry, monsoonal areas as in central and southern Queensland.
- Effect of rainfall quantity. Does pasture rundown occur to the same extent in western Queensland as it does in southern and central areas.
- Quantify productivity differences across locations and management strategies.

4.8.2 Develop sown pasture management packages and extension mechanisms

There is a continuing need to package and extend information on the management of sown pastures. Specifically, graziers and the seed industry called for:

- An overall extension program for improving sown pasture management.
- A coordinated extension program for understanding and managing pasture rundown, covering topics such as soil health, soil nutrients, pasture quality change, mitigation options, economics.
- Specific management packages for important or promising grasses and legumes. Examples include updating the buffel grass book, management packages for shrubby, Caribbean and caatinga stylos, desmanthus, medics under-sown with tropical grasses,
- Demonstration of newer grass and legume varieties.
- Demonstration of mitigation strategies.

4.8.3 Legumes

Legumes were seen as the best option for improving the productivity of rundown grass pastures by most people consulted during the project. However the adoption of legumes in sown grass pastures has not been overwhelming either in Australia or internationally (Shelton *et al.* 2005). Constraints to greater adoption of legume/grass pasture remain including unresolved technical issues, poor perceptions about the benefits of legumes in pastures, lack of sustained extension programs and seed supply issues (Appendices 1 and 2).

4.8.4 Establishment of legumes

Despite the poor results that are achieved, the vast majority of legume sowings continue to be via broadcasting on the soil surface with little or no seed bed preparation. There is a need for research to resolve some technical issues of establishing legumes into buffel grass pastures. There is an overwhelming need to extend what is already known. R,D&E needs include:

- Concerted extension effort to improve the reliability of pasture establishment using existing techniques. This may include demonstration sites and to ensure that workshops and extension materials provide information on establishment.

- Develop reliable and cost effective establishment techniques when planting into buffel grass pastures. This will include testing the herbicide tolerances, seed bed requirements and impact of allelopathy on important legume varieties.
- Seed technology for improved establishment. Seed companies have almost universally adopted seed coats, while many graziers and researchers express doubts as to the usefulness of the technology. It is likely that different seed preparations will be better suited under different conditions.
- Seed supply. Seed of several cultivars of legumes seem to be regularly in limited supply. There seems to be market failure between what is supplied by the seed industry and what is required by graziers which is constraining the use of several promising varieties of legumes.

4.8.5 Rhizobia establishment and survival

Rhizobia survival is unreliable, particularly with small seeded summer growing legumes sown on the surface of soils at high temperatures. Rhizobium status of existing plantings of newer legumes with specific requirements needs to be tested due to the impact on the effectiveness of establishment, persistence and productivity. Effectiveness of different inoculation strategies needs to be tested.

4.8.6 Legume adaptation

R,D&E needs for adaptation involve both improving the mix of species and varieties available to industry as well as gaining a better understanding of the limits of adaptation of the current species and varieties. The ecological limits for many species and varieties is still being “discovered” as they succeed or fail in commercial plantings across a range of climates and soils. There is a need to understand the ecological limits for new varieties as well as likely changes in geographic limits due to climate change.

4.8.7 Comparative productivity of legumes

There is very little comparative data on the relative productivity between different legume/grass pastures between environments. For example, leucaena is considered highly productive, however it is generally established on good soils with good agronomy which is then compared to other legumes on poorer soils where seed is simply thrown on the soil surface into existing grass pastures. How well would other legumes compare to leucaena if they were given similar treatments especially on soils and climates that are sub-optimal for leucaena?

4.8.8 Impacts of grazing management on legumes

A greater understanding of the impact and role grazing management has in maintaining legumes in pasture. Grazing management strategies can influence pasture composition through the relative grazing tolerances and palatabilities of the plants present in the pasture. Grazing management of grass/legume pastures requires a balance between maintaining high legume content for N fixation and feed quality while maintaining grass content for carryover feed and protection from erosion.

4.8.9 Ecology of buffel and adaptability of alternative grasses

Buffel grass is the most important tropically-adapted pasture grass in Australia. Better understanding of its ecology and productivity in relation to root structure, lignin content, nutrient turnover, allelopathy and infiltration characteristics may allow more informed decision making. There are gaps in knowledge that would allow buffel grass productivity to be modelled. The parameters used to

populate the GRASP model rely on only 9 calibration sites, the majority of which were located on the Brigalow Research Station (J. Owens *pers. comm*.), consequently the reliability of modelled estimates could be significantly improved.

There are several other species of sown grass pastures that have been released in Australia that may be better adapted to the soils and climates where buffel is currently the dominant species planted. Anecdotally there is some evidence that other species may be more persistent and productive than buffel under low N availability conditions. The limits of adaptation and persistence across environments is still to be determined for several species. Climate change may influence the geographic limits of adaptation.

4.8.10 Nutrition of pastures

Plant nutrition has a significant impact on pasture productivity, however there has been a reluctance to use fertilisers in tropical pastures in northern Australia. Soil fertility has a large impact on legume productivity, N fixation and subsequent N supply to the companion grass. A better understanding of fertiliser responses of grasses and legumes is required to determine production potentials, soil adaptation and nutrient requirements.

N fixation rates of legume options in different environments and the subsequent impact on pasture productivity is not well understood. Legume species, environment, soil fertility, rhizobium status and effect of fertiliser are factors that need to be investigated.

4.8.11 Impact of renovation strategies

There are a range of renovation options available for mitigating the impact of pasture productivity decline. The impact of these options on pasture and animal performance need to be quantified across a range of environments. The impact on nitrogen and water dynamics has been measured for some mitigation strategies but not others. Quantification of the results from mitigation treatments would allow more informed economic analysis and decision making.

4.9 Research, development & extension priorities

From consulting with industry (graziers, seed industry and researchers), scientific literature and economic analysis it has been confirmed and quantified that:

- The highest priority districts for industry investment are the extensive areas of buffel grass pastures in southern and central Queensland.
- Legumes are the most promising mitigation option for large areas of buffel grass pastures.
- While short term fallows provide economic returns in higher production buffel pastures, it has been well studied and provides lower economic returns than legumes.
- Returns from mechanical renovation are enhanced if combined with establishment of legumes. R,D&E priorities therefore focus on improving results from legumes in buffel grass pastures.
- Some mitigation strategies used within the industry do not provide positive economic returns.

R,D&E priorities therefore focus on improving results from legumes in buffel grass pastures.

The review identified the following high priority R,D&E and pasture seed supply topics:

1. Improved use of existing mitigation technologies.
2. Reliable establishment of legumes into buffel grass pastures.
3. Improving the productivity of legume grass pastures.
4. Better understanding of adaptation of commercially available legumes.
5. Reliability of legume seed supply.
6. Improved understanding of buffel grass physiology

4.9.1 Improved use of existing mitigation technologies

Good agronomy and current technology can improve the production and economic returns from rundown buffel grass pastures. Current legume technologies (e.g. leucaena, stylos) are capable of re-gaining 30-50% of the production losses from rundown. Poor agronomy and variable performance from legumes has resulted in a widely held perception that they are risky and unreliable. Significant investment in D&E is required for widespread improvement in commercial results from legume augmentation technology in buffel grass pastures.

Key areas for investment in D&E within an extension framework are:

- Building pasture manager's understanding of sown pasture production, the process of pasture rundown and mitigation options.
- Assess, compare and demonstrate the commercial impacts of mitigation strategies on pasture production, animal performance and profitability. This would include the use of N fertiliser to demonstrate how much production has been lost.
- Develop management packages for the best adapted emerging legumes to support reliable establishment, production and persistence. These include desmanthus, caatinga stylo, medics, shrubby stylo and Caribbean stylo with buffel and other sown tropical grasses.

4.9.2 Reliable establishment of legumes

Establishment of legumes into buffel grass pastures is widely perceived to be risky and un-reliable. Reliable and cost effective techniques for legume augmentation of buffel grass pastures need to be developed to change this paradigm. Agronomic practices developed for cropping and leucaena establishment need to be assessed for other legumes. Key issues to consider include:

- Herbicide tolerances.
- Seedbed and planting requirements including degree of soil moisture storage.
- Impacts of agronomy practices on legume establishment. For example impact of cultivated or herbicide strips on soil moisture storage and legume establishment e.g. early growth, seed set and rate of spread from strips.
- Nitrogen dynamics, pasture production and animal production.
- Impact of allelopathic effects of buffel grass on important legume species.
- Comparison of rhizobia introduction methods in difficult environments (i.e. shallow sown in high temperatures). This would involve comparing traditional peat culture applied to seed pre-plant to pellets, seed coats, water injection and freeze dried products.
- Role of different seed treatments in enhancing establishment. For example, soft seed for fallowed seedbeds, hard seed for less prepared seedbeds, seed coatings and other treatments effects on establishment.

4.9.3 Improved production from legumes

Generally pasture legumes are not performing to their potential on commercial properties (Radrizzani *et al.* 2007; Shelton *et al.* 2005). With good agronomy it is likely that the productivity of legumes could be improved. High dry matter production by legumes is critical if they are to fix adequate amounts of N to mitigate pasture rundown. Agronomy and grazing management practices need to be assessed for their impact on tropically adapted legumes. Issues to consider include:

- Nutrition. Adaptation and response to nutrient levels (especially P) for commercially used legumes needs to be assessed. If legumes are to fix moderate levels of N it is critical to understand the role of fertiliser in promoting the growth (and N fixation) of legumes.
- Rhizobia for legumes with specific requirements. A pilot study to assess the effectiveness of rhizobia populations in commercial plantings and effectiveness of inoculation techniques (described in section 4.9.2). For example, anecdotally there is wide variation in productivity of caatinga stylo pastures, this may be related to effective nodulation.
- Quantifying N fixation between legumes and across environments. Rates of N accrual in legume grass pastures have not been well studied in buffel grass pastures.
- Grazing management can be used to influence legume content in pastures. Grazing management is an important part of a management package for the successful use of legumes. However, given the poor success with establishment of legumes it is logical to initially focus on the agronomy questions outlined above.

4.9.4 Adaptation of commercially available legumes

The adaptation limit of many legumes used in buffel grass pasture is not adequately described. The adaptation of leucaena in central Queensland is well known and supported through workshops, extension materials and industry groups (especially The Leucaena Network). However this is not the case for the emerging legumes (e.g. caatinga stylo) or for existing legumes used in “new” areas (e.g. leucaena in southern Queensland).

Research sites to assess the comparative adaptation and productivity of legumes across soil types and environments in southern and central Queensland would improve the reliability of advice on legume selection given to graziers and support the extension efforts described in section 4.9.1. These sites would also provide an opportunity to consider nutrition of legumes to improve productivity.

4.9.5 Legume seed supply

Legumes have been identified as the best option for mitigating pasture rundown. However, seed of several of the most promising legumes is often in short supply (e.g. caatinga stylo, desmanthus, hard seeded and early maturing medics) and seed with different treatments to match the sowing environment (e.g. bare seed) are often unavailable. The industry as a whole needs to address this “market failure” if large areas of legumes are to be established to overcome pasture rundown and sustain productivity into the future. If currently available legume varieties prove successful, demand will provide economic incentive to increase seed supply in the longer term.

It is essential that the seed industry is involved and collaborates in R,D&E initiatives. However due to the small size of the Australia pasture seed market they have indicated they are unlikely to invest in a significant way in R,D&E for varieties specifically for the domestic market. There may be a role

for MLA and Government to proactively stimulate the legume augmentation market and seed supply in collaboration with the pasture seed industry for the benefit of the grazing industries.

4.9.6 Buffel grass physiology

Buffel grass is the most economically important sown pasture species in northern Australia (Chudleigh and Bramwell 1996), however its physiology is not as well understood as many crop species. More sites with detailed agronomic information on buffel grass are required to adequately describe and model its performance across environments and levels of rundown. This is critical to report the benefits and impacts on buffel grass pastures and the contribution to the northern Australian beef economy of RD&E activities. Improved understanding of the geographic extent of buffel grass pastures and their current condition would be an initial step with the spatial analysis from this review providing a framework for future mapping.

5 Success in Achieving Objectives

The review provides a contemporary overview of the causes, extent and impacts of productivity decline in sown grass pastures. The review adds significant new knowledge about pasture rundown in sown pastures in Queensland. Specific areas where this review captured new information were:

- Graziers observations and experiences with managing pasture rundown.
- Current outlook and response of the pasture seed industry to pasture rundown.
- Spatial extent of buffel grass pastures in Queensland.
- Economic analysis of mitigation options for improving productivity of rundown buffel grass pastures.
- R,D&E priorities to assist industry in mitigating the impacts of pasture productivity decline.

This project has addressed all of its objectives. An overview of the work completed to address the objectives is provided below:

1. A concise overview of the primary causes, extent and economic impacts of sown pasture 'rundown'.
The primary causes, extent and impact on grazing animal production of pasture rundown were reviewed in the literature and are outlined in section 1 of this report. Comparing rundown pasture productivity to initial production does not provide a realistic estimate of the economic cost of rundown. After clearing, initial pasture production reflects the nutrients released from native vegetation and soil organic matter that have accumulated over millennia. It is not realistic to maintain the high levels of available N in the soil that promote the high levels of pasture growth. However the review did estimate the potential returns from adoption of mitigation strategies on all suitable lands compared to current management practices which provides an estimate of the increase in value of production that could be achieved by addressing pasture rundown. The difference between current and potential returns provides the "best" estimate of the effective cost to industry of not addressing pasture rundown.

2. A review and evaluation of the mode-of-action and cost-effectiveness of options for abating the impact of sown pasture 'rundown', including those currently practiced and any others that have potential value.
Extensive industry consultation (graziers, seed industry and research agencies) captured what mitigation strategies have been used and what results have been achieved. Review of experimental results and a panel of experts approach were used to estimate the likely impacts of mitigation strategies. Economic analysis assessed the cost effectiveness of mitigation strategies using Net Present Values and Benefit Cost ratios and demonstrated that legume augmentation provides the best potential returns for addressing pasture rundown.

3. An assessment of the technical and other (e.g. adoption) issues that constrain the cost-effective abatement of sown pasture 'rundown', and the likelihood of overcoming these constraints through additional research, development and extension.
Technical, social and economic constraints, drivers and un-answered questions regarding mitigation strategies were considered. An extensive review of R,D&E issues considered findings from consultation with industry, economic analysis and literature reviews. Although legumes have demonstrated their potential to improve productivity in trials, improved agronomy and grazing management practices need to be developed and adopted for them to reach their potential.

4. The priority areas for future research, including the likely economic benefit to industry of pursuing these.

R,D&E needs were collated during the consultation phase of the project. The R,D&E needs were evaluated and prioritised considering likely economic benefits to industry and the ability to complete the required work. The highest priority is to increase the adoption of good agronomy and grazing management for improved legume productivity in sown grass pastures. There is a need for both research and extension if legumes are to be productive over large areas of buffel grass pastures in Queensland.

6 Impact on Meat and Livestock Industry

It is clear that pasture productivity decline is significantly reducing production and economic performance of the meat and livestock industries. Sown pasture grasses initially flourish from the release of nutrients and stored water after clearing and pasture establishment. Productivity of sown grass subsequently declines by 50–60% both in terms of pasture production and animal performance (Myers and Robbins 1991; Radford *et al.* 2007; Robbins *et al.* 1987; Robbins *et al.* 1986; Rudder *et al.* 1982). This review concludes that 30-50% of the loss can be regained through the use of legumes.

To estimate the impact of pasture rundown and mitigation strategies on the meat and livestock industry this review undertook:

1. Spatial analysis to estimate the area sown to buffel grass and area suited to mitigation strategies.
2. Economic analysis to extrapolate the property scale economics to the industry scale.

6.1 Spatial Analysis

The review has developed a methodology for producing more accurate maps of distribution of buffel grass pastures and potential area suited to mitigation strategies than previous methods (Lawson *et al.* 2004; Weston *et al.* 1984). However the spatial analysis is a first draft estimate which has not been verified or ground truthed. The spatial analysis provides a framework that can be updated and reviewed as regional ecosystem mapping is updated. A number of challenges were encountered which were unable to be resolved during the review. Issues to be resolved include:

- Grazing land type descriptions for the whole of the state (currently the Darling Downs has not been described).
- Mapping of grazing land type descriptions using regional ecosystem mapping. There are discrepancies between how grazing land types have been matched to regional ecosystems (RE's) in different regions of the state. Grazing land types have not been mapped for several regions which remain "white" on the map. There is missing spatial data for areas of western and northern Queensland.
- The spatial analysis provide a basis for state-wide economic analysis. When the spatial analysis is updated, the economic analysis can also be updated.

Updating the spatial analysis when land type maps become available for the whole of the state is recommended. Updated mapping should involve ground truthing to verify the accuracy of the spatial analysis.

Despite the limitations with the spatial data it is the best information that is currently available and was used for the purpose of state-wide economic analysis.

6.1.1 Buffel grass pastures

The distribution of buffel grass pastures in Queensland is shown in Figure 15. The terms "dominant", "common" and "isolated/absent" were used to describe buffel grass pasture for the purpose of mapping its distribution. The definitions of the pasture density terms and their estimated areas are:

- Dominant - Buffel normally occurs on these land types and is expected to be dominant in the pasture sward; 5.8M ha. The main area of buffel grass dominant pastures are the brigalow and gidgee land types.
- Common - Buffel occurs widely on these land types (e.g. 20% - 80% of land area) and where it occurs it is a large percentage of the pasture sward; 25.9M ha. Buffel grass is common on a large number of land types which cover large areas of Queensland. However a significant percentage of this area is not buffel grass pastures.
- Isolated/Absent - Buffel is seldom on these land types but may occur sporadically and is unlikely to comprise a large percentage of the pasture sward.

The buffel map approximates the main areas of sown pastures in northern Australia as:

- Buffel grass is the most widely adapted and planted sown grass species in northern Australia (Walker *et al.* 1997; Walker and Weston 1990; Weston *et al.* 1984). Buffel grass has been planted in more than 75% of sown grass pastures.
- Buffel has spread onto land types where it is adapted (Researchers workshop).
- Queensland contains the bulk of land suitable for sown pastures in northern Australia. Queensland has a sown pasture potential of 41M ha with the remainder of northern Australia having 6M ha of land suitable for sown pastures (Walker *et al.* 1997; Walker and Weston 1990).

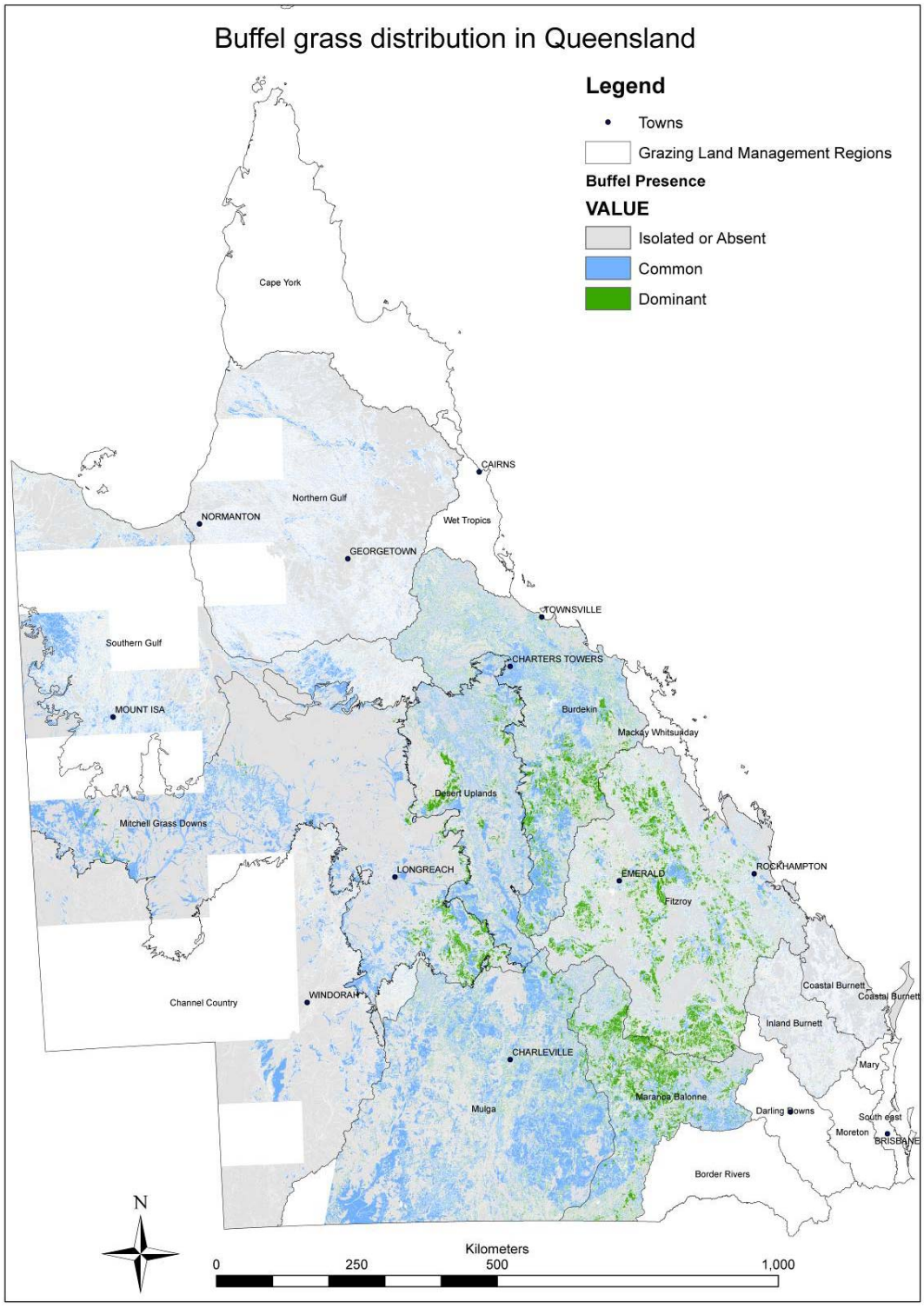

Figure 15: Buffel grass distribution in Queensland.

6.1.2 Potential area suited to mitigation strategies

The areas considered technically and economically feasible for mitigation strategies were calculated (Table 24). For legumes, only establishment in cultivated strips was considered. The mitigation strategies and the case study location where they were applied are:

- Legume Cultivated Strips: For the case study locations all fertility levels provided positive economic returns. Legumes established in cultivated strips were considered suitable for all grazing land management (GLM) regions (Whish 2010) except for the mulga, Mitchell grass downs and channel country which are considered to have no suited sown legumes.
- Leucaena: High and medium fertility soils at Moura, Clermont and Glenmorgan. That is the GLM regions of Fitzroy, Burdekin, Maranoa/Balonne and Inland Burnett.
- Cultivated Fallow: This strategy was assumed to be most relevant to the grain growing region of Queensland and was therefore applied to the Moura, Glenmorgan and Clermont case studies. It was applied to the Fitzroy, Burdekin, Maranoa/Balonne and Inland Burnett GLM regions. Cultivated fallow was applied only to the high and medium fertility land types as economic returns were negative on low fertility soils.
- Blade Plough: Moura high and medium fertility, Clermont high fertility and Glenmorgan high fertility. Economic returns on other land type fertility levels and locations were negative.

Table 24: Area of buffel grass pasture (mapped as "Dominant" or "Common") that is technically and economically feasible for mitigation options in Queensland.

Mitigation	Current Area ('000 ha)	Potential Area ('000 ha)
Legume – Cultivated Strip	1,845	29,846
Leucaena	200	8,421
Cultivated fallow	58	8,563
Blade plough	50	4,925

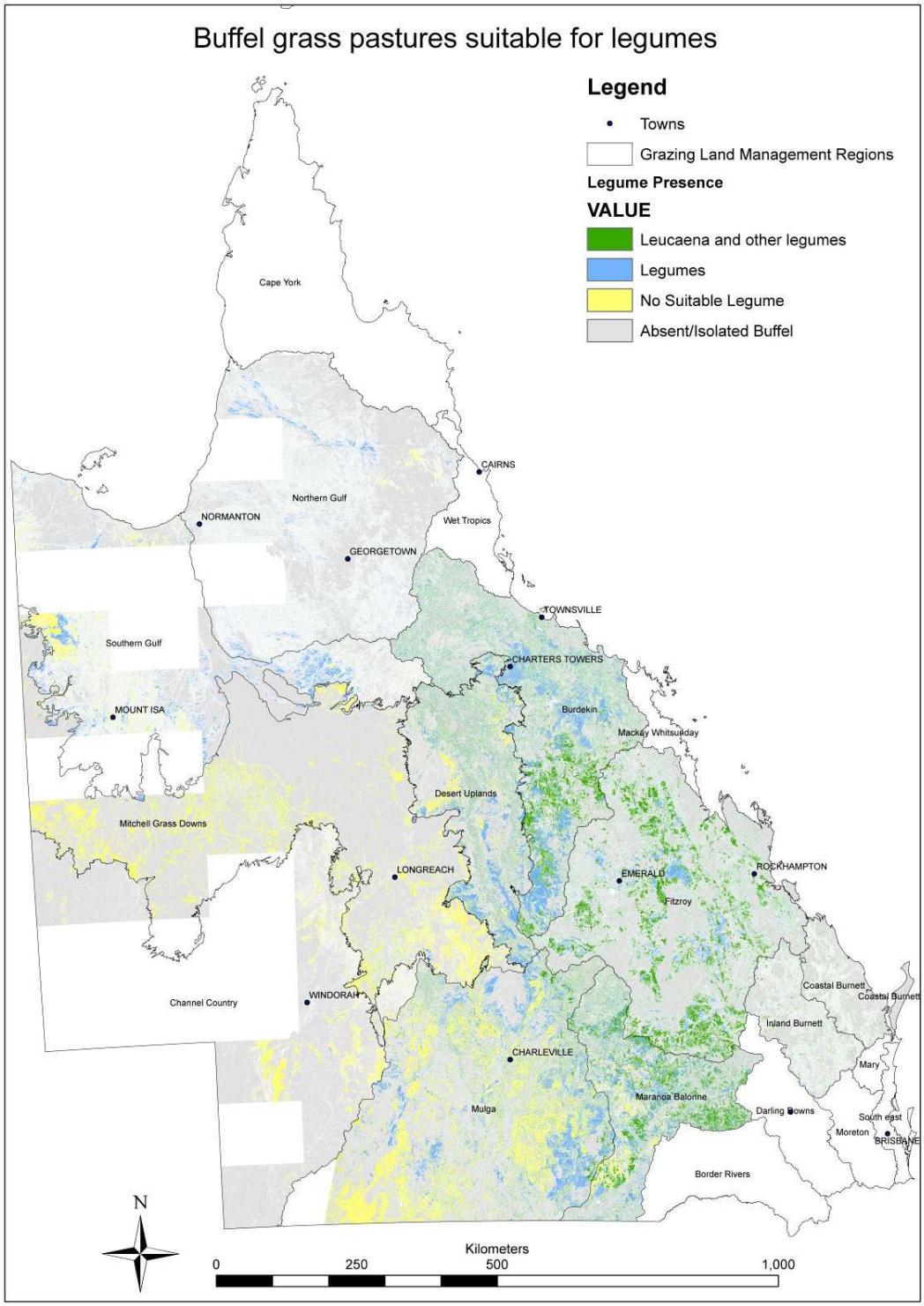

Figure 16: Buffel grass pastures suitable for legumes in Queensland.

6.1.3 Current area treated.

Area treated by mitigation strategies were based on expert opinion and estimated as follows:

- Legumes – 10% of buffel pastures they are suited to. It has been estimated that 30% of pasture sowings include legumes, however in buffel sowings it is likely to be lower (Walker *et al.* 1997; Walker and Weston 1990). In addition, graziers have reported that legumes have not persisted with buffel.
- Leucaena – 200,000 ha planted (The Leucaena Network *pers. comm*.). This represents approximately 2.5% of the land that is considered suitable for leucaena (Table 24).
- Cultivated fallow - 1% of high and medium fertility soils with buffel grass pastures in the grain growing regions, that is the Fitzroy and Maranoa/Balonne. 'Total Adoption' areas also included the Burdekin high and medium fertility soils as the Clermont case study showed positive economic returns.
- Blade plough – 1% of land it is suited to. Blade ploughing has been widely used for regrowth control, however as a mitigation strategy it assumes re-treatment every 10 years, which is not practiced widely by graziers.

These assumptions were applied to the GLM regions described in section 6.1.2. Areas estimated to currently be treated by the mitigation strategies are shown in Table 24.

6.2 Economic impact

The net increase in land area under mitigation and the NPV after 10 and 30 years for the modelled mitigation strategies, at various proportional increases in adoption, are shown in Table 25, 26 and 27.

For example; currently legumes are assumed to have established on 10% of the land they are suited to (approximately 1.8 million ha). A 100% increase in adoption would equate to a doubling in the area established with legumes resulting in legumes being established on 20% of the land they are suited to, which is a net increase of approximately 1.8M ha and a total area of 3.6 M ha.

Table 25: Nett increase in land area from current levels of adoption and total area suited for mitigation strategies.

Increase in area under mitigation (ha)	20%	40%	60%	100%	Total Adoption
Legume CS	369,010	738,019	1,107,029	1,845,049	29,845,957
Leucaena	40,000	80,000	120,000	200,000	8,420,998
Cultivated Fallow	11,609	23,219	34,828	58,047	8,562,951
Blade Plough	9,950	19,899	29,849	49,748	4,925,088

Table 26: NPV ten years after implementation for different levels of adoption of four mitigation options for addressing pasture rundown.

NPV 10 years	20%	40%	60%	100%	Total Adoption
Legume CS	$64,823,614	$129,647,227	$194,470,841	$324,118,068	$3,055,507,965
Cultivated Fallow	$1,589,822	$3,179,645	$4,769,467	$7,949,112	$1,009,200,693
Blade Plough	$731,108	$1,462,215	$2,193,323	$3,655,538	$361,898,291
Leucaena	$46,723,401	$93,446,802	$140,170,203	$233,617,005	$9,201,184,698

Table 27: NPV thirty years after implementation for different levels of adoption of four mitigation options for addressing pasture rundown.

NPV 30 years	20%	40%	60%	100%	Total Adoption
Legume CS	$207,645,521	$415,291,042	$622,936,563	$1,038,227,605	$11,599,126,823
Cultivated Fallow	$2,808,848	$5,617,696	$8,426,544	$14,044,240	$1,783,023,788
Blade Plough	$1,291,698	$2,583,396	$3,875,093	$6,458,489	$639,390,427
Leucaena	$107,119,526	$214,239,052	$321,358,579	$535,597,631	$21,241,957,384

From Tables 24 and 25 it can be seen that the potential farm gate value of addressing pasture rundown with existing mitigation strategies is significant. A doubling of the area with effective legume content would result in an increase in NPV of $324M over the next 10 years and a value of over $1B over 30 years. The 20, 40, 60 and 100% increases over current levels of adoption provide a realistic estimate of the likely benefits to industry from a coordinated R,D&E program to address pasture productivity decline over the medium term.

6.2.1 Economic cost of rundown

Comparing rundown pasture to initial production does not provide a realistic estimate of the economic cost of rundown. After clearing, initial pasture production reflects the nutrients released from native vegetation and soil organic matter that have accumulated over thousands of years. It is not realistic to maintain the high levels of available N in the soil that promote the high levels of pasture growth. Maintaining buffel production at “initial” levels would incur significant costs that have not been accounted for in the economic analysis. However, it is clear that rundown significantly reduces economic returns. The economic analysis indicates that some mitigation strategies reverse these losses to a significant extent.

The potential returns from adoption of mitigation strategies on all suitable lands compared to current management provides an estimate of the total increase in value of production that could be achieved by addressing pasture rundown. The difference between current and potential returns provides the best estimate of the effective cost to industry of not addressing pasture rundown.

If all suitable land was developed to leucaena (high and medium fertility soils in areas considered similar to the 'Moura', 'Glenmorgan' and 'Clermont' case studies) and remaining land established to other legumes the NPV of farm gate production would increase by $9.7B over the next 10 years and $25.6B over 30 years. This is an over estimate of the potential value of production for the following reasons:

- Areas mapped as commonly having buffel pastures (25.9M ha) are not all currently buffel grass pastures. The definition for “common” was that buffel occurs on 20-80% of the land type.
- Not all areas of a land type are used for grazing. For example roads and other reserves are not taken into account.

To provide a more realistic estimate of the costs of pasture productivity decline a 30% discount was applied to the estimates of potential economic returns. Therefore the estimated NPV of production that could be achieved by addressing pasture rundown by the livestock industries over the next 10 years is approximately $6.8B and over 30 years is approximately $17.9B.

From the economic analysis it is clear that increasing the adoption and productivity of legumes (including leucaena) provides significant opportunity to improve the economic returns from buffel grass pastures in Queensland.

7 Conclusions and Recommendations

7.1 Pasture productivity decline

Sown pastures are a successful technology for improving animal production and economic returns in northern Australian grazing industries. The majority of sown pastures have been sown to grasses only (70% of sown pastures) with the dominant species being buffel grass (>75% of plantings) (Walker *et al.* 1997; Walker and Weston 1990). This project has estimated that there are 5.8M ha of buffel grass "dominant" pastures in Queensland, with a further 25.9M ha where buffel grass is "common".

Productivity of grass-only sown pasture is initially very high due to the transient effect of high nutrient and water supply that accumulates subsequent to clearing native vegetation or cropping (on fertile soils). From this initial high production, pasture quality and/or growth declines by 50 – 60% within 5 – 10 years after establishment, which is commonly referred to as pasture rundown (Graham *et al.* 1981; Myers and Robbins 1991; Radford *et al.* 2007; Robbins 1984; Robbins *et al.* 1987; Robbins *et al.* 1986). If stocking rates are held constant, animal performance reduces linearly by 20 – 70% in the first 5 years after establishment (Radford *et al.* 2007; Robbins *et al.* 1987; Rudder *et al.* 1982). Pasture rundown therefore has a significant impact on economic returns for producers.

The decline in productivity of sown grass pastures is due to a reduction in the supply of available N in the soil. For extensive pastures there is no net loss of total soil N, however there is a reduction in the rate at which N is released from organic forms in the soil (Robertson *et al.* 1997). Mitigation options for improving the productivity of sown grass pastures therefore need to either:

- Increase the rate of N cycling. N 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 fertiliser or biological N fixation (i.e. legumes).
- Accept the reduction in pasture productivity and adjust management to maintain animal and enterprise performance.

7.2 Improving production

Mitigation strategies to improve productivity of rundown grass pastures need to be technically and economically feasible. Technical and economic analyses suggest that the options that provide positive economic returns are:

- Legumes in areas receiving > 500mm annual rainfall (approximately) in southern and central Queensland or > 600mm (approximately) in north Queensland.
- Leucaena on high or medium fertility soils receiving approximately 600 - 800mm annual rainfall in southern and central Queensland or > 800mm (approximately) in north Queensland.
- Short term fallows or crop pasture rotations on high or medium fertility soils with >550mm annual rainfall.
- Mechanical renovation (e.g. Blade plough) on more productive buffel pastures, that is high fertility soils in better rainfall regions (>550mm approximately). However blade ploughing is expensive and returns are marginal for renovating pastures and therefore remains primarily a regrowth control strategy.

Legumes can provide long term results with the best returns. Returns from mechanical renovation (cultivated fallow or blade plough) are short lived and economically marginal. Mechanical renovation does however provide an opportunity to establish legumes.

Although legumes provide the best opportunity to increase productivity of rundown grass pastures, commercial results have been mixed. Leucaena is a commercially proven legume that is well accepted and is being widely adopted by graziers. Significant R,D&E combined with many years of commercial trial and error have contributed to reliable establishment and management guidelines for leucaena (Dalzell *et al.* 2006). High production and good economic returns have encouraged leucaena establishment. Other legumes have gained a reputation as being risky and un-reliable in buffel grass pastures (Appendix 1). However the production potentials of many legumes recorded during evaluation trials is much higher than what is generally achieved commercially. There are significant R,D&E opportunities to capture the production potential of such legumes in sown grass pastures.

7.3 R,D&E priorities

Reliable establishment techniques and management guidelines have resulted in leucaena becoming a reliable and productive legume in buffel grass pastures. However, it is not suited to all soils or regions that currently have buffel grass pastures. The development of reliable establishment and management guidelines for the most promising current and emerging pasture legume species has the potential to transform the buffel pastures of northern Australia.

R,D&E opportunities identified during the review to realise the potential of the existing suite of legumes and mitigation strategies were to:

1. Improve the use of existing mitigation technologies. Good agronomy with current legume technologies is capable of regaining 30 – 50% of the production losses from rundown. Investment in D&E would result in improvement in results from legume augmentation in buffel grass pastures. Key targets are:
    a. Improved understanding of pasture rundown and mitigation options by industry.
    b. Assess, compare and demonstrate the impacts of rundown and mitigation strategies on pasture and animal production.
    c. Development of management packages for the best adapted emerging legumes (e.g. caatinga stylo and desmanthus).
2. Improve the establishment of legumes. Most commercial plantings of legumes fail due to poor agronomy. Establishment techniques similar to those used in cropping and leucaena plantings need to be trialled and developed for other promising legumes. Examples of R&D questions include:
    a. Herbicide tolerances
    b. Seedbed and soil moisture storage requirements.
    c. Rhizobia establishment in difficult environments (trial use of newer techniques such as pellets)
    d. Seed treatments to enhance establishment.
3. Improved production from legumes. With better agronomy and grazing management it is likely that the productivity of legumes could be improved. R&D issues include:
    a. Nutrition and fertiliser use, especially phosphorus.
    b. Quantifying N fixation between legumes and across environments.

   c. Grazing management to improve legume content and production.
4. Compare legume adaptation and production in different environments. This would involve research and demonstration sites to assess the adaptation and productivity of legumes across soil types and environments in buffel grass pastures.
5. Improve the understanding of buffel grass physiology. While important, buffel physiology was considered a lower priority in addressing pasture productivity decline than the previous topics. More sites with detailed agronomic information on buffel grass are required to adequately describe and model its performance across environments and levels of rundown. Improved understanding of the geographic extent of buffel grass pastures and their current condition would be an initial step, with the spatial analysis from this review providing a framework for future mapping.

Legume seed supply is a policy issue that grazing industries need to address. Although legumes offer the greatest potential to improve productivity, seed of several of the most promising legumes is often in short supply. The industry as a whole needs to address seed supply constraints in the short term, until demand for seed stimulates investment in seed production, if large areas of legumes are to be gradually established.

7.4 Value to industry

Buffel grass pastures cover a large percentage of the most productive grazing lands in northern Australia. Spatial analysis estimated there are 5.8M ha of buffel grass dominated pastures in Queensland with an additional 25.9M ha where buffel pastures commonly occur. Improving the productivity of buffel grass pastures would dramatically increase animal production for the grazing industries. The farm gate cost of rundown to the industry, estimated as the returns foregone by not adopting appropriate mitigation options across all the suitable area of buffel grass pasture, is approximately $17.9B over the next 30 years.

Using currently available legumes with good agronomy and management has the potential to reclaim 30-50% of the loss in production from pasture rundown. A doubling in the area of legume grass pastures (leucaena and other legumes) is estimated to increase the farm gate NPV of production by approximately $550M over a 10 year time period and $1.5B over 30 years.

Commercial results from legume augmentation of buffel grass pastures have been mixed. There are significant opportunities to improve the productivity and economic returns from legumes. Targeted research is required to overcome some technical issues, especially with some of the newer legumes (e.g. caatinga stylo). Extension is required to improve the management of commercial legume grass pastures. Investment in RD&E has the potential to reap large benefits to the industry in increased productivity.

7.5 Recommendations

This report recommends that the grazing industry through MLA and other stakeholders (Government and graziers) invest in targeted R,D&E to mitigate the effects of pasture rundown. Good management of grass/legume pasture has the potential to reduce the impact of pasture productivity decline. The potential economic returns to individual graziers and the industry as a whole are large and provide a persuasive case for significant R,D&E investment. As well as improving the economic sustainability of grazing enterprises, mitigating pasture rundown will also improve environmental

performance of sown grass pastures through improved pasture stability, improved soil health and reduced erosion. Specific recommendations for targeted investment or activities include:

1. Targeted development and extension activities in the short to medium term to improve understanding and adoption of existing pasture rundown mitigation technologies. Significant opportunities exist for industry to improve animal production and economic returns from existing technologies. This may include adapting technologies from other agricultural industries in improving the reliability of legume establishment.
2. Conduct targeted research to improve the:
    a. Establishment of legumes in buffel grass pastures
    b. Productivity of legume grass pastures (e.g. through grazing management and targeted fertiliser use)
    c. Understanding the comparative adaptation and production of legumes in different environments.
3. MLA and Government engage with the pasture seed industry to address constraints on the supply of seed of the most promising pasture legumes.

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9 Appendices

9.1 Appendix 1: Grazier consultation

Buffel grass productivity decline: Grazier observations and opinions

Results of focus group discussions in Queensland

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Cover photo: Buffel grass pastures showing the result of added nitrogen fertilizer. The grass on the left has had urea applied. Photo courtesy S. Cook, Queensland Murray Darling Committee.

Executive summary:

Background:

Buffel grass is the most important sown pasture species in northern Australia. The grazing industries in Queensland are reliant on buffel grass for a large percentage of production. Buffel grass pastures have been established for decades over large areas. The majority of pastures have either been sown as buffel grass only pastures or where buffel was planted with other grasses and legumes most are now buffel grass dominant. These buffel grass dominated pastures are widely recognised by graziers and the broader industry as declining in productivity.

DEEDI and Meat and Livestock Australia (MLA) are currently reviewing productivity decline in buffel grass pastures in consultation with graziers, research agencies and agri-business. During March and April 2010 six focus group meetings were held with graziers in southern and central Queensland to discuss productivity decline in buffel grass pastures as part of this review. Forty one graziers attended meetings in Moura, Rolleston, Clermont, Roma, Nindigully and Wandoan. This report documents the views and opinions of graziers on buffel grass productivity decline.

Productivity decline

Productivity decline in buffel grass pastures was recognised as a major issue for graziers by all groups. All groups reported that decline happened quicker on low fertility and lighter textured soils however some groups thought there was a greater overall decline on more fertile soils. Symptoms of productivity decline were:

- Reduced pasture growth with a reduced carrying capacity estimated to be between 25% and 50%.
- Changes in pasture density with smaller tussocks and / or reduced numbers of tussocks.
- Nutrient deficiency symptoms of yellowing and / or reddening of leaves.
- Reduced animal performance with lower weight gains and increasing difficulty in reaching market specifications.
- Pasture composition changes with more native grasses and increased density of less productive exotic grasses.

Nutrient cycling (especially nitrogen), over grazing, rainfall infiltration and disease were all recognised as contributing to declining pasture production. There were differing views as to the relative importance of these causes.

Mitigation strategies

Most producers who attended the focus group meeting indicated that pasture productivity decline had to be addressed to maintain profitability for their enterprise. Some producers believed it may not be currently economic to renovate pastures, but as productivity declines further it will reach a point that it pays to do something.

The mitigation strategies used by graziers were:

- Mechanical renovation ranging from single cultivations (e.g. chisel ploughs, ripping or blade ploughing) through to short term cropping or crop/pasture rotations. There were mixed reports on the results of renovation depending on the method used, seasons and the reason

for renovation (e.g. scalded areas compared to poor pasture growth). Many participants observed good responses on initial mechanical renovation but rundown occurred more quickly with poorer responses to subsequent renovations. Other producers have renovation cycles where pastures are cultivated every few years. Some producers have paid for the cost of renovation through seed sales alone. Higher production from blade ploughing is recognised in higher land prices.

- Legumes for improved feed quality and nitrogen fixation. These benefits are recognised through improved land prices for leucaena but not for other legumes. Producers reported mixed results from legumes with successes but also many failures. Many producers did not think legumes other than leucaena were a viable option with buffel grass due to its competitiveness despite notable examples to the contrary. Most producers thought legumes were either not widespread or not as widespread as they should be in their district. Key constraints of legumes identified by producers were:
    - Establishment – legumes are difficult to establish in buffel pastures however most producers are using low cost and low reliability establishment techniques (e.g. "chucked out of a plane").
    - Persistence – even when legumes are established few species have persisted long term.
    - Adaptation – Need commercially proven legumes for clay soils in CQ, and summer growing legumes for all land types in SQ
    - Nitrogen fixation – the amount fixed and the effect on companion grasses was questioned by most participants.
    - Production – the amount of dry matter production has varied widely.
- Fertilizer. No one in the groups routinely uses fertilizer on their pastures however several people have tried fertilizer. Most people did not think fertilizer on buffel pastures is economically viable or environmentally sustainable.
- Spraying out of buffel grass has been used or observed by several graziers to provide a response similar to mechanical renovation.
- Fire. Some people were strongly for using fire reporting greener buffel grass and better growth. Other people were strongly against the use of fire suggesting negative responses.
- Other grasses. Decline was observed to occur in all sown grass pastures however it was considered more of a problem with buffel.
- Grazing management was thought to have some impact on rundown.
- Woody vegetation rotation where suckers are allowed to grow before being chained was thought to improve nutrient cycling by some participants.
- Slashing is thought to improve grass growth by some participants.
- Soil biology treatment – compost teas have been tried by a few participants with no visible response.
- Live with rundown and accept lower production. Options under this strategy were buying more land, developing more land, supplementing cattle and reducing stocking rates.

Limitations to addressing productivity decline

Landholders identified a range of limitations to addressing pasture productivity decline on their properties. These included:

- Economics. All mitigation strategies cost money in the short term with returns being considered marginal by some producers.

- Legume un-reliability. Legumes are difficult to establish with buffel. There are gaps in commercially proven legumes for many land types.
- Understanding about causes, costs and options for addressing productivity decline.
- Nutrient export and fertilizer cost especially in anticipation of increasing demand for fertilizer in the future.
- Having options for non-arable as well as arable land.

Future Research Development and Extension

There was a consistent message from the groups that more work was needed however there was no consensus of future RD&E needs. There was recognition that past innovations such as better breeds and land development drove productivity gains, several producers thought that addressing productivity decline in buffel grass pastures is the next big step. RD&E needs were identified across the following key areas:

1. Understanding and monitoring of rundown – graziers wanted more information and research to better understand the processes of rundown and to quantify productivity decline across land types and regions over time.
2. Improving the commercial performance of legumes. Key needs are:
   - More and better adapted legumes
   - Better management of existing legumes species.
   - Reliable establishment techniques especially into existing buffel grass pastures.
   - Seed availability, seed quality and technology that best suits the industry needs.
3. Grasses. The main needs identified were:
   - Better understanding of the ecology of buffel grass in production systems.
   - Adaptation, persistence and productivity of alternative buffel varieties and other species across regions.
4. Nutrition of pastures.
   - Quantify N and water dynamics with different rundown mitigation strategies.
   - Investigate how soil health, soil nutrients and pasture quality changes over time.
   - Quantify how much N the adapted and available legumes fix and the impact on companion grasses.
5. Economics. Quantify the economics of rundown and mitigation strategies.
6. Grazing management. Management strategies for making the most of the forage produced in a sustainable way need to be adopted by the industry. Grazing management strategies for legume/grass pastures need to be investigated, packaged and extended.

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Contents

Background

Buffel grass is the most important sown pasture species in Queensland and northern Australia. The grazing industries are reliant on buffel grass for a large percentage of production. Buffel grass pastures have been established for decades over large areas. The majority of pastures have either been sown as buffel grass only pastures or where buffel was planted with other grasses and legumes, most are now buffel grass dominant. These buffel grass dominated pastures are widely recognised by graziers and the broader industry as declining in productivity. Addressing productivity decline is important for the long term productivity and sustainability of the Queensland grazing industries.

DEEDI in partnership with Meat and Livestock Australia (MLA) are currently reviewing productivity decline in buffel grass pastures in consultation with graziers, research agencies and agri-business. The project aims to:

1. Provide an overview of the primary causes, extent and economic impact of sown pasture productivity decline.
2. Evaluate results and cost-effectiveness of options for mitigating (renovating) rundown buffel grass pastures.
3. Assess limitations to cost-effectively improving productivity of buffel grass pastures.
4. Recommend future research and extension priorities for addressing buffel grass productivity decline.

Collecting the views and experiences of graziers managing buffel grass pastures is an important part of this project. During March and April 2010 six focus group meetings were held with graziers in southern and central Queensland to discuss productivity decline in buffel grass pastures. This report summarizes the views and opinions of graziers on buffel grass productivity decline from focus group discussions.

Focus group overview

Six Focus group meetings were held in March and April 2010 in Moura, Rolleston, Clermont, Roma, Nindigully and Wandoan.

95 producers were contacted and invited to meetings.
80 were interested and thought pasture productivity decline was an issue in buffel grass pastures.
41 landholders attended the 6 meetings with many unable to attend due to wet weather and flooding.
Some graziers indicated it was not a major concern for them because:

- 2 producers said it was not an issue for them. Several other producers said it was less of an issue this season compared to previous seasons.
- 2 producers said that their country is reasonably new and buffel pastures young. They are expecting problems down the track
- Not an issue yet as had only blade ploughed 7 – 8 years ago.
- Rest and grazing management is the main issue “Have not seen any real problems with buffel in my district not attributable to overgrazing”
- Suggested solutions all have the potential to let parthenium back in to the pasture.
- Pasture productivity is more a seasonal issue based on rainfall than a declining trend over time (two graziers).

- Dieback is a bigger issue than rundown.
- I don't blade plough, I let the suckers grow up and re-chain instead. Carrying capacity has stayed the same but cattle aren't doing as well. I have seen buffel come back poorly after blade ploughing, especially on sodic soils.

At the meetings graziers discussed the following questions:

1. What's the extent of productivity decline?
    - How big a problem is it for your business?
    - How does it affect your business?
2. How do you manage productivity decline in sown pastures?
    - What has been tried?
    - What are the results?
    - What are the main reasons for success or failure?
3. What are the biggest limitations to overcoming productivity decline?
4. What Research, Development and Extension is needed for the grazing industries to address productivity decline?
    - What would you like to try at home if you had the time and money?
    - What would you like MLA and DEEDI to do?

Traits of buffel grass

Sown pastures were recognised as very important to maintain and improve production for the beef industry in central and southern Queensland by improving the quality and quantity of feed for stock and extending the growing season. Buffel grass was recognised as being the most important sown pasture by all six focus groups, because of its:

1. Adaptation – Buffel grows on a variety of soil types and fertility levels across a wide range of rainfall and therefore covers a wide geographic area. Buffel is recognised as being the "only" sown pasture grass for drier areas. It has also been observed that buffel is spreading onto infertile soils and heavy clay soils previously thought to be unsuitable.
2. Persistence – Buffel has proven to be the most persistent sown pasture in much of Queensland. Many other species have been sown, but buffel is the one that survives and eventually dominates.
3. Drought tolerance – Buffel is identified as being the most drought tolerant sown grass in Queensland and has been observed to spread during dry years.
4. Grazing tolerance – Buffel is tolerant of heavy grazing once established and is one of the last good grasses to disappear when heavily grazed.
5. Competitiveness – Buffel is very competitive for moisture and nutrients. Buffel grass was described as having a massive root system that is more competitive than other grasses for water and nutrients. The competitiveness is good for competing with weeds but also makes it hard to get other grasses or legumes to establish and persist with buffel.

Varieties

Gayndah, American and Biloela are the main varieties planted however Nunbank was commonly planted around Clermont. Biloela and Nunbank have not been as palatable or persistent as Gayndah and American. Gayndah and American were recognised as being a more difficult problem for productivity decline as they are more persistent.

Pasture productivity decline

Symptoms

Decline in pasture productivity was recognised as being a major problem in all areas. Symptoms described were:

1. Reduced pasture growth. The grass becomes lower, slower and produces less bulk. Reduced dry matter production is the most important impact of pasture rundown for many people as it reduces carrying capacity (see Table 1).
2. Changes in pasture density. On more fertile land types tussocks have reduced in size but in many cases have thickened into a “carpet of small tussocks”. On low fertility soils large clumpy buffel tussocks can develop with very little ground cover or seedlings between the tussocks.
3. Nutrient deficiency symptoms of yellowing or reddening of leaves were described by all groups. A general yellowing of the plant was recognised as nitrogen deficiency by many producers. Several graziers have noticed a red/orange/purple colouring along the margins of the leaves towards the end of the growing season after which very little grass grows even when more rain falls.
4. Reduced animal performance due to reduced feed quality. Graziers reported lower weight gains and increasing difficulty in meeting market specifications, however this is off set or masked by improving production through better adapted cattle and increased use of supplements.
5. Pasture composition change. Changes in the mix of grass species was noted by all groups. Districts that were cleared and sown to pastures earlier reported a trend where Rhodes grass initially dominated, was replaced by Green Panic, then become buffel grass dominated. The buffel grass in turn has been getting more Sabi grass and native grasses as the pastures age and rundown further. Rhodes grass and green panic were considered to cope with drought when first developed but died out during dry conditions once the pasture had been established for a few years. In more recently developed districts buffel grass was sown initially and is now seeing more native grasses or Sabi grass.

Table 1: Estimates of the carrying capacity since sown pastures were established (where current carrying capacity is described as a percentage of the carrying capacity when pastures are first established).

Focus group	Current carrying capacity	Comments
Moura	50-75%	For some landholders the best scrub country has reduced carrying capacity to being similar to good forest country. Still declining.
Rolleston	50-75%	Still running down after the benefits of blade ploughing for sucker control.
Clermont	NA	Hard to put a figure on as pastures have recovered from drought, overgrazing and parthenium.
Roma	50-75%	Much of the western downs is still riding the benefits of clearing and cutter barring but significant decline evident.
Nindigully	50%	Rundown buffel is still much more productive than the natives it has replaced on red soils (box, mulga country)
Wandoan	50%	50% reduction without renovation. If production is still running down it is now more gradual.

Land type effects

All groups have observed that rundown happens quicker on low fertility and lighter textured soils. Some groups thought that more fertile soils had a greater overall decline in productivity. Hard setting soils were considered to have a more severe problem of not only reduced pasture growth but also reduced infiltration once rundown had occurred due to lack of groundcover.

All groups had observed that cropping, even if only immediately after clearing for sucker control, affected subsequent pastures. Ex-cropping paddocks generally had poorer soil structure, lower nutrients (from removal in grain) and poorer pasture growth.

Causes

Rainfall infiltration, nutrient cycling, over grazing and disease were all recognised as contributing to a decline in pasture production. However, views as to the relative importance of these causes differed within and between groups.

Rainfall infiltration:

There was a general consensus that rainfall infiltration into soils, especially hard setting soils, is a major contributor to pasture production. Seasonal variability was noted as the largest determinant of pasture growth in any particular season by most landholders. The good rainfall last summer was widely acknowledged as producing the best pasture growth for many years and masking the effects of a declining trend in pasture production.

Reduced nutrient availability

Reduced nitrogen availability and cycling was identified by many participants as being the major cause of declining trends in pasture productivity. Nutrient availability was less tangible than

infiltration and runoff. Several participants attributed classic symptoms of nutrient deficiency to moisture stress. Examples of comments include:

- "Blame rain more then we should. It's a combination of grazing management, nutrients and rain. Probably have not matched grazing management to seasons well enough. Native grasses were here for eons before cattle grazing was introduced and have disappeared... Not all management but everything impacts."
- "Nitrogen is the main driver. Need a grazing system where there is a cycle that is self maintaining."

Over grazing

Overgrazing was considered by many people to be a cause or contributing to a faster rate of pasture productivity decline. Reduced ground cover as a result of over grazing was recognised by most graziers as reducing infiltration, reducing tussock health and therefore pasture production. It was also considered to accelerate the rate of nutrient rundown. Allowing mulch to return to the soil was seen by many people as being important to reduce the impact of rundown.

Level of debt and enterprise size were also considered important to pasture productivity decline. Smaller properties and those with higher levels of debt are being forced to "run their country harder" to make ends meet.

Disease

Diseases were recognised as contributing to productivity decline by some of the groups, examples being rust and ergot in wetter years.

The Moura group described buffel dieback, a distinct condition that has been the subject of several years study by the central Queensland University. This condition affects quite small areas, but can severely impact buffel where it occurs. Dieback has the following characteristics:

- Mainly affects US and Gayndah, whereas Biloela appears resistant. Roughly circular patches which grow outward develop a severe reddening of the leaves, stunted root development and eventually die. Patches vary is size from 2m to 60 m in diameter and can join together. Symptoms are more pronounced if the plants are moisture stressed.
- Infected plants are unpalatable to cattle.
- Older patches re-establish with weeds and native grasses.
- To date the causal agent of the dieback has not been identified.

A separate issue discussed by the Rolleston groups was where buffel dies out in patches in relation to soil types.

What has been tried to overcome rundown

Most producers who attended the focus group meeting believed pasture productivity decline had to be addressed to maintain profitability within the industry. Producers face increasing costs of production and reduced real prices for their stock. Maintaining or increasing productivity in a cost effective manner is therefore essential.

Some producers noted that although it may not be currently economic to renovate pastures, that as productivity declines further, that it will reach a point that it pays to do something. Relative costs and returns between the different mitigation strategies were also noted as changing over time.

Understanding the relative costs and returns of mitigation strategies may mean using different options at different times.

“We need to find an answer to decline as we can’t afford to reduce production more and more as costs keep going up.”

“Ways of addressing rundown need to be easy and cheap”

Mechanical renovation

A range of different approaches to mechanical renovation have been used, from single cultivation approaches to short term cropping. Many participants had observed that there is initially a good response to cultivation, but rundown subsequently occurs more rapidly and follow-up renovations do not achieve as good a result.

The degree of disturbance was identified by many people as being important to achieving a good result. “When renovating buffel you need to treat it as if you hate it”. However, some producers have observed buffel butts not breaking down for over 5 years in the soil.

The impact of renovation varied with following seasonal conditions. Deep ripping in dry years improved infiltration, increased pasture production and improved the greenness of the grass. In wetter years several graziers observed no visual difference between ripped and un-ripped areas. However most landholders were only ripping degraded areas with low pasture cover, not large areas of buffel with reduced vigour.

Participants gave mixed responses about the returns from mechanical renovation. Some people reported good returns while others thought it was only worthwhile if controlling suckers or if doing short term forage cropping. Observations included:

- “Can pay for the cost of renovation from buffel seed sales alone, let alone extra forage production”
- “Plough and work… but less and less response when you redo it”
- “Cropping stuffs a lot of country. Loamy soils are worse, black self mulching soils are ok to cultivate.”
- “The only way to establish legumes into buffel is to cultivate it out first.”

Blade Plough or Cutter Barring

Blade ploughs or cutter bars has been the standard sucker control method in many districts. Renovating pastures and the opportunity to establish new pasture species is an added bonus. Some key points made about blade ploughing include:

- It’s expensive. Costs varied from $70-$100 per acre ($180/ha - $250/ha). Some people are using blade ploughs for pasture renovation however it is more commonly used control suckers or break up scalded areas. Most participants saw blade ploughing as an expensive option for pasture renovation alone.
- Pastures after blade ploughing produce better weight gains and can run more cattle. However results diminish with repeated blade ploughing.
- Blade ploughing better soils will give a response for 10 – 15 years. On hard setting lighter soils it does not last as long. Blade ploughing was generally seen as having a longer term response than ripping or chisel ploughing especially for infiltration benefits.

- Provides an opportunity to establish legumes and other grasses.
- Can cause problems if go too deep on soils with dispersive layers.
- Can be very effective on clay pans or scalded areas.
- Blade ploughed country is worth more per hectare.

A quote that summed up many participants thoughts was:
“Fuel and dollars for a short term gain. Blade ploughing to control suckers is fair enough, but for rundown alone it is too expensive”

Deep ripping

Deep ripping was mentioned by the Roma and Wandoan groups. It has been used mostly in scalded areas but also to renovate buffel pastures. Comments on ripping were:

- Shatters the soil and therefore lasts longer than chisel plough.
- Produces results in drier years with better infiltration, more grass and greener. In wetter years several graziers have noticed no difference between ripped an un-ripped areas.
- Some people thought the disturbance was not severe enough to produce much of a response from rundown buffel tussocks and should only be used in rotation with more severe treatments such as offset discs.

Chisel plough

Chisel ploughs or similar implements have been used for renovating pastures that do not have suckers or severe scalding. The main example came from the Roma meeting where it was seen as a cost effective approach to renovating buffel on hard setting soils. Key points from this example were:

- Costs $12/acre and considered to pay for itself in the first year.
- Spreading buffel seed as well. This option could provide an opportunity to establish a legume.
- Significantly more growth in the 4 months after treatment. 30 months later there is still a visual difference (Figure 1).

Figure 1: The effect of renovating buffel grass with a chisel plough 4 months (top photo) and 30 months (bottom photo) after treatment. The left hand side of the photos was treated while the right hand side of the picture was not renovated. (Photo courtesy S. Salter)

Offset Discs or One Way Disc Ploughs

Offsets and one way disc ploughs for renovating buffel pastures were discussed at Wandoan, key point were:

- The one way disc plough was seen as very effective for renovation as it turns the root mass and soil over which kills most buffel plants.
- Costs approximately $16/acre
- Provides an opportunity for going back to either pasture or cropping.

Crop pasture rotations or Short-term cultivation

The Wandoan and Nindigully groups discussed cropping rotations in some depth. The other groups tended to manage their cropping country separately to their grazing areas or were focused on cattle production with little if any cropping lands. Views ranged widely in relation to cropping/pasture rotation from being considered useful to being considered damaging to soil health, key points included:

- Benefits for subsequent crops. There were mixed results ranging from:
    - Dramatic improvement in crop production.
    - Poorer first crop after pastures with lower yields and/or protein levels but subsequent crops performed well.
    - No improvement in subsequent crop performance.
- Short term fallowing and cropping allows forage crops to be used with in the enterprise.
- Short term cropping was seen by many as the most reliable way of establishing legumes. Several examples of using cropping to control buffel to allow establishment of medics before re-sowing buffel were given by the Nindigully group.
- Fallowing for crops releases nutrients from soil organic matter that was built up during the pasture phase. Any fertilizer that is used for cropping is subsequently available to the pasture.
- Cropping was seen by many as exporting too many nutrients and wrecking soil structure. A number of people noted that land was often cropped until it does not produce reliable crops and is then returned to pastures. These pastures then do not perform well.
- Relative economics between grain, sheep and cattle production. When grain prices are high there is an opportunity to put better country back to cropping for few years to improve income in the short term with the added benefit of fixing pasture productivity decline.

Legumes

Legumes were seen by many participants as the most cost effective and sustainable approach to reducing the effects of pasture productivity decline. Many participants recognised benefits from legumes improving animal performance through improved protein levels in the diet and nitrogen cycling to the associated grass. However the industry does not recognise the improved productivity of legumes through improved land prices (other than leucaena) as it does for blade ploughing.

Producers reported mixed results with legumes. There were notable successes but also many failures. Most producers thought legumes were either not widespread or not as widespread as they should be in their district. Many producers did not think legumes other than leucaena were a viable option with buffel grass despite examples to the contrary (e.g. Figure 2).

Figure 2: Caribbean stylo and desmanthus established in buffel grass pastures on brigalow soils near Theodore. The legume seed was sown behind a blade plough 13 years ago (March 1997). Initially there were only isolated legume plants but it has thickened dramatically in recent years. (Photo – G. Peck).

Key constraints to using legumes for buffel grass productivity decline were:

- Establishment. Legumes are difficult to establish in buffel grass pastures due to the competitiveness of the grass and seasonal variability.
    - The majority of producers had used either low intensity establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire or chaining) or severe soil disturbance and a rough seed bed behind a blade plough (e.g. Figure 2). Pasture legumes were very seldom "sown", rather they were "chucked out", "hurled out", "woofed out", "spewed out" and "thrown out" of planes or dozers. Small seeded pasture legumes with weak seedling were noted by many people as being unable to complete with established buffel grass. Only when establishing leucaena does the industry routinely use established cropping methods of establishment (Figure 3). An example of producers experience is - "If you are just throwing legume seed on the surface with buffel grass you are wasting your time".
    - Some producers have ploughed buffel out to establish legumes before re-establishing buffel grass. Complete cultivation is generally more reliable for establishing legumes however participants using this approach still reported some failures.
    - Several landholders recommended that legumes should be established when the buffel grass is established. However most participants would not plough buffel out to establish legumes.
    - Some producers mentioned problems with seed quality or seed coats.
    - Good establishment is recognised as critical to the long term persistence of legumes, however many producers don't think they can afford not to graze to allow establishment. Several producers thought the only reliable way of establishing legumes is to completely plough buffel grass out and store soil moisture before establishing the legume and then rely on cattle to spread the legume further.
- Persistence. Even when legumes establish very few species have proven to be persistent due to the competitiveness of buffel grass.
- Adaptation. Producers identified key gaps in commercially available legumes for different soils or environments.
    - For CQ - Stylos and Wynn Cassia have done well on light soils. There has been a gap in hardy legumes for clay soils. The only widely proven, persistent legume on clay soils is leucaena but it is not suitable for all soils or enterprises and is recognised as a weed in some situations. Butterfly pea and Burgundy bean are considered to perform well as short term pastures.
    - SQ – Medics are widely spread on many land types but rely on winter rain in years without too much grass cover. There are no widely planted, commercially proven, summer active legumes for any land types.
- Nitrogen fixation. How much nitrogen is fixed and the effect on companion grasses was questioned by most participants. However some producers in CQ have observed stylos thickening up and presumably fixing nitrogen before grasses come back and dominate looking greener and lusher. In SQ, paddocks with well established medics have been widely observed to be more productive and have greener grasses. Several people noted that legumes need to be well established and productive for some time before they make a difference to the associated grass. Many graziers also thought that legumes only fix enough N to claw back a small percentage of the lost productivity while others gave examples of noticeable improvements in greenness or productivity of companion grasses.

- Productivity. Legumes have produced good bulk in some situations and not others. Soil fertility, especially phosphorus was discussed and noted as being the cause of poor legume growth by some of the groups. In other situations the reason for poor performance is not known.
  Expectations of legume growth varied widely between participants. Some people were happy to see at least some plants. Others seem to want a legume producing as much bulk as the companion grass.

Figure 3: Reliable establishment of legumes in buffel grass pastures has been developed for leucaena. These methods of establishment are not routinely used for establishing other legumes.
(Photo – G. Peck)

An example of the mixed results from legumes is demonstrated by the comments about caatinga stylo from participants. One of the producers in the Moura meeting had a trial on his property where 10 ha was established to buffel grass, while a neighbouring 10 ha paddock was established to buffel & caatinga on Brigalow/Blackbutt soils. Live weight and pasture growth were monitored for the first 3 years with no difference between the paddocks. The producer saw visual differences between the paddocks from 5 years on. The pastures are now 12 years old with the caatinga paddock still being green with buffel being the dominate grass with lots of the stylo, the other paddock is yellow with native grasses coming into the buffel grass. Other participants in the workshops who had tried caatinga reported either poor establishment, poor production or poor persistence some of which can be attributed to poor seed quality or poor seasons.

Regional differences:

Distinct differences between CQ and SQ were evident in legume discussions. A colder climate with a greater frequency and amount of winter rain mean that medics persist in SQ but have not persisted in CQ. Conversely stylos have been widely used and are persistent in CQ, but they have either not been used or have not persisted in SQ. Leucaena is widely used in CQ but is increasing in area in SQ. The legumes used in the two regions are described below.

Table 2: Legumes mentioned during central Queensland focus group discussions and some typical perceptions of the legume.

Legume	Group*	Comments
Shrubby stylo (Seca, Siran)	All	Tough, persistent legume for lighter soils, can be dominant in some situations notably on gravelly ridges. Does not establish or persist on heavy soils. Slow to establish ("couldn't find it for the first few years, now its everywhere").
Caribbean stylo (Verano, Amiga)	M, C	Hardy legume for lighter soils and more monsoonal areas. Short lived plants that seed heavily. Verano more common and widespread, more planted in native pastures further north. A few participants have Amiga doing well with buffel on scrub country including as far south as Theodore.
Caatinga stylo (Unica, Primar)	M, C	Adapted to heavy soils and more cool tolerance than other stylos. Two producers in the CQ groups have used caatinga stylos, one with great success and the other with poor establishment and production.
Siratro	M, C, Rol	Widely planted but has largely died out. Has grown well on some lighter alluvial soils.
Round-leaf cassia (Wynn)	M, Rol	Has grown well on sandy soils. Does not retain leaf in dry or after frost. Behaves as an annual in many situations.
Leucaena	All	Highly productive on good deep soils. Needs a lot of effort to establish it well. Improves the grass growth especially near the row. Considered the most productive pasture in CQ.
Butterfly pea	All	Good short term legume on cropping soils. Has been used in permanent pastures but is selectively grazed. Some people report good results in permanent pastures, however more examples of it disappearing out of permanent pastures were given.
Burgundy Bean	M, C	Not much planted. Has been promoted as holding on longer into the dry than butterfly pea by seed company. Has performed well for those who have used it.
Desmanthus	M, C	Small trial plantings with mixed results. Only the short variety (Marc) is persisting. Where it has established it has been very persistent and is spreading.
Lucerne	C	Grows well for a few years – short term pasture only.

* M – Moura; C – Clermont; Rol - Rolleston

Table 3: Legumes mentioned during southern Queensland focus group discussions and some typical perceptions of the legume.

Legume	Group*	Comments
Planted medics	All	Good production and benefit to associated grass where they persist. Have not established or persisted for many graziers and therefore not considered to be a viable option by many producers. In other cases not considered to be producing enough. Recognition of P limitations in "red soils". Primarily snail and barrel medics have been tried with snail noted as not persisting. Some producers noted that production is highly variable between years and is dependent on low levels of pasture cover in autumn, winter rainfall and a large soil seed bank.
Naturalised Pastures	All	Considered to be the most persistent option especially in drier areas. Seed unavailable. Some producers noted that production is highly variable between years and is dependent on low levels of pasture cover in autumn, winter rainfall and a large soil seed bank.
Caatinga stylo (Unica, Primar)	All	Has only been tried by some of the participants with generally poor results (either establishment or dry matter production) despite having performed well in trials (in one example on the same property). Questions raised by one participant about the impact of having a specific rhizobium requirement on establishment and growth potential.
Shrubby stylo (Seca, Siran)	All	Isolated patches noted as growing on roadsides in a number of localities. Thought to be persistent in some hilly and forested areas. Questions raised about whether it will adapt to the region especially during years with warmer winters or as a result of climate change.
Leucaena	All	Not much planted by the SQ but generally a lot of enthusiasm for trying it. Questions about its adaptation and productivity in SQ. Several Wandoan participants have tried it with mixed comments on its productivity.
Fine stem stylo	Rom, W	Has persisted in forested hilly country near Injune and east of Wandoan.
Butterfly pea	N, W	Generally has not performed well in SQ.
Tagasaste (Tree Lucerne)	N	Trialled by several producers in the Nindigully area. Has not persisted.
Lablab/Cowpea	N	Good forage crop options and for fixing N for subsequent crops.
Siratro	W	Was widely planted but has largely disappeared. Has performed better on lighter soils.
Wynn Cassia	N, W	Has grown well on lighter soils. Behaves as an annual.
Lucerne	Rom, N	Grows well for a few years – short term pasture only. Need to be able to use the forage when it grows in summer.
Burgundy Bean	Rom, W	Has not been widely planted. Has shown good productivity as a short term pasture for those who have tried it. Has shown some weediness in cropping paddocks with seedlings emerging in subsequent crops.
Vetch	N, W	Winter active annual. Seen by a few producers as an alternative to medics.
Native legumes	N	Rhyncosia and glycines were mentioned as thickening with pasture spelling and some years as having high production.

* Rom – Roma; N – Nindigully; W - Wandoan

Fertilizer

None of the producers in the focus groups are routinely using fertilizer on their pastures. Several have tried strips of Nitrogen and or Phosphorus fertilizer with mixed results. The general response was that fertilizers do produce more grass, however most people did not think it was economically viable or environmentally sustainable to routinely apply fertilizer unless for special purposes such as seed or hay production.

Some interesting responses and examples include:

- "It's disappointing if we need to apply fertilizer in this district"
- "Nitrogen fertilizer is grass cocaine – it just gives a short term fix"
- "We can't afford fertilizer, it's not sustainable and it won't pay"
- A few participants mentioned a nitrogen trial in southern Queensland that produced big yield responses over the last summer and suggests the extra carrying capacity would more than pay for the fertilizer.
- 110kg/ha of ammonium sulphate on Bambatsi Panic for seed production produced no difference in the first year, however in the second year it produced twice as much seed.
- Questions were raised in relation to how long the effects of nitrogen fertilizer last. Generally it was thought to give only a short term (1 or 2 season) response. However there was one example of a strip at a very heavy rate of fertilizer still being evident in the paddock over a decade later.
- Several people gave examples of responses to phosphorus fertilizer on red soils (box or box mulga soils in SQ) or in old cropping soils. Responses included more stools, more roots and more medics.
- Other people gave examples where nitrogen fertilizers produced no visual response which they attributed to either atmospheric losses or other nutrients being more limiting.

Figure 4: Buffel grass pastures showing the result of added nitrogen fertilizer. The grass on the left has had urea applied (120 kg N/Ha). (Photo - S. Cook, QMDC).

Grazing Management

All groups discussed the importance of sustainable grazing management and identified overgrazing as contributing to pasture productivity decline. Leaving enough height in the buffel for it to reshoot, leaving mulch behind to provide ground cover and for nutrient cycling were considered important by all groups.

Spelling to allow pasture recovery was considered to be good management by all groups with most people having some level of spelling. Many participants use some form of rotational grazing including some cell grazers. Participants reported seeing improved pasture condition with more grasses other than buffel in paddocks, especially green panic, native grasses and legumes after changing to a rotational grazing system.

Heavy grazing followed by spelling was seen by several participants as being useful for improving greenness and productivity of buffel grass. The heavy grazing was thought to force buffel to reshoot thereby mobilizing nutrients within the plant and to promote nutrient cycling through trampling and dung. Heavy herd and hoof impact during wet weather has been observed by some producers to improve buffel productivity e.g. in cells, laneways or holding paddocks.

Spraying out

A few people have sprayed buffel out using Roundup™ with one example of using Spray Seed™. Most people reported improved greenness and productivity after spraying. Results relied on killing a large percentage of mature plants and having a good soil seed bank for the buffel to re-establish. Spraying out before forage cropping or establishing legumes was seen as a viable option by some participants if machinery could cope with the buffel tussocks.

In SQ, spraying out has been used to manage medics by a few people. If there are already medics in the paddock spraying out in summer to allow moisture storage and to reduce shading can be effective in promoting medic growth. Alternatively spraying out to store moisture followed by some cultivation was seen by some as a useful way of establishing medics.

Other Grasses

Buffel grass was seen as being the best adapted, persistent and productive sown grass by all groups. For all groups other grasses had been planted, however buffel grass has ended up as the dominant sown pasture grass. Rhodes grass and Green Panic were reported as dying out of the pasture by all groups. Some participants had tried ploughing out buffel grass to plant other grasses only for buffel to become dominant again.

As buffel pastures age all groups reported seeing other grasses such as Sabi grass, bluegrasses or spear grasses coming in. These grasses are more tolerant of low fertility than buffel grass which led some participants to wonder whether they would eventually replace buffel grass. One participant reported a paddock of buffel being entirely replaced by Sabi grass. Several producers commented that better native grasses such as Mitchell Grass or Bluegrasses are as good or better than rundown buffel. However at Nindigully on lighter soils rundown buffel grass was considered to be much better than the native grasses it has replaced.

Table 2: Grasses mentioned during focus group discussion and some typical perception of the grass.

Grass	Group*	Comments
Rhodes grass	All	Initially dominant and productive after sowing before dying out during dry periods when pastures have rundown. Disappears quicker on lower fertility and lower rainfall areas.
Green Panic	All	Initially productive but has died out in most areas. Producers seeing more with rotational grazing or with legumes.
Bambatsi Panic	All	Has performed well on clay soils in SQ, Moura and Rolleston districts. Had not established or persisted for the Clermont participants.
Creeping Bluegrass (Bisset, Hatch)	All	Reported as persisting well including areas with lower fertility by many producers. Reported as not persisting or being low, slow, not producing much bulk and leaf disappearing over winter by others more so in CQ and Nindigully groups.
Sabi Grass	All	Reported as invading rundown buffel pastures in many areas. Disliked by most producers for not providing stand over feed in winter. Has established on difficult Blackwood soils north of Clermont where other grasses have failed.
Gatton Panic	W	Considered to persist and perform better than Green Panic. Some good paddocks in the Wandoan district, but has died out of some paddocks.
Floren Bluegrass	M, C, N	Very palatable and observed to be the first grass eaten. Young plantings only, therefore few comments on persistence. Considered to be a very promising grass by some.
Premier Digit Grass	N, W, Rom	Has done well on sandy soils for some people. Mixed comments on it's productivity and how it has done on lighter brigalow soils.
Purple Pigeon Grass	M, W,	Most comments were that Purple Pigeon is unpalatable. Two producers considered it a good grass for heavy clay soils, but not to be planted in a mix.
Indian Couch	C	Large areas of the Burdekin River region have been naturalized with the Bowen variety of Indian Couch which is a poorer type. Medway is better but had not been tried by the participants.

* Rom – Roma; N – Nindigully; W – Wandoan; C – Clermont; M – Moura; Rol – Rolleston.

Fire

There were mixed comments about using fire with buffel grass. Some people were supporters of using fire reporting greener grass, better grass growth depending on the following season, better animal performance and promoting more tussocks and shoots. Others were strongly against using fire seeing it as a waste of a forage resource, risky if the season turns dry, reducing ground cover thereby increasing erosion, scorching the soil surface as buffel burns hotter than native grasses and promoting weeds like pimelea.

Slashing

A few people have slashed buffel around house yards, sheds etc. They have observed slashed buffel to have more tussocks and to be greener.

Managing woody vegetation

The role of native trees and shrubs in nutrient cycling was mentioned by several participants. Brigalow as a legume was also mentioned.

Having a cycle where suckers were allowed to grow to a moderate height before being chained and allowed to re-grow or alternatively leaving strips of suckers was seen as a useful way of promoting nutrient recycling. However with current vegetation management laws and uncertainty with future legislation, most producers saw these options as risky to their long term property viability. No one in the groups was managing trees for their nutrient cycling attributes.

Soil Biology

A few people were interested in using compost or compost teas for improving nutrient cycling and improving pasture growth. A few participants had tried using compost teas but had seen no response (either visually or in pasture yield or grain yield).

Live with rundown and accept lower production

Many participants commented that graziers need to have realistic expectations of sustainable pasture production levels. Some participants thought that rundown buffel grass pastures may be closer to the long term pasture production levels that can be expected. These comments were balanced with concerns about maintaining viability through increasing productivity to offset increasing costs. Some producers noted that although it may not be currently economic to renovate pastures, that as productivity declines further, it will reach a point that it pays to do something.

In accepting lower pasture production and poorer feed quality several strategies were discussed to reduce the impact on grazing enterprises:

- Supplements for cattle to reduce the impact of lower feed quality. However the increased feed intake needs to be considered so as not to overgraze.
- Reduce stocking rates so as not to over graze and to maintain individual animal performance.
- Develop another paddock although the opportunity to do this varies depending on how developed the property is and is impacted by tree clearing laws.
- Buy more country. Mitigation strategies cost money, it may well be better to buy more land than renovate pastures. In lower production areas the cost of pasture renovation options is a large percentage of the value of the land.
- Adjust management to allow other grasses such as bluegrasses and Mitchell grass to persist with buffel.

Limitations to addressing pasture productivity decline

Participants identified a range of limitations to addressing pasture productivity decline including:

1. Economics was identified by all groups as a major limitation. Returns are tight with increasing needs to improve productivity to counteract increasing input costs. Many of the current options for addressing productivity decline were considered to have marginal returns however there was recognition that doing nothing may be more expensive.

   "There's gotta be an answer…. We can't keep going down and down and down".

   Cash flow was also considered important with the returns from mitigating rundown taking several years to recoup, which does not pay bills in the short term. Agricultural production is intensifying partly due to the increasing value of land, however if pushed too hard it becomes unsustainable.
2. Legume establishment is difficult due to the competitiveness of buffel. Good establishment is critical to the long term persistence of legumes, however many producers don't think they can afford not to graze to allow establishment.
3. Legume adaptation. In CQ, legumes other than leucaena for clay soils are required. In SQ, summer growing legumes for all soils types are required. Also woody legumes other than leucaena.
4. Understanding the reasons for productivity decline and options for addressing the problem were considered a limitation by several participants. Questions such as the long term sustainable production levels? How much has productivity been affected? And what are the costs and returns of different mitigation strategies? were raised. There is a need to better understand the ecology of a plant that is so important to the Queensland economy.
5. Nutrient export and fertilizer demand in the future. Whether it is grain production or cattle, nutrients are being exported and eventually need to be replaced. Global demand for fertilizer is expected to increase as food demand increases.
6. Options for arable and non-arable country. Can't have only mechanical options.
7. Buffel monocultures – it is difficult to introduce or maintain other species.

Research Development & Extension Suggestions

There was a consistent message between the groups that more work was needed. However there was not a clear consensus of future RD&E needs across the groups. There was recognition that past innovations such as better breeds and land development have driven productivity gains, several producers thought that addressing productivity decline in buffel grass pastures is the next big step.

“Poly pipe, Brahman cattle, and blade ploughs have driven productivity gains, the next step is to address rundown and improve pasture production”

RD&E needs were identified across the following key areas:

Understanding and monitoring of rundown

Information access, understanding and monitoring effort were identified as being needed to address productivity decline. Graziers wanted more information on:

1. How much does productivity decline and how much does it cost.
1. How long does it take.
2. How is soil health, soil nutrients and pasture quality changing over time.
3. Long term monitoring is required to compare different rundown management practices over time.
4. How effective are trees at recycling nutrients and improving nutrition of buffel.
5. Not enough known about buffel - Is it different to other grasses? Why does it seem worse?

“Knowing what to do. Grain production has increased over time through things like Zero Tillage and Controlled Traffic Farming - Grazing needs to increase production somehow”

“There’s gotta be an answer…. We can’t keep going down and down and down”

“Need to understand pasture rundown especially buffel to move forward”

Legumes

The RD&E needs identified for legumes were:

1. More and better adapted legumes for clay soils in CQ and summer growing legumes for all soil types in SQ that can compete with buffel.
2. How to better manage existing legume varieties for establishment, persistence and production. The industry needs a management system to go with the legume, not just have the legume released.
3. Reliable establishment techniques that are economical and low risk especially for clay soils. Options suggested included research to develop more reliable establishment techniques, PDS sites to demonstrate existing options and to ensure workshops and courses address establishment adequately.
4. Variable or declining seed availability and seed quality are a problem for some legumes. The industry needs to consider how quality seed and rhizobia inoculants can be made available to the industry at an affordable price.
5. Quantify the impact of different legumes on production in different environments.

“What we need is a legume that is easy and cheap to establish that we can chuck out of a plane. That is persistent and can cop a hammering during years of drought. Is good feed for cattle but not too palatable that it is grazed out. Grows lots of feed and fixes lots of nitrogen for the grass. Does not become dominant and a weed…..And…. kills suckers”

“What we need is the emergence of Urochloa, the strength of mint and the height and growth of Bathurst Burr”

Grasses

Gayndah and US buffel were seen as being more of a problem for rundown perhaps due their longer persistence. It was questioned whether there are other varieties of buffel or other species that are better for long term productivity. There was also considered to be a gap for grasses in some difficult land types e.g. Blackwood country and the bottom of melon holes north of Clermont. Adaptation, persistence and productivity long term for some of the newer varieties of grasses across different districts is needed.

A better understanding of the ecology of buffel grass was thought to be useful by several producers. Is it different to other grasses in root structure, level of woodiness, erosion risk or does it release chemicals that inhibit other plants?

Nutrition of pastures

A better understanding of nutrition of pastures to improve productivity and sustainability of pastures is required including the following points:

- Quantify the costs and production from fertilizer and manure options especially on less fertile soils.
- Quantify how much N the currently available and adapted legumes fix and the impact on companion grasses. Many past trials only ran during the establishment phase but legumes seem to make bigger differences the longer they are in the pasture. The level of N fixation by different legumes in different environments was questioned.
- How is soil health, soil nutrients and pasture quality changing over time.
- Investigate N and water dynamics under different rundown mitigation strategies.

Renovation strategies

The range of rundown mitigation strategies discussed by the groups included mechanical cultivation, herbicides, legumes, fire and slashing. The results of different mitigation strategies need to be quantified.

Economics

The economics of further rundown compared to the different mitigation strategies needs to be quantified to allow graziers to make an informed decision about which is the best option for them.

Grazing Management

Management strategies for making the most of the forage produced in a sustainable way need to be widely adopted by the industry. Grazing management strategies for legume/grass pastures need to be investigated, packaged and extended.

Grazing animal management on rundown pastures with different feed quality needs to be investigated. The impact on feed quality and animal performance of rundown and different mitigation strategies needs to be quantified. For example what are the protein levels in green, yellow, and purplish buffel?

9.2 Appendix 2: Seed industry consultation

Sown Pasture Rundown Review – Seed industry & merchant/retailers

These comments are a collection of views from 11 seed industry & merchandising agronomists in Queensland. The comments include those of 8 specialist seed marketers and 3 more general merchant/retailers who focus on cropping but also sell pastures seed and service some pasture inquiries in their main cropping activities

1. "What's the extent of productivity decline…or 'pasture rundown' with your clients?"

All but one of the seed industry specialists believed sown pasture decline was widespread, and while it was most common in buffel grass would also occur in other sown grass species. The dissenting view was that all pasture rundown and condition decline could be attributed to grazing management and remediated by rotational grazing.

> *I am confident that nutritional rundown would be occurring in most of my client's pastures where more than 5 years had past since last development/renovation has occurred*
>
> *(There's) two categories of rundown: (i) rundown due to poor grazing practices is an increasing problem due to financial pressures and bad management. Going backwards due to poor stocking rate management. Across all pastures including buffel – but comes back to resilience - buffel is very resilient so can tolerate high stocking rates for long periods….(ii) In buffel grass, rundown is an agronomic issue – 3:1 root:shoot biomass ratio and so N gets tied up in roots etc and start seeing rundown due to this*
>
> *Outside buffel not really a problem (less than 10%)…Higher percentage with buffel grass (50% or more)*
>
> *No issue with pasture rundown in this area – grazing management is the issue. Can restore poorly producing pastures with the right grazing management*

Nitrogen tie-up was recognised as the major mechanism in the decline of pastures that were not attributable to simple overgrazing. Estimates of the areas affected ranged from 50% to 100% of pastures that had been established for 5+ years. However, this nutrient-based rundown was recognised to be 'more-of an issue' on poorer soils.

Merchant/retailers prime market was cropping and they serviced pasture inquiries as they arose. They had varying experience in their current positions and different opinions on the extent of rundown. One was unaware of it, while another in the same town said 'everyone talks about it'. A retail agronomist who has worked in both southern and central Queensland noted that nutrient -based rundown was widespread in the south where pastures were on

soils not good enough to crop, but was not a big issue in central Queensland where people looked to more rain when production was down, not better soil nutrition.

Buffel's the main one (pasture) affected…everyone talks about it, has got it…Buffel is 'hungry' stuff

You can see it in most buffel…starts off well and drops off. …It's worst in the 'red country' but that's where most of it (the buffel) is. Maybe its worse where you can't plough up, so can't turn it and give it a tickle

There was a lot more comment on it at Goondiwindi where lots of comment that buffel doesn't go as well as it did. Farmers then want to change varieties….but its nutrition and a tickle up helps. Its inevitable. Up here its more fertile, certainly more potassium…so who knows when it will come (here as well). Up here (Biloela) its (loss of production) mostly water related…Up here they all talk buffel and the need for rain….

2. "How does it affect the seed industry (your business) and your clients?"

There was a fairly pessimistic view about current trading conditions and the future of the pasture seed industry. While most seed industry reps believed that rundown was negatively affecting their business, they saw development restrictions (e.g. tree clearing legislation) and tough economic times as larger deterrents to sales of pasture seed. The merchandise/retailers were mostly focussed on cropping and did not see rundown as a major impact on their business other than reduced sales of animal health products from the lower stock numbers that properties could carry.

Sown pasture is an issue for clients but the overriding factors are: (i) money is pretty tight so producers are not remediating their pastures, either by sown species or renovation with ploughs; (ii) clearing laws has stopped land development so limited amount of improved pastures being sown – this is causing significant issues with producers

Rundown and clearing guidelines are impacting on business – no more large-scale pasture establishment etc so sales have died…(But) there is a bigger impact of tree clearing laws than on sown pasture rundown for our business

Pasture rundown is affecting business. Producers are not dealing with it,…so not spending money on improved seed

Most seed industry representative believed that 'rundown' was affecting their clients through lower carrying capacity, poorer animal performance and lower economic returns.

Clients regularly report decreased paddock production in numbers of cattle able to be ran and/or fattened as time from development passes. Many report that pasture volume and height is noticeably lower as time progresses without actually being able to give an accurate % of loss

Lowers carrying capacity…but some are overstocking anyway. (Its) impacting on the number of head to run to make their properties viable…this hasn't been quantified (but it's) ultimately impacting on their profitability

Opinions on graziers' responses to rundown were split. Many graziers were considered to ignore the problem and just live with it. However, others were considered to investigate legumes because they could not simply develop new land and most of the land developed earlier did not include legumes.

> *Many people close their eyes and ignore the problem. (So) many producers don't admit they have a problem…only in drought years they talk about rundown. We sell more seed in drought years than in good years. We do better in droughts but need the good times to restore their faith in sown pastures (e.g. Rhodes performs better in wet seasons)*
>
> *Producers are just living with the reduced production from rundown*
>
> *Most country was developed without legume incorporation so allows more scope for sales and consultancy on legume variety choice, grazing management and method of establishment*
>
> *Pasture renovation has become a massive part of the industry as graziers come to realise the importance and value of renovation, legume incorporation and long term grazing management*
>
> *There is greater interest with Legumes into pasture as producers now can't clear any more land*
>
> *(In summary), there is an impact on Stocking rates and bottom line – but try telling them this! The cattle producer is the hardest to convince that spending a dollar will make a dollar - very hard to translate this message to the cattle producer. They are happy to spend big money on machinery expenses such as blade ploughing but low dollars on good pasture seed. Farmers are a lot easier to convince to spend $50/ha on seed due to their understanding that doing this will provide faster production on land with higher values. They are also use to spending large dollars on chemicals so spending some on pasture seed is not hard to convince.*

The combination of tough times, tree clearing restrictions and pasture rundown means seed sales are becoming smaller and there were concerns about the future of the industry. A recent swing back to open pasture varieties (not plant variety right protected lines) was also seen to be damaging some businesses as grazier bought less expensive seed from neighbours and other farmers

> *Rocky used to be a huge area for pastures but not anymore…sales in recent years are dropping right off*
>
> *Buffel sales have died permanently…some private though which we don't see. No big sales of legumes either. 100kg (is) a big sale to one person. Used to be 1000kg of legumes go out to one producer (e.g. Seca) but not any more*
>
> *Pasture industry is a minor business these days and might not be around into the future.*

These comments from and about the seed industry are of concern and present a serious challenge to continued production, supply and support of pasture species, and in particular the legumes, that are critical for sustainable grazing and mixed farming systems across Queensland in future.

3. "How do you advise clients to manage rundown in sown pastures?"

All seed industry reps and merchant/retailers have encouraged and supported their clients to address rundown with informed abatement methods. Their advice showed a good understanding of the process or rundown and their suggested methods all fall within one of the following three general approaches.

(i) Legume incorporation for N fixation and also for increased pasture quality - the detailed methods and sequencing for establishing legumes and ensuring sustainable mixed grass-legume pastures varied to include practices to move from cropping to pasture (legumes first, grasses first and legume and grass mixtures), use tillage or herbicides to kill existing grasses and introduce legumes with less grass competition, etc.

> *Legumes are the only way to go… We also advise to add in medics – only annuals but they do a job. There are ample grasses available on the market but legumes are the only way to go*
>
> *Legumes are the obvious answer*
>
> *We do provide recommendations on how to address rundown: (a) We tell them there is no silver bullet…(it) will take some time; (b) Put the steel away and apply stylos, Wynn cassia etc first, then cultivate. I prefer chisel plough over blade ploughs. Once legume seed bank going, then look at blade ploughing/chisel plough due to higher seed bank number – basically a numbers game. There will be a lot more seed from seed set than from the initial seeding to this improves plant pop after the tillage operation; (c) I have recommended spraying out pasture with roundup and sow legumes into this material – so I inform producers about the establishment techniques for legumes establish (more work on this is required however)*
>
> *Butterfly pea, burgundy bean, siratro, Wynn cassia…(its) soil type specific etc*

(ii) Renovation for woody weed control, legume and improved grass establishment, moisture retention and release of stored inorganic N trapped in the soil

> *Renovation probably an economical option – but only a bandaid, short term option*
>
> *Legumes seem to be the answer for rundown but some put legume seed out in blade plough situations and don't see establishment – due to N mineralisation and buffel takes over (comes back twice as good) and legumes can't persist*

(iii) Rotational grazing and limiting of grazing numbers to best maintain grass/legume balance and achieve sustainable, long term, economic production

> *Have seen that grazing management is the key – rotational grazing seems to correct production issues*

So advise producers to use rotational grazing management first, then discuss improved grass species options as well. Also getting a legume in is very important as well

Fertilisers were considered effective but too expensive by seed industry reps however, some retail agronomists believed that they were worthy of further investigation

Fertiliser is very expensive these days and once start using can't stop – so come back to cost structures – producers aim to minimise costs as best as possible. Therefore fertiliser is not an option.

Not economical to fertilise – but have done it prior to planting old cultivation using starter fertilisers. Or in the second summer in old cultivation have fertilised with N primarily. This is because in second or third year of pasture plants have high vigour and are taking N out, but there is no N cycling yet. So might run in some urea as a corrective application – not economical but do it to increase pasture life – up to about 50kg/N/ha.

Regardless of the strategy used, the methods that best matched the situation, it was felt that subsequent management will dictate the success after the seeding operation through stocking rates and whether the new pasture was locked up for up to 6-8 months after seeding etc.

4. "More information on legumes"

The northern regions of Australia have benefitted from stylos that have helped to maintain pasture quality, and medic and temperate legumes have been a boon for southern Australia. The sown pastures of Queensland also need a legume with grass species still making up the majority of seed sales.

The northern grazing & pasture sales industry has been very fortunate to have had the stylo legumes to use in the fight to maintain pasture quality. The stylos have limitation in that they do not do well in heavy clay soils and in higher frost prone areas and this is where the northern industry is in urgent need of a cold tolerant, rhizobium promiscuous heavy soil legume

Which legume? While everyone acknowledges the need to plant legumes, indeed to plant the right one for the situation at hand, there was considerable difference of opinion about how good each of the species were. Some of this may have been commercially-based with exclusive rights, but there was a wide range of views of individual pasture legumes. For example:

(i) Desmanthus

We sell legumes such as desmanthus and there is a big market for it out there. We find desmanthus is the only legume that persists in buffel grass country – have looked at them all in the past – stylos, BFP etc but desmanthus seems to be the best, especially in the drier years we have been having.

Still no really good legume to get into buffel grass – desmanthus and caatinga stylo are the only ones for long term productions but still someway away – need more seed to be multiplied and failures.

Desmanthus never got established due to poor seasons etc and PBR issues initially.
Desmanthus/caatinga stylo – question the value of these in the system. Nodulation is poor/ineffective. Rhizobium won't survive. Desmanthus is very slow to establish and doesn't appear to do the job.

(ii) Stylos (including caatinga)

Stylos are good in CQ…Seca stylo is the biggest legume seller in CQ, but sales have dropped off in recent time

Caatinga stylo ok with rhizobium

Caatinga stylo is a dead duck - very hard to establish, rhizobium an issue, doesn't seem to persist

(iii) Medics & vetches

Medics and vetches in the southern edge of the state are worth having in the system however medic years are few and far between though – every 2-3 yrs.

Vetch is the most underutilised legume we have. Do recommend applying Namoi (hard seeded) 2 -3 years in a row due to its hard seed to get an adequate population. Vetches (Namoi) are good for N fixation.

Medics – only sell a fraction compared to in the past due poor seasonal conditions and hence medics are not performing etc i.e. reliability issues

lucerne doesn't really fit – short lived

(iv) Burgundy Bean

In South QLD burgundy bean is an oxygen bandit... It's a ley legume only species (i.e. 2-3yrs) and not for long term pastures (palatability very high so cattle flog it out)

burgundy bean been ok in short term – but hard to manage with grazing management…(you) have heaps of DM or cattle flog it out – seems there is no happy medium.

(v) Others

Wynn cassia brilliant on acid soils

Atros (siratro) in coastal areas are good but high palatability but grow well due to higher rainfall (i.e. can keep up with the stocking rates). Atro has worked OK in Carnarvon area due to lower stocking rates and reasonable rainfall.

There was a recognition from one respondent that the pasture industry should look past our traditional views of where legumes are sown, particularly explore or re-visit the potential for sowing temperate winter legume species e.g. medics, vetches, clovers into more tropical environments e.g. coastal areas and inland CQ. This was on the basis that these species

might not perform every year, however in the right year (possibly 1yr in 3) would provide a useful contribution.

Establishment, persistence and grazing. Establishment, persistence and grazing management were all raised as key issues for use of legumes in pastures for feed quality and to abate sown pasture productivity decline. Discussion covered the issues of planting depth, seed quality, big production gains from weed control in pastures, whether to establish legumes and grass together or separately, and the importance of grazing management. Indeed, cattlemen were not considered by some seed industry/ reps/merchants to be good grazing managers. However, there were two specific issues that generated some interesting insights

Inoculation. While inoculation is important, it was also often ignored as seed may be surface sown and left in harsh conditions before rains arrive. As a consequence people sought better inoculation technology and 'promiscuous' legumes that could effectively use native Rhizobia.

To be useful in an extensive form legume should be rhizobium promiscuous, attaching to natural soil rhizobia to nodulate and fix N which is why the stylos - Seca/Siran/Amiga & Verano have been so successful. They also have the advantage of hard seed, drought tolerance and higher tannin content that allows for better grazing management, establishment and seed set under extensive grazing practices

We don't use rhizobium on desmanthus as in recent years a producer would plant seed and it would sit in dry soil for months – so the rhizobium won't last anyway. We have found that in some situations the native rhizobium takes hold but in other situations it hasn't.

Caatinga stylo ok with rhizobium. Inoculation only necessary for annual legumes. Don't bother with perennials particularly if tossed out of a plane (e.g. Seca) as rhizobium won't survive anyway. If a producer is going to plant legume into the soil would inoculate, but if broadcasting on surface won't bother

Don't inoculate seed crops so caatinga can pick up native rhizobiums. All stylos do nodulate with native rhizobiums but it might take some time – but Seca etc probably better than caatinga

Seed Coating. Seed coating is widespread in the industry. It helps with ease of sowing through machinery and applying ant treatments, inoculum etc. However, naked seed can provide greater numbers of viable seed. The retailers provided strong evidence of a large shift in attitude by graziers against seed coating. However, this is not reflected in the seed industry discussions.

All legumes seeds are scarified - 80% of sales verses bare seed. Less seeds/kg in coated seed but have a larger establishment rate – we work on seeds germinating in the first year. Coated including rhizobium but I do question the survival with surface sowing – typically high temps and low moisture

(From merchant/retailer) Guys ask for both bare and coated (seed). I prefer coated as it goes through the air-seeder into prepared seedbeds. (But some graziers) won't even buy (coated)…if you mention coated seed they just turn around and walk out the door…there's a huge mindset against coated seed

- *50% of people just go with your recommendation.*
- *50% don't want it, but you can get 20% into coated…but*
- *30% are died in the wool against coated*

lot more feeling this year than any other year (re coated seed)…e.g. sowing naked lucerne. For inoculation (coated) is good…but this year a few guys only went bare seed….and paid a significant premium

5. "What R,D&E would you like to see for sown pasture rundown?"

It is clear that money is tight in the pasture seed industry with businesses working on tight margins. It was suggested that more collaboration is needed between seed companies, DPI and industry consultants…and at least some businesses are keen to collaborate. A range of key R,D&E areas were nominated by interviewees.

so we need some money to do some R&D…We are keen to collaborate with DPI etc to undertake PDS trials – we can supply the seed so no problems here, and so develop things from there

(We need) greater communication and collaboration between graziers, pasture sales, industry bodies (e.g. Ag Force) and Government funded worlds - such as this review is always going to help

(i) Demonstrations and extension of the new grass and legume species that are available.

Companies have many new varieties that producers don't know much about - producers are very suspicions about new varieties…need to demonstrate to producers to improve adoption. Ongoing promotion of legumes is important

(ii) Develop and extend 'Management in pastures' to maximise the legume components in grass-pastures. There was a range of comments that people did not know how to get the best out of their pastures, especially their legumes. Suggested topics included: establishment; grazing management; species selection; soil fertility; and matching the system with the people, soils etc

The whole legume system needs work – management of the system – understanding the growth of legumes and their timing of palatability – including weight gains of adding in legumes into pastures.

There also needs better uptake of existing information – there is plenty of information available but some producers either ignore it or don't know about it

(iii) New species. There were suggestions for identification and development of new species. However, there was also a sense that we had the best already and that there was no magic legume still left uncovered.

(We) need a good perennial legume that establishes easily, fixes N and persists…looking at new varieties would be good but as we all know won't happen

Should industry look at developing existing legumes or look for new ones? Both are important so ideally do both.

Have exhausted the world's flora of species – no new species available to us

All levels of govt have said user pays – therefore the private sector has to breed and release varieties but domestic market so small there will never be any significant work in this area
For example there are 5 – 6 Rhodes grasses to be released based on export – salt tolerance and hay in middle east market. These will slot into domestic as well but this is not the main game. No one is going to pour $2-300K into a breeding program for the domestic market due to long time to payback (10yr +)…Therefore there needs to be a re-think of breeding and development work in pastures.

(iv) Develop and extend good economic comparisons of the major abatement strategies. Suggestions focussed around basic comparisons of: "Rundown pasture" Vs "Introducing legumes" Vs "Blade ploughing". Specific needs also included the assessment and economic comparisons of fertiliser treatments to address pasture rundown to establish some solid data for assessing feasibility

Increasing grazier awareness of the issue would help as well as trial data that shows the loss of production over a 5, 10 & 20 year period

Need to look at the short term profitability and long term profitability of
- *a rundown pasture with no intervention Vs,*
- *a rundown pasture with legumes Vs,*
- *blade plough very 6 – 8yrs.*

There is very limited work on fertiliser applications in the past – hard to find data
Applying fertiliser can catalyse the release of soil N so this should be looked at – instead of looking at legumes only – so look at the production of DM on different soil types with urea application

Work on economics – cost and returns of fertiliser applications – irrigation production etc

(v) Establishment is still seen as one of the major issues for pastures and especially for pasture legumes into existing pastures. RD&E to compare options and help people get the best out of their legume investments was identified as a priority

There needs to be a bigger look at establishment, especially best practice of establishing legumes into buffel pastures e.g. comparing aerial seeding, impacts of ground cover, spray topping etc

people don't know how to get the best establishment out of them…especially into established grass

(vi) Rhizobium - research into more effective inoculation technologies and contribution of native Rhizobium

There needs to be more awareness of rhizobium issues particularly with species that take a long time to establish.

We still recommend to inoculate anyway even though legumes might take months to establish - Newer technology with rhizobium is good as well

(vii) Grazing and animal performance

Grazing management is very important - this needs to be factored into the work – especially as when a legume is included grazing management needs to look at both the legume and the grass, therefore different management is needed.

Grazing management once established also very important… because many producers don't know any better and don't do it right

Cost of pasture rundown as well is very important – cold hard figures in front of producers – destocking, and restocking when seasons and pasture production is better – these sorts of scenarios

It's interesting that dairy producers are good pasture managers (they need to be to keep milk production up) however most cattleman are good with cattle but poor pasture managers – we need to educate cattlemen about pasture management

(viii) Leucaena - views were polarised about the need for further R,D&E on leucaena. There was a role for more work in southern Queensland but also an argument for focussing on other legume species

Pursue leucaena in SQLD – investigate soil types and environments it's going into

There has got to be a bigger future for leucaena – wonderful plant – high quality, drought and salt tolerance, very hardy tough plant.

The work on leucaena has been done. Need more work with other legumes but don't re-invent the wheel – research needs to be cutting edge – needs that wow factor so producers get excited and want to learn about new things

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9.3 Appendix 3: Economic returns from mitigation strategies

Table 28: Economic returns for mitigation strategies across four case study locations and three discount rates.

Mitigation Strategy	Moura				Clermont				Glenmorgan				Tambo			
	NPV / ha			B/C Ratio	NPV / ha			B/C Ratio	NPV / ha			B/C Ratio	NPV / ha			B/C Ratio
	6%	7%	8%	7%	6%	7%	8%	7%	6%	7%	8%	7%	6%	7%	8%	7%
Supplements	$13	**$12**	$11	**1.41**	$11	**$10**	$9	**1.40**	$5	**$5**	$4	**1.39**	$2	**$2**	$2	**1.37**
Blade Plough	$41	**$31**	$23	**1.12**	-$19	**-$22**	-$25	**0.88**	-$33	**-$37**	-$41	**0.86**	-$60	**-$58**	-$57	**0.48**
Chisel Plough	-$29	**-$27**	-$26	**0.65**	-$29	**-$27**	-$25	**0.52**	-$44	**-$41**	-$39	**0.48**	-$26	**-$24**	-$23	**0.27**
Fertiliser (60kg)	-$73	**-$67**	-$61	**0.93**	-$89	**-$81**	-$74	**0.87**	-$159	**-$145**	-$132	**0.84**	-$171	**-$155**	-$142	**0.63**
Fertiliser (60kg) (1/2 yrs)	$402	**$364**	$331	**1.79**	$251	**$227**	$206	**1.69**	$316	**$286**	$260	**1.62**	$54	**$48**	$43	**1.22**
Fertiliser (60kg) (1/3 yrs)	$560	**$507**	$462	**2.60**	$364	**$329**	$299	**2.45**	$474	**$429**	$390	**2.35**	$128	**$115**	$105	**1.77**
Fertiliser (120kg)	-$33	**-$30**	-$27	**0.98**	-$105	**-$95**	-$87	**0.92**	-$222	**-$202**	-$185	**0.88**	-$240	**-$219**	-$200	**0.71**
Fertiliser (120kg)(1/2 yrs)	$869	**$787**	$717	**1.90**	$539	**$488**	$444	**1.78**	$679	**$614**	$559	**1.70**	$167	**$150**	$136	**1.38**
Fertiliser (120kg)(1/3 yrs)	$1,169	**$1,059**	$965	**2.76**	$754	**$682**	$621	**2.59**	$980	**$886**	$807	**2.47**	$302	**$273**	$247	**2.00**
Herbicide	-$5	**-$6**	-$7	**0.94**	-$19	**-$18**	-$18	**0.74**	-$34	**-$32**	-$31	**0.67**	-$30	**-$28**	-$26	**0.33**
Cultivated Fallow	$126	**$114**	$103	**1.54**	$38	**$33**	$28	**1.22**	$42	**$35**	$30	**1.17**	-$34	**-$33**	-$32	**0.63**
Leucaena	$1,506	**$1,332**	$1,184	**5.43**	$816	**$721**	$640	**4.99**	$997	**$879**	$779	**4.65**	-	**-**	-	**-**
Legume BP	$468	**$396**	$336	**3.26**	$256	**$213**	$176	**2.70**	$372	**$312**	$261	**2.99**	$52	**$37**	$25	**1.50**
Legume CF	$686	**$606**	$538	**5.04**	$389	**$341**	$300	**4.16**	$555	**$489**	$432	**4.67**	$100	**$84**	$70	**2.30**
Legume CS	$610	**$532**	$466	**9.07**	$361	**$314**	$274	**7.55**	$510	**$444**	$388	**8.19**	$109	**$93**	$80	**4.28**
Legume HS	$516	**$442**	$379	**10.86**	$308	**$263**	$225	**9.00**	$436	**$373**	$320	**10.18**	$96	**$81**	$68	**5.15**

BP – blade plough; CF – cultivated fallow; CS – cultivated strip; HS – herbicide strip.

9.4 Appendix 4: Spatial data set descriptions.

Queensland Land Use: This dataset is a digital land use map of the state of Queensland. As nearly as possible it shows land use in 1999. The dataset is a product of the Queensland Land Use Mapping Program (QLUMP) and was produced by QDNRM. It is part of a national catchment scale land use mapping project coordinated by the Commonwealth Bureau of Rural Sciences (BRS) and being undertaken by QDNRM as well as government agencies in other states and territories. The dataset is a baseline (1999) land use map for the entire state and comprises one digital map in vector format at nominal scales of 1:50,000 and 1:100,000, dependent on intensity of land use in individual catchments. The map consists of a mosaic of 79 catchment-based land use datasets. Coordinates are geographic referred to the Geocentric Datum of Australia 1994 (GDA94) on the Geodetic Reference System 1980 (GRS80) ellipsoid. The map is a polygon coverage with each polygon having attributes describing land use. Land use is classified according to the Australian Land Use and Management Classification (ALUMC) Version 5, February 2002.

Foliage Projected Cover: Statewide Landcover and Trees Study (SLATS) 2005 Woody Vegetation Extent and Over-storey Foliage Projective Cover (FPC) Ver. 2.1 Dec 2007, Landsat SLA
Foliage projective cover (FPC) is the percentage of ground area occupied by the vertical projection of foliage. The product described here is calibrated to over-storey FPC. The SLATS FPC mapping involves an automated decision tree classification technique with a nominal accuracy of 85%. Landsat image dates used in the classification were all dry season (May to October). The field data used to calibrate the imagery / FPC relationship was mostly collected over the 1996–1999 period. A number of corrections were applied to minimise the effects of topography, cloud, cloud shadow, water bodies and regrowth on the resulting product. Limitations of the product include:- some areas of regrowth being classified as non-woody; some recently cleared areas being classified as woody, and errors due to residual topographic effects. The analysis has been completed on each of 87 satellite scenes.

GLM Land Types: The GLM Land Types of Queensland is the spatial representation of Queensland Grazing Land Management (GLM) Land Types as described by the Queensland Department of Employment, Economic Development and Innovation (DEEDI). The spatial representation of GLM land types has been produced by the Department of Environment and Resource Management by correlating Queensland Grazing Land Management Land Type's (version 1.3) textual data with Pre-clearing Vegetation Communities and Regional Ecosystems of Queensland (version 6b) spatial data. This has produced land type mapping at a map scale of 1:100,000 and 1:50,000 in part. The map scale of 1:50,000 applies to part of South-eastern Queensland and map amendments areas. GLM Land types are described in terms of their landform; woody vegetation; expected pasture composition (including suitable sown pastures and introduced weeds); and soil characteristics. Limitations to use of the land and grazing management recommendations are also provided. More than 230 land types from 19 grazing land management regions in Queensland have been described. Development and compilation of the names and descriptions of the 'Land types of Queensland' was undertaken by Queensland Department of Employment, Economic Development and Innovation (DEEDI) Grazing Land Management Team (formerly of DPI&F). A CD of these descriptions came be obtained by calling the Business Information Centre on 13 25 23, or online at www.deedi.qld.gov.au and searching for 'Land Types of Queensland'

9.5 Appendix 5: Land types – buffel presence, suitability for legumes, suitability for mechanical renovation

The following tables describe land types (Whish 2010) considered to have buffel densities of "dominant" or "common" and whether they are technically suitable for legumes and mechanical renovation for the purposes of the spatial analysis described in Section 6.1. Land types not in the following tables are considered to have buffel grass densities of "isolated/absent". The definitions of the pasture density terms are:

- Dominant - Buffel normally occurs on these land types and is expected to be dominant in the pasture sward.
- Common - Buffel occurs widely on these land types (e.g. 20% - 80% of land area) and where it occurs it is a large percentage of the pasture sward.
- Isolated/Absent - Buffel is seldom on these land types but may occur sporadically and is unlikely to comprise a large percentage of the pasture sward.

Table 29: Border rivers region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus; SA – some areas, for leucaena this means >120cm).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Leucaena	Burgundy Bean	Medics	Shrubby stylo	Fine stem stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Belah and Brigalow plains on texture contrast soils	BR01	Dominant	High		Yes	Yes			Yes	Yes	Yes	Yes	Yes
Poplar box flats	BR17	Dominant	Low	SA		Yes			Yes			Yes	Yes
Poplar box on red soils	BR19	Dominant	Low			Yes			Yes		Yes	Yes	Yes
Softwood vine scrub on clay or loam	MB18	Dominant	Medium	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes

Table 30: Maranoa, Balonne region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus; SA – some areas, for leucaena this means >120cm of effective rooting depth).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Leucaena	Burgundy Bean	Medics	Shrubby stylo	Fine stem stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Gum-topped box flats	FT16	Common	Low									Yes	
Mountain coolibah woodlands	FT19	Common	Medium			Yes			Yes			SA	
Brigalow with melanholes	MB04	Common	High	SA	Yes	Yes			Yes	Yes		Yes	
Cypress Pine on deep sands	MB06	Common	Low					Yes			Yes	Yes	Yes
Poplar box/silver leaved ironbark	MB13	Common	Low			Yes			Yes			Yes	
Poplar box with mulga understorey	MB14	Common	Medium								Yes	Yes	Yes
Soft mulga	MB17	Common	Low								Yes	Yes	Yes
Wooded downs	MGD06	Common	Medium		SA	Yes			Yes	Yes	Yes	Yes	Yes
Gidyea	MU03	Common	Low			Yes			Yes	Yes	Yes	Yes	Yes
Brigalow belah scrub	MB03	Dominant	High	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
Poplar box on alluvial plains	MB11	Dominant	Medium			Yes			Yes			Yes	Yes
Poplar box on duplex soils	MB12	Dominant	Medium	Yes		Yes			Yes			Yes	Yes
Poplar box with sandalwood understorey	MB15	Dominant	Medium			Yes			Yes			Yes	Yes
Poplar box / brigalow	MB16	Dominant	Low			Yes			Yes		Yes	Yes	Yes
Softwood vine scrub on clay or loam	MB18	Dominant	Medium	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes

Table 31: Inland Burnett region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus; SA – some areas, for leucaena this means >120cm and for butterfly pea >90cm of effective rooting depth).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Leucaena	Butterfly pea	Burgundy Bean	Medics	Shrubby stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Bastard scrub	IB01	Common	Low					Yes			Yes	Yes	Yes
Brigalow and belah scrub	IB07	Common	Medium	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Brigalow melon-hole	IB08	Common	Medium	SA	Yes	Yes	Yes		Yes	Yes		Yes	
Ironbarks on basalt upper slopes and benches	IB12	Common	Medium		Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Softwood scrub	IB18	Common	Medium	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainforest (closed forests) on basalts	MO09	Common	High		Yes	Yes		Yes	Yes		Yes	Yes	Yes

Table 32: Fitzroy region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus; SA – some areas, for leucaena this means >120cm and for butterfly pea >90cm of effective rooting depth).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Leucaena	Butterfly pea#	Burgundy Bean	Medics*	Shrubby stylo	Caribbean stylo#	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Blue gum river red gum flats	FT02	Common	High	Yes	Yes		Yes	SA	SA	Yes	Yes	Yes	Yes	Yes
Box flats	FT03	Common	Low		SA	SA	Yes	Yes	Yes	Yes			Yes	Yes
Coolibah floodplains	FT11	Common	Medium	Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
Alluvial brigalow	FT01	Dominant	High	Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
Brigalow with softwood scrub species	FT06	Dominant	High	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Softwood scrub	FT29	Dominant	High	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Brigalow blackbutt	FT04	Dominant	Medium	SA	SA	SA	Yes	Yes	Yes	Yes		Yes	Yes	Yes
Brigalow with melanholes	FT05	Dominant	Medium	SA	Yes	Yes	Yes		Yes	Yes	Yes		Yes	
Poplar box / brigalow / bauhinia	FT26	Dominant	Medium				Yes	Yes	Yes			Yes	Yes	Yes

* Medics considered suitable south of Isla gorge and Carnarvon range. # Butterfly pea and Caribbean stylo considered suitable north of Isla gorge and Carnarvon range

Table 33: Burdekin region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus; SA – some areas, for leucaena this means >120cm and for butterfly pea >90cm of effective rooting depth).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Leucaena	Butterfly pea	Burgundy Bean	Shrubby stylo	Caribbean stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Box country	BD05	Common	Medium				Yes	Yes				Yes	Yes
Clayey alluvials	BD08	Common	Medium	SA	Yes	Yes			Yes	Yes	Yes	Yes	Yes
Goldfields country - black soils	BD10	Common	High		Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Goldfields country - red soils	BD11	Common	Low				Yes	Yes	Yes		Yes	Yes	Yes
Loamy alluvials	BD13	Common	Medium		Yes		Yes	Yes	Yes		Yes	Yes	Yes
Silver-leaved ironbark	BD18	Common	Low		SA		Yes	Yes	Yes		Yes	Yes	Yes
Box country	DU01	Common	Low				Yes	Yes				Yes	Yes
Scrubs on shallow clays	DU12	Common	Low					Yes	Yes			Yes	
Eucalypts and bloodwood on clays	FT13	Common	Medium	SA	Yes	Yes		Yes	Yes		Yes	Yes	Yes
Eucalypts and bloodwood on loamy red tablelands	FT14	Common	Low				Yes	Yes	Yes		Yes	Yes	Yes
Alluvial flats and plains	MW01	Common	High				Yes	Yes			Yes	Yes	Yes
Alluvial	WT01	Common	High	Yes			Yes	Yes			Yes	Yes	Yes
Brigalow/gidgee scrubs	BD06	Dominant	Medium	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
Softwood scrub	BD19	Dominant	Low	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes
Scrubs on deep clays	DU11	Dominant	High	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Poplar box / brigalow / bauhinia	FT26	Dominant	Medium				Yes	Yes			Yes	Yes	Yes

Table 34: Desert Uplands region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Shrubby stylo	Des.	Blade plough	Chisel plough	Short term fallow
Box country	DU01	Common	Low	Yes			Yes	Yes
Frontal dunes	DU06	Common	Low	Yes			Yes	
Scrubs on shallow clays	DU12	Common	Medium				Yes	
Wooded downs	MGD06	Common	Medium		Yes	Yes	Yes	Yes
Open alluvia	MGD14	Common	Medium		Yes	Yes	Yes	Yes
Scrubs on deep clays	DU11	Dominant	Medium		Yes	Yes	Yes	Yes
Brigalow blackbutt	FT04	Dominant	Medium	Yes		Yes	Yes	Yes

Table 35: Mulga region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. Legume suitability for areas east of Charleville/Cunnamulla. (Codes – Des – Desmanthus).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Burgundy Bean	Medics	Shrubby stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Cypress Pine on deep sands	MB06	Common	Low						Yes	Yes	Yes
Cypress Pine on duplex soils	MB07	Common	Low							Yes	
Narrow-leaved ironbark	MB10	Common	Low							Yes	
Poplar box/silver leaved ironbark	MB13	Common	Low		Yes		Yes			Yes	
Mulga sand plains	MU05	Common	Low						Yes	Yes	Yes
Poplar box woodlands - Red soil	MU08	Common	Low		Yes		Yes		Yes	Yes	Yes
Soft mulga	MU09	Common	Low						Yes	Yes	Yes
Frontage / alluvial country	CC04	Common	Medium	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Brigalow with melanholes	MB04	Common	Medium	Yes	Yes		Yes	Yes		Yes	
Brigalow	MU01	Common	Medium	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Gidyea	MU03	Common	Medium	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Poplar box on alluvial plains	MB11	Dominant	Low		Yes		Yes			Yes	Yes
Poplar box on duplex soils	MB12	Dominant	Low							Yes	Yes
Brigalow belah scrub	MB03	Dominant	Medium	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Poplar box with sandalwood understorey	MB15	Dominant	Medium		Yes					Yes	Yes
Poplar box / brigalow	MB16	Dominant	Medium		Yes		Yes	Yes	Yes	Yes	Yes
Softwood vine scrub on clay or loam	MB18	Dominant	Medium	Yes	Yes		Yes	Yes	Yes	Yes	Yes

Table 36: Mitchell grass downs region land types - buffel presence, fertility and suitability for mechanical renovation. Legumes considered unsuitable in the region due to low rainfall.

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Blade plough	Chisel plough	Short term fallow
Box country	DU01	Common	Low		Yes	Yes
Frontage	SG04	Common	Medium	Yes	Yes	Yes
Gidyea country	SG05	Common	Medium	Yes	Yes	Yes
Hard gidyea	MGD08	Common	Low			
Ironbark country	DU08	Common	Low	Yes	Yes	Yes
Mulga sand plains	MU05	Common	Low	Yes	Yes	Yes
Occasionally flooded alluvia (C2)	CC02	Common	Medium	Yes	Yes	Yes
Open alluvia	MGD14	Common	Medium	Yes	Yes	Yes
Open red country	SG11	Common	Low	Yes	Yes	Yes
Sandy forest country	SG13	Common	Low	Yes	Yes	Yes
Scrubs on shallow clays	DU12	Common	High		Yes	
Soft mulga	MU09	Common	Low	Yes	Yes	Yes
Wooded alluvia	MGD15	Common	Low	Yes	Yes	Yes
Wooded downs	MGD06	Common	Medium	Yes	Yes	Yes
Wooded downs	MU11	Common	Low	Yes	Yes	Yes
Brigalow	MU01	Dominant	Medium	Yes	Yes	Yes
Brigalow belah scrub	MB03	Dominant	Medium	Yes	Yes	Yes
Gidyea	MU03	Dominant	Medium	Yes	Yes	Yes
Poplar box woodlands - Red soil	MU08	Dominant	Low	Yes	Yes	Yes
Scrubs on deep clays	DU11	Dominant	Medium	Yes	Yes	Yes
Soft gidyea	MGD07	Dominant	Medium	Yes	Yes	Yes

Table 37: Northern Gulf region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus).

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Shrubby stylo	Caribbean stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Frontage	NG03	Common	High	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Old alluvials	NG07	Common	Medium	Yes	Yes			Yes	Yes	Yes
Gidyea country	SG05	Common	Medium			Yes	Yes	Yes	Yes	Yes

Table 38: Southern Gulf region land types - buffel presence, fertility, legume suitability and suitability for mechanical renovation. (Codes – Des – Desmanthus).

Dominant Land Type	Land Type Code	Buffel presence*	Fertility	Shrubby stylo	Caribbean stylo	Caatinga stylo	Des.	Blade plough	Chisel plough	Short term fallow
Open downs	MGD01	Common	Medium					Yes	Yes	Yes
Open alluvia	MGD14	Common	Medium				Yes	Yes	Yes	Yes
Frontage	SG04	Common	Medium	Yes	Yes			Yes	Yes	Yes
Gidyea country	SG05	Common	Medium			Yes	Yes	Yes	Yes	Yes
Open red country	SG11	Common	Medium	Yes	Yes			Yes	Yes	Yes
Rough spinifex country	SG12	Common	Low							
Silver leaf box on open red country	SG14	Common	Low	Yes	Yes			Yes	Yes	Yes
Silver leaf box with perennials	SG15	Common	Low	Yes	Yes			Yes	Yes	Yes
Silver leaf box with spinifex	SG16	Common	Low					Yes	Yes	Yes

* Buffel more common in southern part e.g. Cloncurry region + hollows of Mt Isa uplands

Table 39: Channel country region land types - buffel presence, fertility and suitability for mechanical renovation. Legumes considered unsuitable in the region due to low rainfall.

Dominant Land Type	Land Type Code	Buffel presence	Fertility	Blade plough	Chisel plough	Short term fallow
Occasionally flooded alluvia (C2)	CC02	Common	Medium	Yes	Yes	Yes
Gidyea woodlands	CC05	Common	Medium	Yes	Yes	Yes
Soft gidyea	MGD07	Common	Medium	Yes	Yes	Yes
Brigalow	MU01	Common	Medium	Yes	Yes	Yes
Gidyea	MU03	Common	Medium	Yes	Yes	Yes
Soft mulga	MU09	Common	Low	Yes	Yes	Yes