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A grazier survey of the long-term productivity of leucaena (*Leucaena leucocephala*)-grass pastures in Queensland

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Abstract. *Leucaena leucocephala* subsp. *glabrata* (leucaena)-grass pastures are productive, perennial and long-lived (>40 years). However, little is known about changes in the productivity of these pastures as they age even though they are grazed intensively and are rarely fertilised. A postal survey of beef cattle producers in Queensland who grow leucaena pastures was conducted. The questionnaire gathered information regarding: property location; extent and age of leucaena pastures; soil type; leucaena and grass establishment methodology; grazing and fertiliser management; and grazier perceptions of changes over time in leucaena productivity, grass growth and ground cover, prevalence of undesirable grasses and weeds, and livestock productivity. Graziers were asked to report on both young (≤10 years old) and aging (>10 years old) pastures under their management. Eighty-eight graziers responded describing 124 leucaena paddocks covering 11 750 ha. The survey results described the typical physical and management characteristics of leucaena pastures in Queensland. Graziers reported a decline in leucaena productivity in 58% of aging pastures, and declines in grass growth (32%) and livestock productivity (42%) associated with declining leucaena growth. Leucaena decline was greater in soil types of marginal initial fertility, particularly brigalow clay, soft wood scrub, downs and duplex soils. Maintenance fertiliser was not applied to most (98%) leucaena pastures surveyed despite significant amounts of nutrient removal, particularly phosphorus and sulphur, occurring over prolonged periods of moderate to high grazing pressure. It is predicted that large areas of leucaena pasture will continue to suffer soil nutrient depletion under current management practices. Research is needed to develop ameliorative actions to reinvigorate pasture productivity.

Introduction

The fodder tree legume *Leucaena leucocephala* (Lam.) de Wit subsp. *glabrata* (Rose) Zárate (leucaena) planted in hedgerows with companion grass (leucaena pasture) is one of the most productive, profitable and sustainable grazing systems in subtropical and tropical northern Australia (Shelton and Dalzell 2007). Leucaena produces protein-rich fodder that increases the liveweight gain (LWG) of beef cattle by more than 70% compared with pure grass pastures, achieving gains of 275–300 kg/head.year (Mullen *et al*. 2005). Leucaena has a deep root system that exploits subsoil moisture and nutrients beyond the reach of grass roots, thus remaining productive in the dry season when tropical grasses mature and contain insufficient protein and digestible energy to sustain animal growth. For these reasons, leucaena pastures have become a valuable forage option for large-scale beef production, not only in Queensland, but also in other subtropical and tropical regions of the world, such as the Chaco region in South America.

A long and productive life of the leucaena component is a key contributor to profitability of leucaena pastures (Shelton and Dalzell 2007). A long-term study of persistence under grazing of individual trees (cv. Peru) grown in a grid pattern with companion-sown grass on well drained alluvial soils at Samford, south-east Queensland (1100 mm average annual rainfall) revealed average tree survival rates of 89% at 16–20 years, 82% at 25–29 years, 76% at 31–35 years and 74% at 37–41 years after planting, respectively, (Jones and Harrison 1980; Jones and Bunch 2000). These pastures experienced on average eight frosts each year (many <−3°C), were periodically slashed in winter and received 440 kg phosphorus (P)/ha applied between 1959 and 1996 (Noble *et al*. 1998). A more rapid decline in leucaena plant population was observed in an adjacent well fertilised [123 kg P/ha and 52 kg potassium (K)/ha were applied over the period] pasture with 47% plant survival 23 years after planting. The higher rate of plant mortality was caused by a combination of poorly drained podzolic soil and regular severe defoliation under rotational grazing which reduced the size of the plants woody inedible framework and weakened them (Jones and Bunch 1995). It is presumed that these increasing rates of mortality were preceded by weakening and thus declining productivity of the leucaena plants.

No other published information on the productive lifespan of leucaena pastures under extensive grazing has been sighted, probably related to the fact that most grazed leucaena pastures are currently <20 years old. Commercial plantings for extensive grazing in Queensland commenced in 1979 and reached 450 ha by 1981 (Wildin 1981); 3000 ha by 1985 (Wildin 1985); ~20 000 ha by 1992 (Wildin 1994); and over 150 000 ha

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planted to date (Shelton and Dalzell 2007). Most of these pastures have been heavily grazed, often without fertiliser application, and it is not known if there has been any loss of vigour or decline in productivity since planting.

A survey was conducted to describe typical leucaena pastures in Queensland, determine current management practices that influence pasture productivity and resilience, and ascertain graziers' perceptions of changes over time in leucaena pasture and livestock productivity. The objective of the study was to identify and assess the importance of factors influencing long-term productivity of leucaena pastures.

Materials and methods

Grazier recruitment

In October 2005, a questionnaire was posted to 200 Queensland graziers identified from the membership list of The Leucaena Network, a volunteer group of graziers and researchers who promote research and development for leucaena pastures in Australia (McLaughlin *et al*. 2005). This survey study was approved by the Behavioural and Social Sciences Ethical Committee, The University of Queensland (Ethical Clearance No. 2005000607).

Questionnaire

Graziers were asked to choose two typical paddocks, a younger and an older pasture, that best represented the performance of well established leucaena pastures on their property. Graziers were asked to describe the condition and management of their chosen leucaena pastures and give their perceptions of changes in leucaena, grass and livestock productivity that may have occurred over time by comparing productivity in the last 2 years (i.e. the current productivity) with their recollection of productivity 2–3 years after planting the pasture. The 37-item questionnaire was organised in four sections: (i) property location and extent and age of leucaena pastures; (ii) soil type and establishment methodology of leucaena and grass; (iii) grazing and fertiliser management; (iv) perceptions of changes over time in leucaena productivity, grass growth and ground cover, prevalence of undesirable grasses and weeds, and livestock productivity. Sections 2, 3 and 4 were multiple-choice questions (with up to five possible responses) including extra space to allow graziers to choose another option and/or to make comments. Questions and optional responses were prepared after interviews with leucaena growers and technicians, and from a review of literature. A draft questionnaire was tested with 10 graziers to ensure there was no ambiguity about the meaning of each question. The survey questionnaire is available as an Accessory Publication to this paper.

Statistical analyses

For statistical analyses, pastures were categorised as being young ($\leq$10 years old) or aging (>10 years old) based on age since planting irrespective of whether the grazier categorised them as 'younger' or 'older'. Data were tested using the analysis of general linear models (ANOVA and correlation analysis) and/or Pearson Chi-square analyses and logistic regression (binary and ordinal). The hypothesis that forage and livestock productivity in aging pastures was lower than in young pastures was tested. To test the hypothesis, the frequency distribution of the responses to each question was compared between young and aging pastures. Factors affecting the distribution of these responses (e.g. soil type, and grass and weed cover) were examined. Statistical analyses were conducted using Minitab 15 (2007, Minitab, State College, PA, USA).

Results

Leucaena pastures surveyed

One hundred and two graziers responded to the questionnaire (51%), of whom 88 had leucaena pastures under grazing and their complete responses were further analysed. Fifty-three graziers reported on a single paddock, 34 reported on two paddocks and one reported on three paddocks. Surveys were thoroughly answered with few missing responses. The 88 leucaena growers had a total area of 24 223 ha of leucaena pastures with an average 275 ha per property (median 134 ha, range 6–2024 ha) and the majority (>70%) had <324 ha. They reported the forage and animal performance on 124 leucaena pastures (selected paddocks), covering an area of 11 750 ha, with an average of 74 ha (median of 53 ha) per paddock. The age of leucaena ranged from 1 to 30 years; the average age was 7.7 years and the median age was 5 years. Ninety-two of these leucaena pastures (74%) were young ($\leq$10 years old) and 32 (26%) were aging (>10 years old). ANOVA and Chi-square analyses compared the characteristics of the young and aging pastures selected by graziers and revealed both pasture groups were similar ($P > 0.05$) in terms of paddock area; grass composition, establishment methods, ground cover and vigour of growth; fertiliser application practices; and grazing system, management and intensity employed. There was no significant correlation between leucaena age and paddock area under leucaena. However, distribution of paddock area significantly changed with age ($P = 0.004$; binary logistic regression); all large paddocks >160 ha (n = 8) were <12 years old, whereas most (70%) aging leucaena pastures were in small paddocks <60 ha.

Most leucaena pastures (95%) were located in the 600–800-mm average annual rainfall zone of central and southern Queensland. One hundred and seventeen of the pastures were dryland (94%) and only seven pastures (6%) were irrigated.

Description of leucaena pastures

Most leucaena pastures (84% in both ages) were growing on either brigalow clay (Vertosol), alluvial (Kandosol, Vertosol) or softwood scrub soils (Dermosol, Ferrosol, Vertosol), with 16% established on downs (Vertosol) and duplex soils (Chromosol) (Isbell 1996) (Table 1). The distributions of plantings on soil types between young and aging pastures were not significantly different.

Leucaena was planted before grass in most pastures (62%), and at the same time as grass in a few pastures (6%) (Table 2). Leucaena was less frequently planted into existing sown or native grass pastures (20%). No grass was sown in some pastures (13% in both ages) where there was insufficient soil moisture after leucaena establishment. Graziers commented that

Table 1. Dominant soil types in leucaena pastures
n.s., not significant

Soil type	Young pastures (n = 92) (≤10 years old)		Aging pastures (n = 32) (>10 years old)	
	n	%	*n*	%
Brigalow clay (Vertosol)	38	41.3	12	37.5
Alluvial (Kandosol, Vertosol)	21	22.8	11	34.4
Softwood scrub (Dermosol, Ferrosol, Vertosol)	18	19.6	4	12.5
Downs (Vertosol)	10	10.9	1	3.1
Duplex (Chromosol)	5	5.4	4	12.5
Difference between distributions		n.s. (P = 0.266)		

Table 2. Planting methods of leucaena pastures
n.s., not significant

Method	Young pastures (≤10 years old)		Aging pastures (>10 years old)	
	n	%	*n*	%
Planting method of leucaena and grass	n = 92		n = 31	
Grass sown after leucaena establishment	57	62.0	19	61.3
Grass sown same time as leucaena	5	5.4	2	6.5
No grass sown in the inter-row	12	13.0	4	12.9
Leucaena planted into sown grass	17	18.5	4	12.9
Leucaena planted into native pasture	1	1.1	2	6.5
Difference between distributions		n.s. (P = 0.998)		
Row spacing	n = 91		n = 32	
Less than 3 m	0	0	2	6.2
Between ~3 and 4 m	19	20.9	5	15.6
Between ~5 and 6 m	48	52.7	19	59.4
Between ~7 and 8 m	15	16.5	3	9.4
More than 8 m	9	9.9	3	9.4
Difference between distributions		n.s. (P = 0.795)		

the leucaena plant density within rows in the establishment year was higher in younger pastures (P = 0.034) than in older pastures; on brigalow clay and soft wood scrub soils than in alluvial or duplex soils (P = 0.025); and in twin rows (P = 0.01) than in single rows.

Row spacing (centre to centre for twin row configurations) ranged from 3 to 8 m with 54% of pastures having spacing of 5–6 m (Table 2). The distributions of row spacing were similar for both ages. The two paddocks that had row spacing <3 m were old paddocks (17 and 25 years old). Independent of row spacing, the use of single versus twin rows was different (P < 0.001) with most young leucaena stands planted in twin rows (64%) whereas most aging stands were planted in single rows (78%). Twin rows are typically spaced 50–100 cm apart (Dalzell *et al*. 2006).

Most graziers responded that grass was important for both cattle production and the long-term sustainability of leucaena pastures (96 and 92%, respectively). Grass establishment strategies were similar for young and aging pastures (Table 2) and were not related to soil type. The most common grass species used were the introduced species buffel grass (*Cenchrus ciliaris* L.) and green and Gatton panic (*Panicum maximum* Jacq.) and various native grasses such as Queensland blue grass [*Dichanthium sericeum* (R.Br.) A. Camus subsp. *sericeum*], forest blue grass [*Bothriochloa bladhii* (Retz.) S.T. Blake subsp. *glabra* (Roxb.) B.K. Simon] and black spear grass (*Heteropogon contortus* L.) (Table 3). Other improved grass species used were Rhodes (*Chloris gayana* Kunth), Bambatsi (*Panicum coloratum* L. var. *makarikariensis* Gooss), sabi [*Urochloa mosambicensis* (Hack.) Dandy], creeping blue [*Bothriochloa insculpta* (Hochst. ex A. Rich.) A. Camus] and pangola (*Digitaria eriantha* Steud.). The distributions of grass species used in young and aging pastures were not significantly different.

Grazing and fertiliser management

Most leucaena pastures (84%) were managed under rotational and seasonal grazing systems (Table 4), with 11% managed under continuous grazing. Cell grazing was used in 5% of pastures surveyed, mainly on larger properties. The height of leucaena plants after grazing was between 1 and 2, and 2 and 3 m in most of the pastures (82%) and >3 m and <1 m in few leucaena pastures (15 and 3%, respectively). Neither age nor height of leucaena

Table 3. Grass species sown into leucaena pastures
n.s., not significant

Planted grass species	Young pastures ($n = 87$) (≤10 years old)		Aging pastures ($n = 32$) (>10 years old)	
	n	%	*n*	%
Buffel grass	48	55.2	15	46.9
Green and Gatton panic	16	18.4	6	18.8
Native grasses	10	11.5	6	18.8
Rhodes grass	6	6.9	5	15.6
Bambatsi	4	4.6	0	0
Others: sabi, creeping blue and pangola	3	3.4	0	0
Difference between distributions		n.s. ($P = 0.190$)		

Table 4. Grazing and fertiliser management employed for leucaena pastures
n.s., not significant

Management	Young pastures (≤10 years old)		Aging pastures (>10 years old)	
	n	%	*n*	%
Grazing system	$n = 88$		$n = 32$	
Rotational grazing	48	54.5	12	37.5
Seasonal grazing	27	30.7	14	43.7
Continuous grazing	10	11.4	3	9.4
Cell grazing	3	3.4	3	9.4
Difference between distributions		n.s. ($P = 0.232$)		
Grazing pressure	$n = 88$		$n = 32$	
Very high	5	5.7	0	0
High	50	56.8	14	43.7
Moderate	31	35.2	16	50.0
Low	2	2.3	2	6.3
Difference between distributions		n.s. ($P = 0.172$)		
Fertilisation application	$n = 92$		$n = 29$	
Never	82	89.1	25	86.2
At leucaena establishment	9	9.8	3	10.3
Not at establishment, but occasionally thereafter	1	1.1	1	3.5
Difference between distributions		n.s. ($P = 0.265$)		

pasture was associated with the grazing system employed. The results from two questions regarding grazing pressure (stocking rate and leucaena leaf remaining after grazing) were integrated to create an indicator of grazing pressure (low, moderate, high and very high). The distributions of responses to grazing pressure applied in young and aging pastures were not different (Table 4).

Most pastures (88%) had never been fertilised (Table 4) with 10% fertilised at establishment and 2% not fertilised at establishment but occasionally thereafter. The distribution of survey responses to fertiliser application questions did not differ according to age of pasture.

Changes in pasture and livestock productivity over time

Current leucaena productivity was categorised as better in young than in aging pastures ($P < 0.001$) (Table 5). Most graziers (80%) reported zero or few volunteer leucaena seedlings becoming established in the grass inter-row. In aging pastures, significantly fewer ($P < 0.05$) seedlings were reported under continuous grazing than seasonal or rotation grazing.

The current status of grass growth was categorised as excellent or good in most leucaena pastures (77% of young and 61% of aging pastures) (Table 5), and current grass ground cover was more than 60% in most leucaena pastures (67% of young and 81% of aging pastures) (Table 5). Grass vigour was reported to be better ($P < 0.05$) under continuous and rotational grazing than seasonal grazing. However, current grass ground cover was not associated with grass species, planting method, soil type, row spacing or grazing system. Vigour of grass in the first 2–3 years after planting was associated ($P = 0.025$) with the grass species, with buffel grass more vigorous than green and Gatton panic. As many of the pastures surveyed were <5 years old, grass cover 2–3 years after planting and in the current condition were highly correlated and there was no significant difference observed in current grass growth and ground cover between young and aging leucaena pastures.

Table 5. Current condition (last 2 years) of leucaena pastures
n.s., not significant

Condition	Young pastures (≤10 years old)		Aging pastures (>10 years old)	
	n	%	*n*	%
Leucaena growth	*n* = 74		*n* = 30	
Excellent	26	35.1	1	3.3
Good	27	36.5	8	26.7
Moderate	14	18.9	15	50.0
Low and poor	7	9.5	6	20.0
Difference between distributions	$P < 0.001$			
Grass growth	*n* = 60		*n* = 28	
Excellent	19	31.7	6	21.4
Good	27	45.0	11	39.3
Moderate	11	18.3	7	25.0
Low and poor	3	5.0	4	14.3
Difference between distributions	n.s. ($P = 0.343$)			
Grass ground cover	*n* = 61		*n* = 26	
More than 80%	25	41.0	15	57.7
Between 60 and 80%	16	26.2	6	23.1
Between 40 and 60%	8	13.1	1	3.8
Less than 40%	12	19.7	4	15.4
Difference between distributions	n.s. ($P = 0.411$)			
Ground cover of undesirable grasses and weeds	*n* = 68		*n* = 29	
Less than 20%	44	64.7	22	75.9
Between 20 and 40%	10	14.7	4	13.8
Between 40 and 60%	8	11.8	0	0
More than 60%	6	8.8	3	10.3
Difference between distributions	n.s. ($P = 0.279$)			

The current ground cover of undesirable grasses and weeds was less than 40% in most (82%) pastures (Table 5) and there was no difference between young and aging pastures or across different soil types, leucaena row spacing or different companion grass species. However, 2–3 years afters planting, there was significant negative association between grass ground cover and undesirable grass and weed ground cover; paddocks with grass ground cover >60% had <20% undesirable grass and weed ground cover ($P < 0.001$).

Current livestock productivity was perceived to be higher ($P < 0.001$) in young than in aging leucaena pastures (Table 6). Livestock productivity, both current and 2–3 years after planting, was reported to be higher in: continuous and rotational grazing systems than in seasonal grazing systems ($P = 0.01$); and in paddocks with higher grass cover and grass growth rate (both $P < 0.001$). Livestock productivity was not related to grazing pressure, soil type, dominant grass species or weed ground cover.

Graziers reported leucaena vigour had declined over time in 8% of young, 58% of aging and 23% of all pastures (Table 7). The perceived decline in leucaena growth was reported in >75% of aging pastures growing on soft wood scrub, brigalow clay and downs soils, but in only 30% of aging pastures growing on alluvial soils ($P = 0.024$). Declining leucaena vigour was significantly associated with the actual age of the leucaena ($P < 0.01$), with graziers noticing a decline in vigour when leucaena reached ~15 years old ($n = 20$), but was not associated with dominant grass, row spacing, planting method, grazing system or grazing pressure. Decline in leucaena vigour was observed in three (25%) pastures fertilised at establishment (aged 14, 15 and 17 years old)

Table 6. Current condition (last 2 years) of livestock productivity in leucaena pastures

Livestock productivity	Young pastures (*n* = 70) (≤10 years old)		Aging pastures (*n* = 31) (>10 years old)	
	n	%	*n*	%
Excellent	32	45.7	3	9.7
Good	27	38.6	16	51.6
Moderate	8	11.4	10	32.3
Low and poor	3	4.3	2	6.4
Difference between distributions	$P < 0.001$			

Table 7. Grazier perceptions of decline in pasture productivity parameters over time
n.s., not significant

Pasture productivity parameter	Young pastures (≤10 years old)			Aging pastures (>10 years old)		
	Total	Decline		Total	Decline	
	n	*n*	%	*n*	*n*	%
Leucaena growth and soil type						
Brigalow clay (Vertosol)	29	4	14	12	9	75
Alluvial (Kandosol, Vertosol)	16	0	0	10	3	30
Softwood scrub (Dermosol, Ferrosol, Vertosol)	17	1	6	4	3	75
Downs (Vertosol)	8	1	13	1	1	100
Duplex (Chromosol)	5	0	0	4	2	50
Total for all soils	75	6	8	31	18	58
			$P < 0.001$			
Grass growth	62	1	2	28	9	32
			$P < 0.001$			
Grass ground cover	61	1	2	27	9	33
			$P < 0.001$			
Proportion of desirable grass in total ground cover	72	7	10	29	7	24
			n.s. ($P = 0.11$)			
Livestock productivity	69	4	6	31	13	42
			$P < 0.001$			

and two (50%) pastures not fertilised at establishment but periodically thereafter (aged 10 and 30 years old). Grass growth and ground cover were perceived to have declined in 32 and 33% of aging pastures, respectively, and only 2% of young pastures (Table 7). Graziers also reported a decline in livestock productivity associated ($P < 0.01$) with the decline in leucaena growth with age (Table 7). This effect became more profound in paddocks where there was also a decline in grass cover ($P = 0.021$).

Discussion

Leucaena pastures surveyed

The survey response level of 51% is an underestimation of grazier interest in the issue as the mailing list used to identify leucaena growers was not up to date and contained graziers who were not actively growing and managing leucaena pastures. The surveyed area of 11 750 ha represented ~8% of the total area (150 000 ha) of leucaena pastures in Queensland (Shelton and Dalzell 2007). The high proportion of young pastures (74%) indicated that there was significant leucaena establishment between 1995 and 2005 and this is in agreement with estimations of Middleton *et al*. (1995) and Mullen *et al*. (2005). The average leucaena area of 275 ha (median of 134 ha) per property showed that leucaena was adopted as a large-scale grazing system in Queensland. Only 6% of the pastures were irrigated, indicating that the dominant management was dryland. Most leucaena pastures were planted in a subhumid environment (average rainfall of 600–800 mm/year) with light to moderate winter frost where damage caused by the psyllid (*Heteropsylla cubana* Crawford) insect pest is less severe (Bray 1994). Typical leucaena soils were brigalow clay, alluvial and soft wood scrub that are moderately deep and fertile, well drained neutral to alkaline clay soil types, in agreement with Mullen *et al*. (2005) and Dalzell *et al*. (2006).

Planting methods

Most leucaena stands (80%) were established after a complete fallow as recommended by Dalzell *et al*. (2006) as the best approach to minimise grass and weed competition for stored soil water. A relatively low proportion of leucaena stands (20%) were established into existing grass pastures and the large majority of these were sown into improved grass swards. The reported improved success of leucaena establishment (i.e. plant density) in most young pastures can be related to the development and adoption of improved planting technologies (i.e. mechanically scarified seed; planting twin rows; planters with twin press wheels; and the use of pre-emergent herbicides for weed control). These technologies have been promoted through 23 'Leucaena for Profit and Sustainability' courses held throughout Queensland since 2004 that have trained >460 graziers and agronomists (S. A. Dalzell, pers. comm.).

The main grass species planted with leucaena was buffel grass (53%), which is known for its tolerance of drought and heavy grazing. It is well adapted to brigalow clay and softwood scrub soils (Hall 2000). However, buffel grass is extremely competitive for soil moisture and may limit leucaena productivity, particularly in dry seasons (Budisantoso 2005). Nevertheless in this study, the presence of buffel grass was not implicated to a greater extent than other companion grasses in the decline in leucaena productivity with age. It was not surprising that green and Gatton panic were the second most common companion grass species (18%) given their ability to take advantage of shady and rich nitrogen (N) environments (Wilson 1996) that are created in leucaena pastures. Rhodes grass, Bambatsi, sabi, creeping blue and pangola were less frequently used. The same grasses were chosen for pure grass swards in the surveyed area indicating that graziers were planting companion grass species best adapted to their environment as recommended by Dalzell *et al*. (2006).

Grazing and fertiliser management

Rotational and seasonal grazing were the most common grazing systems adopted (84%) followed by continuous grazing (11%) in agreement with the previous report of Larsen *et al*. (1998). Seasonal grazing was originally recommended to strategically supplement cattle grazing native pastures in south-east and central Queensland (Wildin 1983; Cooksley 1984). This approach involves deferring grazing of edible leucaena forage accumulated over the growing season (spring-summer) to the dry-cool season (autumn-winter) when tropical grass pastures are typically protein deficient and low in metabolisable energy. As greater areas of leucaena have been planted, it is not surprising that more intensive management, such as rotational and cell grazing, have been adopted; these grazing systems enable graziers to better ration their leucaena resource as well as improve pasture management (Dalzell *et al*. 2006). Larsen *et al*. (1998) reported that rotational grazing systems (e.g. 1 week grazing/6 weeks' rest) were commonly used in irrigated leucaena pastures.

Even though fertiliser application at planting has long been recommended when establishing leucaena in Queensland (Wildin 1981), particularly in soils low in P, i.e. <15 ppm plant available (bicarbonate extractable) P (Colwell 1963), or those suffering long fallow disorder (i.e. depletion of soil vesicular arbuscular mycorrhiza populations) (Dalzell *et al*. 2006), few leucaena pastures (10%) were fertilised at establishment. Wildin (1983) suggested maintenance fertiliser application after planting might be necessary as leucaena pastures age but few graziers surveyed adopted this practice. This survey failed to determine whether fertiliser application enhanced the long-term productivity and sustainability of leucaena pastures, largely due to few respondents having applied fertiliser to their pastures.

Little research has been undertaken to assess soil fertility changes in aging leucaena pastures. One such study in south-east Queensland (Prinsen *et al*. 1992) reported responses in leaf yield and plant nutritional status to sulphur (S) application in a 10-year-old leucaena stand growing on a Vertosol soil of marginal S status (4 ppm of SO_4^{2-}) but not on a prairie soil with higher S level (>5 ppm of SO_4^{2-}). Another study on a black Vertosol found a 5-year-old leucaena pasture did not respond to S fertiliser (Cooksley *et al.* 1984). These fertiliser responses highlight the variable nature of initial soil fertility of soils on which leucaena pastures are grown and the need for robust diagnostic tools to determine and monitor leucaena plant nutrient status.

Changes in pasture productivity over time

The most important change reported confirmed the hypothesis that there was lower leucaena growth in aging pastures than in young pastures. The decline in leucaena growth in aging pastures was not related to cover of associated grass species and weeds, or to grazing pressure. Since there were no significant differences between young and aging pastures in planting method or configuration, companion grass species or grazing management, these factors may not be influential in leucaena decline.

However, decline in aging leucaena pastures was related to soil type. It was higher (75%) in brigalow clay and softwood scrub soils than in alluvial soils (30%). This may be related to nutrient deficiencies and subsoil constraints in the former soil types. Isbell's survey of the brigalow land (Isbell 1962) found that there was significantly more plant-available P in alluvial soils than in other soil groups, except those derived from basalt. In the same study, high salt content or strongly acid subsoil horizons were found at relatively shallow depths (0.50 m) in most of the brigalow clay and softwood scrub soils compared with a moderately alkaline soil reaction throughout the whole profile in alluvial soils. In particular, P and to a lesser extent S, K, molybdenum, zinc and copper have been reported to limit forage legume growth and persistence in Queensland soils (Russell 1978; Maltby and Webb 1983; Standley *et al*. 1990).

This finding might be exacerbated by the fact that most aging leucaena pastures (94%) sustained moderate or high grazing pressures. Substantial amounts of nutrients, particularly P (8 kg/ha.year) and S (2 kg/ha.year), would have been removed from theses pastures by grazing animals (Whitehead 2000). Leucaena also has a high P requirement (Ruaysoongnern *et al*. 1989; Khan *et al*. 1997), principally to maintain a high level of biological N fixation (Marschner 1995). Given that most graziers were not replacing nutrients removed by cattle, it is hypothesised that soil nutrient deficiency might be affecting productivity of aging leucaena pastures, especially on poorer soils (Shelton and Dalzell 2007).

Soil acidification under legume pastures may be caused by: accumulation of organic matter and carbonic/carboxylic acids; base cation and organic anion depletion; and leaching of excess N from the soil profile (Tang and Rengel 2003). Acidification could suppress leucaena growth because leucaena roots are sensitive to increased exchangeable aluminium in soils with pH <5.2 and take up calcium poorly under these conditions (Blamey and Hutton 1995). Noble and Jones (1997) found significant acidification (decrease in pH of ~1 unit) under a 22-year-old grazed leucaena pasture when compared with an adjacent ungrazed grass sward in a sandy soil in north coastal Queensland (836-mm average annual rainfall). In contrast, minor soil acidification was observed under a 36-year-old leucaena pasture in a heavier textured soil in a humid environment (1100-mm average annual rainfall) in southern Queensland (Noble *et al*. 1998). Soil acidification is unlikely to be associated with the decline in leucaena productivity reported in this study, where most pastures were grown on alkaline and highly buffered brigalow clay, softwood scrub and alluvial soils in subhumid environments.

Apart from soil chemical properties, severe successive defoliation from grazing and frost were mentioned as possible factors associated with a decline in leucaena plant population in a well fertilised 23-year-old leucaena pasture in south-eastern Queensland (Jones and Bunch 1995). In the present study, there was no correlation between defoliation intensity and leucaena decline. Severe frost may limit leucaena persistence, especially when associated with heavy grazing (Dalzell *et al*. 2006). However, most (70%) aging leucaena stands on alluvial soils, the soil type usually associated with severe frost in Queensland, were reported to be maintaining long-term productivity.

A slight declining trend in grass growth (productivity) in leucaena pastures over time was noted from grazier responses. This trend was not significant ($P < 0.343$), possibly due to a lack of power in the statistical analysis due to the smaller number of respondents describing aging (n = 28) versus young (n = 62) pastures. Overall, the grass component of the pasture remained resilient probably due to enhanced soil N status resulting from leucaena biological N fixation. This N is predominantly cycled onto the grass via animal excreta under moderate to high grazing intensity (Burle *et al.* 2003), with smaller amounts cycled via leucaena leaf fall, and the senescence of roots and nodules. Weed invasion is common in aging pure swards of introduced N-loving grasses that become 'rundown' with age (Humphreys 1994) related to the gradual immobilisation of plant available N in recalcitrant soil organic matter of high carbon : N ratio (Robbins *et al*. 1989; Robertson *et al*. 1997). In this study, graziers reported grass cover was very good (>60%), and weed invasion was not a problem in most aging pastures indicating the absence of grass rundown in, and ecological stability of, leucaena pastures.

It was not surprising that, even though the grass remained resilient and reasonably productive, livestock productivity followed the same declining trend as leucaena growth. Cattle LWG has been closely related to the amount of leucaena (and protein supply) in the diets selected by grazing animals (Galgal 2002). The fact the survey did not find a significant relationship between grazing pressure (an integrated measure of stocking rate and degree of leucaena defoliation under grazing) and animal productivity contrasts the well known linear and negative relationship between annual LWG in kg/head and stocking rate (animals/ha) and the curvilinear relationship between annual LWG in kg/ha and stocking rate described by Sandland and Jones (1975). This could be due to the fact that the strongly perennial woody leucaena hedgerows are very tolerant of regular heavy defoliation that would severely and irreversibly damage most other grass-legume pastures and subsequently suppress both LWG/head and LWG/ha. Alternatively, the categorical stocking rate data (very low, low, moderate, high and very high) collected from graziers may not have been sensitive enough to investigate this relationship.

In conclusion, many leucaena pastures in Queensland >10 years old appear to be maintaining grass and animal productivity. However, leucaena growth in these aging pastures appeared to be declining on less fertile soils, possibly due to depletion of soil nutrients associated with intensive grazing and turn off of cattle and absence of fertiliser application over an extended period of time. It is predicted that amelioration will be needed to reinvigorate the productivity of these pastures to ensure maximum sustainability and profitability of the system.

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