DOI: 10.17138/TGFT(7)120-126

*ILC2018 Keynote paper**

Leucaena shows potential in Northern Inland New South Wales, Australia

Leucaena muestra potencial en el norte del interior de New South Wales, Australia

CAROL HARRIS[1], SUZANNE BOSCHMA[2], MARK BRENNAN[2], LAUREN BORG[3], STEVEN HARDEN[2] AND BRIAN CULLIS[3]

[1]*NSW Department of Primary Industries, Glen Innes, NSW, Australia.* dpi.nsw.gov.au
[2]*NSW Department of Primary Industries, Calala, NSW, Australia.* dpi.nsw.gov.au
[3]*Centre for Bioinformatics and Biometrics, National Institute for Applied Statistics Research Australia, University of Wollongong, Wollongong, NSW, Australia.* niasra.uow.edu.au

Abstract

A study was conducted during 2013–2017 to evaluate the potential of 5 cultivars/experimental lines of leucaena (*Leucaena leucocephala*) at 2 sites in Northern Inland NSW. In this frost-prone, summer-dominant rainfall region, all cultivars/lines established well and survival was >70% at Bingara and >95% at Manilla. Cultivars Wondergraze and Cunningham were the most productive, producing up to approximately 2.4 t DM/ha and 1.9 t DM/ha per growing season at Bingara and Manilla, respectively. Tropical grass establishment in the alleys was poor with plant productivity inversely related to leucaena productivity. Although this study has confirmed the persistence and productive potential of leucaena, the challenges around tropical grass establishment and persistence as well as the weed potential of leucaena in this region need to be addressed before broad-scale use could be recommended in Northern Inland NSW.

Keywords: *Digitaria eriantha*, persistence, tree legumes, variance components analysis.

Resumen

Se realizó un estudio para evaluar el potencial de cinco cultivares/líneas experimentales de leucaena (*Leucaena leucocephala*) en dos sitios en la región norte del interior de NSW durante 2013–2017. En esta región, que se caracteriza por lluvias en verano y ser propensa a heladas, todos los cultivares/líneas se establecieron bien y su supervivencia fue >70% en Bingara y >95% en Manilla. Los cultivares Wondergraze y Cunningham fueron los más productivos, alcanzando hasta 2.4 t MS/ha y 1.9 t MS/ha por época de crecimiento en Bingara y Manilla, respectivamente. El establecimiento de la gramínea tropical asociada (*Digitaria eriantha*) fue deficiente y su producción estuvo inversamente relacionada con la de la leucaena. Aunque este estudio ha confirmado el potencial de persistencia y productividad de la leucaena, antes de poder recomendar su uso a mayor escala en el interior del norte de NSW es necesario abordar los desafíos relacionados con el establecimiento y la persistencia de las gramíneas tropicales asociadas, así como el potencial de la leucaena de volverse una maleza invasiva en esta región.

Palabras clave: Análisis de la varianza de componentes, *Digitaria eriantha*, leguminosas arbóreas, persistencia.

Introduction

Northern Inland New South Wales (NSW) is a subhumid summer rainfall zone (Tweedie and Robinson 1963) with approximately 60% of annual rainfall falling between October and March, commonly in high-intensity thunderstorms. Pasture growth in the region is limited by low temperatures in winter and high temperatures and soil

Correspondence: C.A. Harris, Glen Innes Agricultural Research and Advisory Station, 444 Strathbogie Road, Glen Innes, NSW 2370, Australia. E-mail address: carol.harris@dpi.nsw.gov.au

*Keynote paper presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

moisture stress during summer (Harris and Culvenor 2004). The average period of frost occurrence is 145 days with approximately 50 frosts received per year (Hobbs and Jackson 1977), while summer rainfall tends to be relatively ineffective as high summer temperatures lead to high evapotranspiration (Murphy et al. 2004).

In the Northern Inland mixed farming zone of NSW sown grass pastures were traditionally based on temperate species (e.g. Archer 1989; Lodge and Orchard 2000; Harris and Culvenor 2004); however, they have now largely been replaced by tropical grasses (Harris et al. 2014). To maintain the productivity of tropical pastures, soil nutrients, in particular nitrogen, are required (Boschma et al. 2014), which can be applied as inorganic sources and by addition of a companion legume. Research has been conducted in Northern Inland NSW to expand the range of legume options available as a companion to the tropical perennial grass-based pastures. Leucaena was included in this research based on its productivity and persistence in an experiment established at Tamworth in January 2009 (S.P. Boschma unpublished data).

As part of these studies an experiment was conducted at 2 sites in the North West Slopes region of NSW to evaluate 4 cultivars and an experimental line of leucaena in a mix with digit grass (*Digitaria eriantha* cv. Premier). The agronomic traits used to evaluate suitability were establishment, persistence and herbage production of both leucaena and tropical grass over 4 years (2013–2017).

Methodology

Sites

The experimental sites were located near Bingara (29º42'39" S, 150º27'07" E; 297 masl) and Manilla (30º42'11" S, 150º30'10" E; 412 masl) in Northern Inland NSW. Some site characteristics are shown in Table 1. For 2 years prior to the commencement of the experiments both sites were sown to winter oats (*Avena sativa*) with a summer fallow. In the spring prior to establishment of the experiments, weeds were sprayed with glyphosate (450 g/L a.i. at 1.5 L/ha).

Table 1. Long-term average annual rainfall (AAR, mm), soil type and some soil chemical properties [pH (pH_{Ca}, $CaCl_2$), phosphorus (P, Colwell, mg/kg) and sulphur (S, KCl_{40}, mg/kg)] for the experimental sites in Northern Inland NSW.

Site	AAR (mm)	Soil type	Soil chemical properties (0–10 cm)		
			pH_{Ca}	P	S
Bingara	742	Brown Chromosol	5.0	50	3.2
Manilla	576	Brown Chromosol	6.1	36	4.2

Species, sowing and experimental designs

Four commercial cultivars of leucaena (Wondergraze, Cunningham, Tarramba and Peru) and an experimental line developed by the University of Queensland (Expt. Line) were sourced from seed companies and the University of Queensland, respectively. Seedlings of each line were established in glasshouses in December 2012 and transplanted as 6–8-week-old seedlings into the field at Bingara and Manilla in January 2013 and watered for up to 8 days after transplanting.

The experiments were designed as randomized complete blocks with 3 replicates. Each plot consisted of 16 plants of a cultivar/line of leucaena transplanted 0.5 m apart in twin rows (1 m apart). Each row and plot was 4 m in length and each replicate was 20 m long (5 cultivars/line × 4 m each) with an additional 1 m row of leucaena (i.e. 2 plants) at each end of both twin rows as a buffer. The alley between individual replicates was 6 m.

Digit grass cv. Premier was sown in the 6 m alleys between leucaena twin rows at 1 kg/ha (viable seed) at Bingara and Manilla in December and November 2013, respectively, but failed to establish at both sites and was resown in November 2014. The grass again failed to establish at Bingara and the experiment continued at this site without a sown grass in the alleys.

Site management

At the Bingara site, grass weeds along the twin leucaena rows were controlled with haloxyfop (520 g/L a.i. at 100 mL/ha) in August 2014 and 2015. The alley between leucaena rows was maintained in weed-free fallow with 3 applications of glyphosate (1.5 L/ha) during the period April–November 2013. After 2015, grass and broad-leaf weeds were controlled in alleys with glyphosate (1.5 L/ha) and 2,4-D ester (680 g/L a.i. at 1.3 L/ha) on 3 occasions.

At the Manilla site, grass weeds along the twin leucaena rows were controlled with fluazifop-P (128 g/L a.i. at 0.5 L/ha) in February 2013. Imazethapyr (700 g/kg a.i. at 70–100 g a.i./ha) was applied as granules in July and December 2013, and July and October 2015 to provide residual weed control. The alley between leucaena rows was maintained in weed-free fallow with 5 applications of glyphosate (1.5 L/ha) during the period April–November 2013. Broad-leaf weeds in digit grass were controlled with 2,4-D ester (720 g/L a.i. at 1.7 L/ha) in June 2015.

At both sites single superphosphate (8.8% P, 11% S) was applied at 200 kg/ha in spring-early summer each year from 2013. In September each year, as leucaena plants were recommencing growth, the dead frosted stems were cut to a height of 0.3 m and the woody material removed from the experiment. Leucaena pods were removed and destroyed to eliminate the risk of recruitment throughout the experiment.

Data collection

Rainfall data at both sites were recorded manually. Long-term average monthly and annual rainfall data for both sites were extracted from Bureau of Meteorology sites.

Leucaena establishment and persistence. Plant numbers were recorded 2–3 months after transplanting in the paddock to determine establishment success. Persistence of individual leucaena plants was assessed in spring and autumn each year by recording their presence and health.

Leucaena herbage production. Leucaena herbage mass was assessed from late spring/early summer to autumn each growing season, whenever the tallest leucaena plants reached approximately 1.8 m in height. At each assessment the number of stems was recorded for 8 plants, i.e. the middle 4 plants in each row except when the plants were not representative of those in the plot. A representative stem on each assessed plant was selected, cut at the point where the stem diameter was about 10 mm and bagged. All leaves from the remainder of this stem were also removed to the base of the plant and placed in the same bag. The harvested stem plus leaf material represented the edible portion of the plant and was dried in a dehydrator for 48 h at 80 ºC, then weighed to calculate herbage dry weight (kg DM/ha). After each assessment all leucaena plants were cut back to a height of 0.5 m and material removed from the plots. Herbage mass was assessed 1, 3, 3 and 4 times (total 11 times) at Bingara and 1, 2, 3 and 2 times (total 8 times) at Manilla in Years 1, 2, 3 and 4, respectively.

Grass establishment, production and persistence. Counts of seedling density (seedlings/m^2) of digit grass were taken 4–6 weeks after sowing in 6 quadrats (0.1 × 0.5 m) in each plot.

At Manilla the grass sown in the alleys was assessed at the same time as the leucaena from November 2015 using visual assessment (i.e. a total of 5 times). For each plot, 4 assessments of total herbage mass were made visually (continuous 0–5 scale, where 0 = nil and 5 = highest herbage mass) and the percentage of digit grass (dry weight herbage mass) assessed. Fifteen calibration quadrats (0.4 × 0.4 m), representing the range of herbage mass at a site were also scored, harvested to 10 mm above ground level and sorted into digit grass and other species. The samples were dried at 80 ºC for 48 h and weighed. Herbage mass scores and percentage estimates were regressed (linear or quadratic R^2>0.80) against actual herbage mass (kg DM/ha) and percentage of digit grass to determine herbage mass of the sown grass. After each assessment the plots were mown with a rotary mower and the herbage removed from the plots.

In spring and autumn each year commencing spring 2015, plant frequency of the digit grass was assessed. The proportion (%) of cells (each 0.1 × 0.1 m) containing a live plant was used to estimate frequency of occurrence (plant frequency, Brown 1954) in 2 permanent quadrats (1.0 × 0.5 m, i.e. 50 cells/quadrat) located in the alley on either side of the leucaena twin rows. Estimates were taken 0–10 days after the experimental area was defoliated.

Statistical analyses

Variance components analysis. Three traits were analyzed: leucaena herbage mass, grass herbage mass and grass frequency. Data for each combination of trait and site were analyzed individually using a variance components analysis. A linear mixed model was fitted to the data for each trait by site combination using the software ASReml (Gilmour et al. 2006) in R (R Core Team 2017).

Leucaena herbage mass, grass herbage mass and grass frequency data were cube-root transformed to more closely resemble a Gaussian distribution. Non-genetic effects associated with the experimental design of the trials were crossed with the longitudinal factor for sampling times (Brien and Demetrio 2009) and fitted as random effects. In terms of the genetic effects, the random component of the model included a main effect for legume varieties and an interaction term between sampling times and varieties and assumed a simple variance component structure for these effects. The statistical significance of genetic terms in the model was assessed using the residual maximum likelihood ratio test (REMLRT) to compare the likelihood of the full model against the model excluding the effect under examination. The resulting test statistic was then compared with the reference distribution of a mixture of chi-squared variates (Stram and Lee 1994).

Effects related to varieties were fitted as random effects and the empirical best linear unbiased predictors (BLUPs) obtained (Smith et al. 2005). The BLUPs of the overall performance for each cultivar (Smith and Cullis 2018) for each trait were calculated for each site, as well as the 90% confidence interval for these predictions. The overall performance was added to the BLUP of the overall mean for cultivars, averaged across environments. This value was then back-transformed as an approximation of the overall mean performance on the scale of the original data to provide a value for each legume treatment that was biologically meaningful. When interpreting BLUPs, the confidence intervals provided are not a formal test for comparison of treatments (i.e. significance) because treatment effects were fitted as a random effect. Instead they are a test for the true value of each treatment individually.

Leucaena persistence. There was very little change in persistence during the experiment and little variation between many of the species, so no statistical analyses were conducted.

Grass establishment. Seedling densities (seedlings/m^2) were analyzed by ANOVA with leucaena cultivar/line as the explanatory factor and replicate as a block term. Data transformation was not required.

Results

Rainfall

During the leucaena establishment period (January–April 2013), rainfall at the Bingara and Manilla sites was above average and average, respectively (Table 2). Growing season (November–April) rainfall at both sites was below average in all years, except 2014/15 at Bingara.

Leucaena establishment and persistence

Plants established successfully at both sites with 98–100% survival 2.5–3.0 months after transplanting. At the Bingara site plant numbers for all cultivars declined during the first 12 months of the experiment to 88–73%, and then remained relatively stable. At the end of the experiment cvv. Tarramba, Cunningham, Wondergraze and Peru had similar plant survival (85–81%) and Expt. Line was the least persistent at 71%. Despite the dry conditions at the Manilla site plants of cvv. Tarramba, Wondergraze and Peru persisted during the course of the experiment (i.e. maintained 100%). Small numbers of plants in the Expt. Line and cv. Cunningham died, but survival rates were 96% at the end of the experiment.

Leucaena herbage production

At Bingara cv. Wondergraze was ranked highest over the 4 years of the experiment with an average herbage mass of 2,394 kg DM/ha/assessment (back-transformed predicted mean herein referred to by units only), which was similar to cv. Cunningham (2,059 kg DM/ha/assessment). The remaining treatments had below-average productivity (BLUP<0; Table 3).

At Manilla cv. Cunningham had an average herbage mass of 1,904 kg DM/ha/assessment and was ranked highest, followed by cv. Wondergraze (1,704 kg DM/ha/assessment), with both having above average productivity (BLUP>0). The Expt. Line was ranked 5th (1,302 kg DM/ha/assessment; Table 3).

Table 2. Rainfall (mm) received during each leucaena growing season (November–April) and non-growing season (May–October) from January 2013 to April 2017, at the Bingara and Manilla sites. Long-term average (LTA) rainfall data are from Bureau of Meteorology sites Bingara (054004; 1878–1997) and Manilla (55274; 1909–2013).

Year	Bingara		Manilla	
	Growing season (Nov–Apr)	Non-growing season (May–Oct)	Growing season (Nov–Apr)	Non-growing season (May–Oct)
2013	316[1]	211	203[1]	145
2013/14	172	99	238	75
2014/15	482	252	239	200
2015/16	333	411	155	314
2016/17	362	-[2]	150	-
LTA	436	306	334	242

[1]Rainfall January–April 2013. [2]Experiment concluded April 2017.

Table 3. BLUPs (empirical best linear unbiased predictors) of the treatment effects, treatment means and their confidence intervals (CI), plus back-transformed means (scaled mean kg DM/ha/assessment) for leucaena herbage mass at the Bingara and Manilla sites.

Treatment	Bingara					Manilla				
	BLUP	Mean	CI Lower	CI Upper	Herbage mass (kg DM/ha)	BLUP	Mean	CI Lower	CI Upper	Herbage mass (kg DM/ha)
Wondergraze	0.91	13.38	12.34	14.42	2,394	0.37	11.94	11.20	12.69	1,704
Cunningham	0.25	12.72	11.68	13.76	2,059	0.82	12.40	11.65	13.14	1,904
Tarramba	-0.16	12.31	11.27	13.35	1,866	-0.06	11.51	10.77	12.26	1,526
Peru	-0.66	11.81	10.76	12.85	1,646	-0.48	11.09	10.35	11.84	1,365
Expt. Line	-0.34	12.13	11.09	13.17	1,784	-0.65	10.92	10.17	11.64	1,302

Table 4. BLUPs (empirical best linear unbiased predictors) of the treatment effects, treatment means and confidence intervals (CI), plus back-transformed means (scaled means kg DM/ha and % per assessment) for digit grass herbage mass and plant frequency at the Manilla site.

Treatment	Herbage mass					Plant frequency				
	BLUP	Mean	CI Lower	CI Upper	Back-transformed (kg DM/ha)	BLUP	Mean	CI Lower	CI Upper	Back-transformed (%)
Wondergraze	-0.28	7.28	6.69	7.88	386	-0.09	2.70	2.51	2.89	19.6
Cunningham	-0.10	7.47	6.87	8.06	416	0.01	2.79	2.60	2.98	21.8
Tarramba	0.13	7.70	7.10	8.29	456	0.04	2.83	2.63	3.02	22.6
Peru	-0.28	7.28	6.69	7.88	386	-0.08	2.71	2.52	2.90	19.8
Expt. Line	0.53	8.09	7.50	8.69	530	0.12	2.91	2.72	3.10	24.6

Grass establishment, herbage production and persistence

Establishment of digit grass at the Manilla site was poor and ranged from 4 plants/m^2 in the alley adjacent to cv. Tarramba to 0.5 plants/m^2 adjacent to cv. Wondergraze (P>0.05). Digit grass herbage mass varied, although the range was small; digit grass adjacent to Expt. Line was ranked highest (530 kg DM/ha/assessment), while cvv. Wondergraze and Peru had the lowest grass herbage mass (386 kg DM/ha/assessment; Table 4). Plant frequency ranking reflected herbage mass ranking with Expt. Line ranked highest (24.6%) and cv. Wondergraze ranked 5th (19.6%; Table 4).

Discussion

This study showed that leucaena can establish successfully and is persistent in Northern Inland NSW. While productivity varied with site, cvv. Wondergraze and Cunningham were consistently the most productive cultivars and Expt. Line the least. Cultivar Cunningham, bred by CSIRO and released in Australia in 1976, has good basal branching giving it a 'bushy' habit (Cook et al. 2005; Dalzell et al. 2006). Cultivar Wondergraze was bred in Hawaii, released in Australia in 2010 and has higher basal branching than cv. Tarramba.

All cultivars of leucaena established at both sites and were productive, the best cultivar producing approximately 7 and 5.3 t DM/ha per growing season at Bingara and Manilla, respectively. This confirms previous research conducted at Tamworth (S.P. Boschma unpublished data).

Leucaena is reported to have poor cold tolerance (Cooksley et al. 1988) but, while plant growth ceased over winter at both sites, plant survival was not adversely affected, demonstrating that leucaena can survive in these colder environments and be productive, despite the shorter growing season.

Establishing the tropical grass in the inter-row spaces proved challenging even though best-practice recommendations for establishing leucaena-grass pastures developed in central Queensland were followed (Dalzell et al. 2006). Dalzell et al. (2006) recommend establishing leucaena hedgerows in the first summer and then sowing grass in the following summer as leucaena has a weak seedling and is slow to establish (Lambert 2013). While this method allowed leucaena to establish well, the leucaena was highly competitive against seedling grasses in the second summer and no grass survived. Extensive cracks in the soil surface were present across the full width of the 6 m alley indicating that the leucaena had dried the soil profile. Growing season rainfall in 2013/14 was well below average at both sites. However, when grass was resown in 2014/15, when growing season rainfall was above average at Bingara, grass establishment at this site also failed. This raises the possibility of increasing the distance between the twin rows to at least 8–10 m on soils in the area similar to these sites to reduce competition from the leucaena for moisture. Failure to establish a grass in the alley may result in poor ground cover, weed invasion, increased potential for erosion and reduced livestock production (e.g. Shelton and Dalzell 2007). An alternative technique to establish a leucaena-grass pasture would be to sow both species in the same year, leaving a 2–3 m buffer on either side of each leucaena hedgerow to minimize competition between the 2 species during the first year. A similar strategy, using 1 m buffers, was found to have merit in Southern Inland Queensland (Lambert 2013).

During this study, flowers and pods were removed before pods could ripen to reduce the potential for seed spread. Leucaena has weed potential (Walton 2003a; 2003b) due to its ability to produce seed year-round (in the tropics), build a substantial seed bank, resprout after cutting or burning, tolerate drought and produce thickets (Hughes and Jones 1998). This is a biosecurity concern to a number of state government agencies in NSW, as well as Western Australia (WA). In Queensland, The Leucaena Network (Christensen 2019) has developed a Code of Practice for managing leucaena by a combination of grazing strategy and slashing/mulching to minimize seed set; however, an effective means of overcoming weed potential is development of a seedless or sterile leucaena. A project to develop sterile lines commenced in 2017 in a collaborative exercise involving WA Department of Primary Industries and Regional Development, University of Queensland and Meat and Livestock Australia Donor Company.

Our study has confirmed the persistence and productive potential of leucaena as a summer-growing companion legume for tropical perennial grasses in Northern Inland NSW. It has, however, highlighted challenges in establishing a productive and persistent perennial tropical grass base. More research is needed to identify a suitable companion grass for this promising legume.

Acknowledgments

We gratefully acknowledge the financial support of Meat and Livestock Australia and NSW Department of Primary Industries and the technical support provided by Karen Lowien, Geoff Bevan and Peter Sanson is appreciated. We also appreciate the support of producers who provided sites to conduct this study: Phillip and Annette Butler, 'GlenAyr', Bingara, and Robert and Lea Bowman, 'Fairfield', Manilla.

References

(Note of the editors: All hyperlinks were verified 8 May 2019.)

Archer KA. 1989. Persistence of temperate grasses, northwest slopes, NSW. Proceedings of the 5th Australian Agronomy Conference, Busselton, Katanning, Merredin and Perth, Western Australia, 25–29 September 1989. p. 627. bit.ly/2Hk8M7V

Boschma SP; Murphy SR; Harden S. 2014. Herbage production and persistence of two tropical perennial grasses and forage sorghum under different nitrogen fertilisation and defoliation regimes in a summer-dominant rainfall environment, Australia. Grass and Forage Science 70:381–393. doi: 10.1111/gfs.12130

Brien CJ; Demétrio CGB. 2009. Formulating mixed models for experiments, including longitudinal experiments. Journal of Agricultural, Biological and Environmental Statistics 14:253–280. doi: 10.1198/jabes.2009.08001

Brown D. 1954. Methods of surveying and measuring vegetation. Bulletin No. 42, Commonwealth Bureau of Pastures and Field Crops. Commonwealth Agricultural Bureaux, Farnham Royal, UK. p. 71–78. bit.ly/2VU37yt

Christensen B. 2019. The Leucaena Network and The Leucaena Code of Practice. Tropical Grasslands-Forrajes Tropicales 7 (in press).

Cook BG; Pengelly BC; Brown SD; Donnelly JL; Eagles DA; Franco MA; Hanson J; Mullen BF; Partridge IJ; Peters M; Schultze-Kraft R. 2005. Tropical Forages: An interactive selection tool. CSIRO, DPI&F (Qld), CIAT and ILRI, Brisbane, Australia. tropicalforages.info

Cooksley DG; Prinsen JH; Paton CJ. 1988. *Leucaena leucocephala* production in subcoastal, south-east Queensland. Tropical Grasslands 22:21–26 goo.gl/scgxXB

Dalzell SA; Shelton HM; Mullen BF; Larsen PH; McLaughlin KG. 2006. Leucaena: A guide to establishment and management. Meat and Livestock Australia, Sydney, Australia. bit.ly/2YHs66P

Gilmour AR; Gogel BJ; Cullis BR; Thompson R. 2006. ASReml, User Guide, Release 2.0. NSW Department of Primary Industries, Orange, Australia. bit.ly/2Hd7z1Q

Harris C; Culvenor R. 2004. Use and improvement of tall fescue and phalaris for the North-West slopes. In: Boschma SP; Lodge GM, eds. Proceedings of the 19th Annual Conference of the Grassland Society of NSW, Gunnedah, NSW, Australia, 27–29 July 2004. p. 15–21. bit.ly/2JqWQDZ

Harris CA; Boschma SP; Murphy SR; McCormick LH. 2014. Tropical perennial grasses for Northern Inland NSW. 2nd Edn. Future Farm Industries Cooperative Research Centre, Perth, WA, Australia. bit.ly/2LvYt5Y

Hobbs JE; Jackson IJ. 1977. Climate. In: Lea DAM; Pigram JJJ; Greenwood LM, eds. Atlas of New England. Department of Geography, University of New England, Armidale, NSW, Australia. p. 75–99.

Hughes CE; Jones RJ. 1998. Environmental hazards of *Leucaena*. In: Shelton HM; Gutteridge RC; Mullen BF; Bray RA, eds. Leucaena - adaptation, quality and farming systems. Proceedings of a Workshop held in Hanoi, Vietnam, 9–14 February 1998. ACIAR Proceedings No. 86. ACIAR, Canberra, ACT, Australia. p. 61–70. purl.umn.edu/135197

Lambert G. 2013. Leucaena in southern inland Queensland. Demonstrating the productivity and value of newly-established leucaena in selected area of the Darling Downs. Final Report. Meat and Livestock Australia, Sydney, Australia. bit.ly/2Lsz6St

Lodge GM; Orchard BA. 2000. Effects of grazing management on *Sirosa phalaris* herbage mass and persistence in a predominantly summer rainfall environment. Australian Journal of Experimental Agriculture 40:155–169. doi: 10.1071/EA98006

Murphy SR; Lodge GM; Harden S. 2004. Surface soil water dynamics in pastures in northern New South Wales. 3. Evapotranspiration. Animal Production Science 44:571-583. doi: 10.1071/EA03041

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. R-project.org

Shelton HM; Dalzell S. 2007. Production, economic and environmental benefits of leucaena pastures. Tropical Grasslands 41:174–190. goo.gl/nAHLzN

Smith AB; Cullis BR; Thompson R. 2005. The analysis of crop cultivar breeding and evaluation trials: an overview of current mixed model approaches. The Journal of Agricultural Science 143:449–462. doi: 10.1017/S0021859605005587

Smith AB; Cullis BR. 2018. Plant breeding selection tools built on factor analytic mixed models for multi-environment trial data. Euphytica 214:143. doi: 10.1007/s10681-018-2220-5

Stram DO; Lee JW. 1994. Variance components testing in the longitudinal mixed effects setting. Biometrics 50:1171–1177. doi: 10.2307/2533455

Tweedie AD; Robinson KW. 1963. The regions of Australia. Longmans, Green & Co Ltd, Melbourne, Australia.

Walton C. 2003a. The biology of Australian weeds. 42. *Leucaena leuocephala* (Lamark) de Wit. Plant Protection Quarterly 18:90–98. bit.ly/2vKAcOH

Walton C. 2003b. Leucaena (*Leucaena leucocephala*) in Queensland. Pest Status Review Series – Land Protection. Department of Natural Resources and Mines, Brisbane, Australia. bit.ly/2IBCUOj

(Accepted 7 May 2019 by the ILC2018 Editorial Panel and the Journal editors; published 31 May 2019)