Recent tropical perennial grass research and their potential role in maintaining production in a variable and changing climate

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Abstract: *Tropical perennial grass pastures have come under the spotlight for their capacity to respond quickly to summer rainfall and produce large quantities of herbage. These pasture traits are valuable in an area with a highly variable climate, but fertility and grazing management are essential to maintain the quality of a tropical grass pasture. This paper summarises some of the results from research conducted at Tamworth, NSW, the characteristics of sown tropical perennial grass-based pastures, their role in farming systems under future variable and/or changed climates, and some future research areas.*

Introduction

Climate variability is a major issue facing producers (Lodge *et al.* 2009*a*) as they try to maintain production from their feed base. The variability we have been experiencing in our climate over the last few years (e.g. Lodge and McCormick 2010*b*) is setting the scene for the future, and as an industry we need to have flexibility within our grazing systems to help meet the challenge. In the coming years, producers who are equipped to manage this variability and the predicted climate change (e.g. Cullen *et al.* 2009) will be better positioned. This variability can be managed, with flexibility within livestock enterprises and by utilising a range of forage sources that produce high quality feed at different times of the year under different environmental conditions. In northern New South Wales (NSW), native pastures play a significant role, as does lucerne, forage oats and more recently tropical perennial grass pastures.

Northern inland NSW has significant summer and winter rainfall, providing a unique and challenging environment for perennial pastures. Summer rainfall tends to be relatively ineffective as it falls as storms and is quickly lost through evapotranspiration due to high temperatures. In contrast, winter rainfall is more effective and useful for refilling the soil profile (Murphy *et al.* 2004, 2010). While this may make the area potentially suitable for both summer- and winter-growing pasture species, the challenge is for these species to survive hot summers and cold winters. To do this sown temperate perennial grasses need to be summer dormant (Boschma *et al.* 2009), while sown tropical perennial species need to be frost-tolerant (McCormick *et al.* 1998; Boschma *et al.* 2009). Recent studies conducted on the North-West Slopes of NSW have shown that the most persistent and productive pasture options available are tropical perennial grasses and lucerne (Boschma *et al.* 2009; Boschma *et al.* 2010).

Tropical grasses were first evaluated in northern NSW in the 1950s (Johnson 1952; Buckley 1959). Although their potential was recognised and their use recommended, limited seed availability and the pursuit of cropping resulted in low adoption. During the 1970s, species were evaluated on the North-West Plains (Watt 1976) and establishment methods investigated in the 1980s–1990s (Bowman 1990; Campbell *et al.* 1993). Widespread evaluation of grass species and cultivars was conducted during the 1990s at over 27 sites in an area from Forbes in central NSW to the Queensland border and west from Scone to Walgett (McCormick *et al.* 1998).

Despite tropical perennial grasses being available for 60 years, it is only in the last ~10 years that there has been widespread interest in these grasses and a rapid increase in the area sown. Estimates from commercial seed sales in NSW indicate that over 250,000 ha have been sown over the last 3 years (LH McCormick, pers. comm.). This interest was sparked by the ability of tropical perennial grass pastures to respond to summer rainfall and produce large quantities of herbage in recent years which have been characterised by highly variable seasons (e.g. Boschma *et al.* 2009) and long dry periods with predominantly dry autumns (Lodge and McCormick 2010*b*).

In this paper, we outline some of the results from recent research at Tamworth, NSW, the characteristics of sown tropical perennial grass-based pastures, their role in our farming systems under future variable and/or changed climates, and some future research areas.

Characteristics of sown tropical perennial grass pastures

The seasons we have experienced over the last decade or so have highlighted the productivity and resilience of tropical perennial grasses. During this time, temperate perennial grasses and annual legumes have often failed to persist or respond to intermittent rainfall events, and native pastures have been persistent, but not highly productive. In contrast, tropical grass pastures have responded quickly to summer rainfall producing large quantities of herbage, which has been invaluable, particularly when there has been a lack of follow-up rain. They have also shown good persistence under extended dry periods and a wide range of grazing management.

Tropical perennial grasses are adapted to a wide range of environments and soil types with different pH (Table 1). There is also a range in their tolerances for aluminium toxicity, inundation by flooding, and salinity. Pastures have been successfully established on a broad range of soils and environments throughout northern inland NSW including the Northern

Table 1. Tropical grass species and cultivars suitable for light, medium, heavy and saline soils in northern inland NSW (McCormick *et al.* 1998).

Species and cultivar	Light Sand, sandy loam; pH_{Ca} <5.0–7.0	Medium Clay loam, silty clay loam; pH_{Ca} 5.0–7.0	Heavy Red/grey clay, black earth; pH_{Ca} 6.0–8.0
Digit grass (*Digitaria eriantha* ssp. *eriantha*) cv. Premier	✓	✓	
Forest bluegrass (*Bothriochloa bladii* ssp. *glabra*) cv. Swann	✓	✓	
Rhodes grass (*Chloris gayana*)			
cv. Pioneer	✓		
cv. Katambora	✓	✓	
Buffel grass (*Cenchrus ciliaris*)			
cv. America and Gayndah	✓		
cv. Biloela			✓
Lovegrass (*Eragrostis curvula* type conferta) cv. Consol	✓		
Creeping bluegrass (*Bothriochloa insculpta*) cv. Bisset		✓	
Panic (*Panicum coloratum* var. *makarikariense*) cv. Bambatsi[A]		✓	✓
Purple pigeon grass (*Setaria incrassata*) cv. Inverell[BC]		✓	✓
Bluegrass (*Dicanthium aristatum*) cv. Floren[A]			✓

[A] Tolerant of flooding; [B] Tolerant of waterlogging; [C] Performs with higher nutrition;

Tablelands at Bundarra, west of Guyra and near Woolbrook, at altitudes as high as 1000 m.

In inland NSW, tropical pastures grow during the warmest months of the year. Growth commences in spring as day temperatures rise and slows in late summer and autumn as overnight temperatures fall, ceasing when frosts commence, with little to nil growth in the winter period. Therefore, tropical perennial grasses can be productive for ~9 months of the year on the North and Central-West Plains, 7–8 months on the North-West Slopes and 5–6 months on the Northern Tablelands. They also have high water use efficiencies, with for example, Premier digit (*Digitaria eriantha* ssp. *eriantha*) and Katambora Rhodes (*Chloris gayana*) producing 32.4 and 22.3 kg dry matter (DM)/ha/mm of water, respectively, compared with 6.5 kg DM/ha/mm from a native pasture dominated by summer-growing grasses (Murphy *et al.* 2008*a*, Table 2).

Tropical grasses respond well to good nutrition, and grazing management is the key to maintaining forage quality. All grasses need nitrogen (N) to maximise herbage production and protein levels for optimum livestock performance. The nutritive value of tropical grasses is lower than that of temperate grasses at the same growth stage, but temperate and tropical grasses grow at different times of the year so direct comparisons are often irrelevant. When assessing the role of tropical grass pastures on your farm they should be compared with other summer-growing species such as forage sorghum, lucerne and native pastures dominated by summer-growing grasses.

Tropical grass pastures have several environmental benefits. These include the ability to maintain high ground cover year-round, reducing runoff and soil erosion. Ground cover of at least 70% can be achieved within the establishment year (SR Murphy, unpublished data) and maintained by good grazing management. Once established, tropical grass pastures are effective at controlling weeds such as spiny burr grass (*Cenchrus incertus* or *C. longispinus*), blue heliotrope (*Heliotropium amplexicaule*), lippia (*Phyla canescens*) and galvanised burr (*Sclerolaena birchii*) (McCormick 2004). Tropical grasses produce large amounts of herbage and have large, fibrous root systems which may help improve soil carbon levels and soil structure, particularly on old, degraded cropping lands. They are also deep rooted (Murphy *et al.* 2008*b*, Table 2) so are effective in reducing water tables and ground water recharge in salinity prone areas (Lodge *et al.* 2010*a*).

Tropical pastures in our farming systems

Tropical perennial grass establishment

Establishing a tropical grass pasture requires planning and preparation. Weed control is essential for up to 2 years prior to sowing to reduce annual summer grasses (Lodge *et al.* 2010*b*). Choose a grass and cultivar suitable for the soil type in your paddock (McCormick *et al.* 1998, Table 1) and buy seed with good purity and germination (McCormick *et al.* 2009). Seed quality can be extremely variable so always ask for a copy of a recent certificate of seed analysis. Tropical grass seed is commonly bought as a mixture of species. This has the advantage of each species finding its niche in the paddock, but some grass seedlings are more competitive than others. For example, Katambora Rhodes grass is more competitive than both Premier digit and Bambatsi panic (*Panicum coloratum*

Table 2. Soil drying, herbage mass, water use index and rooting depth of 3 tropical grass species and a native grass pasture [dominated by Bunderra wallaby grass (*Austrodanthonia bipartita*), redgrass (*Bothriochloa macra*), bluegrass (*Dichanthium sericeum*) and windmill grass (*Chloris truncata*)] from September 2006–May 2007 (Murphy *et al.* 2008*a, b*).

Species	Soil drying (mm)	Herbage mass (kg DM/ha)	Water use index (kg DM/ha/mm)	Rooting depth (m)
Premier digit	137	16157	32.4	1.2
Katambora Rhodes grass	149	11516	22.3	1.6
Swann forest bluegrass	119	6893	13.7	1.4
Native grasses	39	2689	6.5	1.0

var. *makarikariense*) and should not exceed 25% of the seed mix (Lodge *et al.* 2009*b*).

Tropical grasses should be sown in the warmer months of the year. In northern NSW, tropical grasses are best sown from November–January, although sowing in November increases the likelihood of sufficient rainfall to establish the pasture (Lodge and Harden 2009). Sowing after early February on the North-West Slopes and early-January on the Northern Tablelands should be avoided, as the risk of plant losses from frost increases. Late sowing can result in plant losses of up to 70% of some species when they are not well established (Lodge *et al.* 2010*b*). Tropical grass seed is generally small and needs to be sown shallow at ~10 mm depth. Sowing into cereal stubble may assist establishment in marginal years (MA Brennan, unpublished data) and it is important to have ~1 m of subsoil moisture (Lodge and McCormick 2010*a*) to promote early growth. Further information on establishing tropical grasses can be found on the Industry & Investment NSW website (www.dpi.nsw.gov.au/primefacts), and Lodge and McCormick (2010*a*) have provided tips for establishment.

Managing an established tropical grass pasture

Once established, tropical grass pastures are responsive to nutrition and management. To achieve the best value from a tropical pasture it needs to be treated as a high value crop and managed to its potential (McCormick 2004). Tropical grass pastures are generally considered to be better suited to cattle, but they are also suitable for sheep – grazing management is the key.

Tropical grasses can have growth rates of ~170 kg DM/ha/day when there is good soil moisture and fertility. Without N, growth rates decline to ~35 kg DM/ha/day and growth ceases (<10 kg DM/ha/day) when available soil moisture is low (SP Boschma, unpublished data). As a general rule-of-thumb, for every kg of N applied, an additional 100 kg of herbage can be produced over a growing season. For example, at Tamworth unfertilised Premier digit produced 5000 kg DM/ha over the 2007–08 season,and 15000 kg DM/ha when fertilised with 100 kg N/ha.

One of the biggest challenges with tropical grass pastures is maintaining high feed quality. This can be achieved with good soil fertility and grazing management. Fertility can be improved by annual application of fertiliser, including N applied either as fertiliser or provided by a legume in the pasture. Good grazing management is required to maintain the pasture in a vegetative state, because once stem elongation commences the quality of the pasture decreases. This is because flowering plants have a higher proportion of stems, which have lower quality and a lower green leaf quality. Recent research at Tamworth has shown that crude protein and metabolisable energy levels of Premier digit defoliated every 2 weeks were higher than when defoliated every 6 weeks (Table 3). These studies also showed that the proportion of leaf after 2 weeks regrowth

Table 3. Crude protein (%) and metabolisable energy (MJ/kg DM) of green leaves of Premier digit unfertilised or fertilised with 100 kg/ha nitrogen during the growing season (SP Boschma, unpublished data).

Month	2-week regrowth		6-week regrowth	
	Unfertilised	Fertilised	Unfertilised	Fertilised
		Crude protein (%)		
November	15.9	18.7	14.2	17.0
January	14.7	18.4	13.4	16.9
March	13.1	18.0	11.8	17.4
		Metabolisable energy (MJ/kg DM)		
November	9.5	9.6	9.1	8.6
January	9.1	9.5	9.2	9.5
March	7.1	7.7	7.2	7.3

was ~75%, but declined to ~30% after 6 weeks of regrowth (SP Boschma, unpublished data). Unfertilised tropical grass pastures can utilise soil N that results from mineralisation in winter, but this N is rapidly depleted, and so plant crude protein levels often decline. In contrast, when the pasture is fertilised with 100 kg N/ha, crude protein levels are maintained throughout the summer growing season (Table 3).

All grasses need adequate N to maximise protein levels for optimum livestock performance. Research has shown that if the crude protein content of tropical grasses falls below 6–8%, animal intake will be depressed because of a crude protein deficiency in the animal's rumen (Minson 1990). Crude protein levels are lower when the pasture is unfertilised, allowed to flower or to accumulate large amounts of stem and dead material. Raising crude protein levels from 4.1 to 9.9%, increased dry matter intake of beef cattle from 4.3 to 7.7 kg/head/day. Similarly, when fed unfertilised tropical grass, cattle lost 0.22 kg/head/day, but when fed fertilised grass they gained 0.69 kg/head/day (Chapman and Kretschmer 1964). Recent work at Tamworth (e.g. Table 3) suggested that animal production from a tropical grass pasture may be limited by energy not protein. To more fully understand the role of these pastures in livestock production systems a better understanding of the role of different supplements throughout the year is required.

In the middle of summer, when there is good soil moisture, tropical pastures require high stock numbers and regular grazing to maintain them in a high quality, leafy stage of growth. For a tropical grass pasture growing at 100 kg DM/ha/day, for example, the stocking rates required to prevent the pasture from accumulating herbage would be ~100 lambs/ha (25 kg liveweight with an intake of ~1 kg DM/head/day) or 13 steers/ha (~300 kg liveweight, intake ~7.5 kg DM/head/day) (Bell 2006). Therefore, in the growing season, these pastures need to be either set stocked or rotationally grazed with only a couple of weeks rest, both at high stocking rates, to prevent the pastures from flowering and producing too much stem material.

High utilisation of tropical grass pastures may well require paddocks being subdivided into smaller areas which are easier and more flexible to manage. As an example, if a farm had 4 paddocks of tropical pastures, in spring these could be heavily grazed, but following summer rainfall pasture growth rates will be higher and so rest periods between grazings may need to be shortened and possibly only 2 paddocks grazed to keep the pasture vegetative and maintain quality. Alternative strategies for using excess forage could include; buying additional store stock to fatten; turning the excess feed into hay or silage; leaving the ungrazed paddocks to be used as a 'standing haystack' in winter with supplements; or a combination of these options. Some producers are adopting the coastal strategy of, slashing or mulching their tropical grass pastures to keep them in a leafy vegetative growth stage.

Legumes are the most sustainable means of providing N and lifting the overall quality of a pasture. Research on the North-West Slopes is currently investigating a range of annual and perennial legumes for use in tropical grass pastures (Boschma and Harris 2009). At Tamworth, the summer-growing perennial legumes lucerne (*Medicago sativa*), desmanthus (*Desmanthus virgatus* cv. Marc), round-leaf cassia (*Chamaecrista rotundifolia* cv. Wynn) and leucaena (*Leucaena leucocephala* ssp. *glabrata* cv. Tarramba) are showing potential (SP Boschma, unpublished data). At Bingara, Phoenix birdsfoot trefoil (*Lotus corniculatus*) a newly developed medium leaf, fine stem type that is high yielding in cool and warm season environments (Ayres *et al*. 2008) is also showing potential (CA Harris, unpublished data). Desmanthus, round-leaf cassia and leucaena are tropical legumes and their foliage is frosted in winter, but desmanthus and leucaena reshoot from plant crowns in spring. Round-leaf cassia plants are killed by severe frost, but following spring rainfall regenerate from seed set the previous year. Annual legumes are also being investigated, although dry autumns in the last few years have been unsuitable for establishment and regeneration of annual legumes (Lodge and McCormick 2010*b*). These studies will continue until June 2011.

Role of tropical grass pastures in future environments of variable climates

Rainfall variability and changed rainfall patterns, higher temperatures and higher levels of atmospheric carbon dioxide are likely to be features of future environments. At Barraba in northern NSW, for example, annual rainfall in the past 10 years (2000–09), has been below the long-term average (Lodge and McCormick 2010*b*), while rainfall received in December has been higher than average. This would have favoured the establishment and growth of tropical perennial grass pastures and to some extent may have 'buffered' the declines in production from annual legumes (e.g. subterranean clover and annual medics), forage oat and lucerne pastures in autumns that were markedly drier than average. This trend may continue in the future, with feed grown in summer increasingly being used to offset production declines in other seasons.

Similarly, climate change predictions for a site near Barraba (Cullen *et al.* 2009; Lodge *et al.* 2009*a*), indicated that by 2030 annual temperatures were likely to be 1.2°C higher (high-emissions scenario) and rainfall to remain unchanged compared with the baseline period of 1971–2000. By 2070, temperatures were predicted to be 2.7°C higher for a mid-emissions scenario and 4.4°C higher for a high-emissions scenario, but annual rainfall increases were only ~1.0% higher than the baseline period. However, at Barraba, the trend in the climate change projection data was for total annual rainfall to increase by up to 12% compared with the long-term mean and for rainfall in January–February to be higher (Lodge and McCormick 2010*b*). Other climate change models have indicated that rainfall in the future may increase in spring and decrease in autumn (Watterson *et al.* 2007). These changes in rainfall pattern, combined with the predicted temperature increases, would favour the establishment and growth of tropical species.

Future research for tropical grass pastures in NSW

The potential for tropical pastures in NSW is still largely untapped. Demand for red meat is predicted to increase, with greater quantities required for both the domestic and export markets. To achieve this, livestock numbers will need to increase, as will the quantity and quality of pastures to feed them. In the summer dominant rainfall areas of northern NSW, tropical pastures have an important role on-farm in contributing to an improved supply of forage throughout the year.

Over the past few years there has been some discussion on the potential of tropical grass pastures in the more winter rainfall dominant areas of southern NSW, but their persistence and productivity in environments with less summer rainfall needs to be determined.

If the summer-growing perennial legumes that are showing promise in current studies continue to persist, then further research will be required to develop the best methods for their establishment and management in future environments.

Evaluation of 130 species/lines of perennial tropical grasses in northern NSW (Harris 2008) has identified elite lines of green panic (*Megathyrsus maximus*) that are more persistent than the commercial cultivars Gatton and Petrie green panic, which failed to persist for more than 3 to 4 years in the evaluation conducted by McCormick *et al.* (1998). Promising lines of *Panicum coloratum* and Rhodes grass have also been identified. These elite lines are currently being evaluated under grazing throughout northern NSW by Industry & Investment (Harris *et al.* 2009) and Heritage Seeds (W Swann, pers. comm.) and in Western Australia. Several legumes, such as desmanthus, round-leaf cassia and leucaena are also showing some potential for the North-West Slopes and are new to NSW. Further work will be needed to evaluate and incorporate them into future farming systems.

Strategies to utilise carryover herbage produced by tropical grass pastures in the summer-growing season will need to be developed for both current and future farming systems. Studies are needed to determine techniques for maximising vegetative growth in-season, as well as make use of excess herbage out-of-season by using supplements and fodder conservation of hay and silage.

Conclusion

Tropical perennial grass pastures have an important role in grazing systems in northern NSW, and this role is likely to increase given their resilience in our increasingly variable climate. In order for tropical grass pastures to provide quality forage for grazing animals, both high soil fertility and good grazing management are essential. While our knowledge of tropical grass pastures in northern NSW is increasing, further research needs to be conducted, including on suitable legumes and the use of supplementation, and to determine the potential of tropical grasses in southern NSW.

Acknowledgements

The research projects described in this paper were funded by Future Farm Industries Cooperative Research Centre (CRC) (formerly CRC for Plant-based Management of Dryland Salinity), Meat and Livestock Australia and Industry & Investment NSW.

References

Ayres, JF, Kelman, WM & Lane, LA (2008) Phoenix, Venture and Matador – new birdsfoot trefoil cultivars for permanent pasture applications in eastern Australia. In 'Proceedings of the 23rd Annual Conference of The Grassland Society of NSW'. (Eds SP Boschma, LM Serafin and JF Ayres) pp. 107–109. (NSW Grassland Society Inc.: Orange)

Bell, AK, Ed. (2006) PROGRAZE ™ Manual. NSW Agriculture, Orange and Meat and Livestock Australia. Sixth edition 2003.

Boschma, SP & Harris CA (2009) Grass-legume mixtures on the north-west slopes of New South Wales – finding a compatible legume. *Tropical Grasslands* 43, 267–268.

Boschma, SP, Lodge, GM & Harden, S (2009) Herbage mass and persistence of perennial grass and herb cultivars and lines in a recharge area, North-West Slopes, New South Wales. *Crop & Pasture Science* 60, 753–767.

Boschma, SP, Lodge, GM & Harden, S (2010) Evaluation of perennial legume and herb cultivars and lines, North-West Slopes of New South Wales. In 'Proceedings of the 25th Annual Conference of The Grassland Society of NSW'. (Eds C Waters, D Garden) This proceedings (NSW Grassland Society Inc.: Orange)

Bowman, AM (1990) Rehabilitation of degraded pastures and abandoned cropland in semi-arid New South Wales. Final report to the Australian Wool Corporation, Wool Research & Development Council. (NSW Agriculture & Fisheries: Walgett)

Buckley, KS (1959) Plant testing for soil conservation at Inverell. *Journal of Soil Conservation of NSW* 15, 227–245.

Campbell, MH, Munnich, DJ & Bowman, AM (1993) Rehabilitation of degraded native pasture and croplands for grazing in the semi-arid summer rainfall pastoral zone. Final report to Australian Wool Research and Development Corporation. (NSW Agriculture: Orange)

Chapman, HL & Kretschmer, AE (1964) Effect of nitrogen fertilizer on digestibiluity and feeding value of Pongola grass hay. *Proceedings of the Soil and Crop Science Society of Florida* 24, 176–183.

Cullen, BR, Johnson, IR, Eckard, RJ, Lodge, GM, Walker, RG, Rawnsley, RP & McCaskill, MR (2009) Climate change effects on pasture systems in south-eastern Australia . *Crop & Pasture Science* 60, 933–942.

Harris, CA (2008) New *Panicum* cultivars on the horizon for northern NSW. In 'Proceedings of the 23rd Annual Conference of The Grassland Society of NSW'. (Eds SP Boschma, LM Serafin, JF Ayres) p. 114 (Grassland Society of NSW Inc.: Orange)

Harris, CA, Boschma, SP & Moore, G (2009) Developing a more productive, persistent panic grass cultivar. *Tropical Grasslands* 43, 269–270.

Johnson, A (1952) Sown pastures for Inverell, Moree and Boggabilla Districts. *The Agricultural Gazette of NSW* 63, 343–366, 410–414, 418.

Lodge, GM & Harden, S (2009) Effects of depth and time of sowing and over-wintering on tropical perennial grass seedling emergence in northern New South Wales. *Crop & Pasture Science* 60, 954–962.

Lodge, GM, Johnson, IR & Cullen, BR (2009*a*) Effects of climate scenarios on simulated intake of sheep grazing native pastures in northern New South Wales, Australia. *Animal Production Science* 49, 1015–1022.

Lodge, GM, Boschma, SP & Harden, S (2009*b*) Replacement series studies of competition between tropical perennial and annual grasses and perennial grass mixtures in northern New South Wales. *Crop & Pasture Science* 60, 526–531.

Lodge, GM, Brennan, MA, Harden S & Boschma, SP (2010*a*) Changes in soil water content under annual, perennial and shrub-based pastures in an intermittently dry, summer rainfall environment. *Crop & Pasture Science* 61, 331–342.

Lodge, GM, Brennan, MA & Harden S (2010*b*) Field studies of the effects of pre-sowing weed control and time of sowing on tropical perennial grass establishment, North-West Slopes, New South Wales. *Crop & Pasture Science* 61, 182–191.

Lodge, GM & McCormick LH (2010*a*) Ten tips for better establishment of sown tropical perennial grasses in northern New South Wales. In 'Proceedings of the 25th Annual Conference of The Grassland Society of NSW'. (Eds C Waters, D Garden) This proceedings (NSW Grassland Society Inc.: Orange)

Lodge, GM & McCormick, LH (2010*b*) Comparison of recent, short-term rainfall observations with long-term distributions for three centres in northern New South Wales. In 'Proceedings of the 25th Annual Conference of The Grassland Society of NSW'. (Eds C Waters, D Garden) This proceedings (NSW Grassland Society Inc.: Orange)

McCormick, LH (2004) Managing the pasture phase as a high value crop. In 'Proceedings of the nineteenth Annual Conference of The Grassland Society of NSW'. (Eds SP Boschma, GM Lodge) pp. 93–98. (Grassland Society of NSW Inc: Orange)

McCormick, LH, Lodge, GM, Boschma, SP & Murray, S (2009) Simple rules to use when buying seed of tropical perennial grasses. In 'Proceedings of the 24th Annual Conference of The Grassland Society of NSW'. (Eds D Brouwer, N Griffiths, I Blackwood) pp. 97–100. (NSW Grassland Society Inc.: Orange).

McCormick, LH, McGufficke, BR, Harden, S & Ross, BA (1998) Subtropical grass evaluation for pastures in northern NSW. In 'Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga'. http://www.regional.org.au/au/asa/1998/1/028mccormick.htm

Minson, DJ (1990) The chemical composition and nutritive value of tropical grasses. In 'Tropical Grasses' (Eds PJ Skerman, F Riveros) pp 163-180 (Food and Agriculture Organisation of the United Nations: Rome, Italy)

Murphy, SR, Lodge, GM & Harden, S (2004) Surface soil water dynamics in pastures in northern New South Wales. 3. Evapotranspiration. *Australian Journal of Experimental Agriculture* 44, 571–583.

Murphy, SR, Lodge, GM & Brennan, MA (2008*a*) Water use indices of tropical grasses in a temperate environment. In 'Multifunctional Grasslands in a Changing World' Vol. 1, p. 837 (Edited by Organising Committee of IGC/IRC Congress – Guangzhou), (Guangdong People's Publishing House, 2008. 06).

Murphy, SR, Lodge, GM & Brennan, MA (2008*b*) Plant root depth of tropical grasses in a temperate environment. In 'Multifunctional Grasslands in a Changing World' Vol. 1, p. 464 (Edited by Organising Committee of IGC/IRC Congress – Guangzhou), (Guangdong People's Publishing House, 2008. 06).

Murphy, SR, Lodge, GM & Brennan, MA (2010) Tropical grass pastures capture winter rainfall. In 'Proceedings of the 25th Annual Conference of The Grassland Society of NSW'. (Eds C Waters, D Garden) This proceedings (NSW Grassland Society Inc.: Orange).

Watt, LA (1976) Evaluation of pasture species for soil conservation on cracking black clays – Gwydir district, northwestern New South Wales. *Journal of Soil Conservation Service of NSW* 32, 86–97.

Watterson, I, Whetton, P, Moise, Al, Timbal, B, Power, S, Arblaster, J & McInnes, K (2007) Regional climate change projections. Climate change in Australia – Technical Report. (Eds. K Pearce, P Holper, M Hopkins, W Bouma, P Whetton, K Hennessy, S Power) pp. 49–107. (CSIRO, Australia) Available at: http://www.climatechangeinaustralia.gov.au/technical_report.php