A summary of grazing trials carried out by CSIRO in northern Australia from 1950-2000: treatments imposed and attributes measured

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Abstract

The published records of 73 grazing trials that measured pasture and animal production, carried out by CSIRO in northern Australia from the 1950s to 2000, have been collated. They have been grouped into 5 geographical regions: coastal subtropical Queensland, subcoastal subtropical Queensland, tropical Queensland, the Northern Territory and northern Western Australia. No CSIRO experiments of this type are currently in progress. The duration of each trial is given and also an indication of whether it included native pastures, oversown native pastures and/or fully improved pastures. The treatments imposed, *e.g.* stocking rates, tree killing, introduction of legumes, use of supplements, fertilisation (N, P, K or lime) and burning, have been tabulated for each trial. This format makes it easy to find all the trials that have examined the effects of any particular variable. Many trials have measured attributes other than cattle liveweight gain and pasture yield and composition, including: demography, biodiversity, seed contents of faeces, pasture quality, carcase quality and economics, dietary composition, run-off following rainfall and soil fertility. The extra attributes measured in each trial are also listed, making it possible to determine which trials have information on any specified attribute. No experimental data are presented in this paper; rather it is a record of where experimental data can be found. Similar pasture information is given for a further 12 trials where grazing treatments were imposed but no measurements made of animal production.

Some comments are made about regional differences in the emphasis placed on native pastures as compared with fully improved pastures. It is suggested that inadequate emphasis was given to burning and to grazing management, other than stocking rates, as variables and also that there has been inadequate use of grazing trials as a resource in which to measure how attributes such as biodiversity and soil properties have been affected by the treatments imposed. It is also pointed out that writing up the results of grazing trials for the conventional scientific paper has resulted in the loss of data that could be useful in model development and validation. Some comments are made about attributes which could have been measured, at least in some trials, but were not. Finally, it is stressed that the value of many grazing studies, in terms of measuring changes in botanical composition, has been limited by their short duration.

Introduction

CSIRO has played an important part in developing improved pastures and an understanding of how to manage improved and native pastures in northern Australia. Almost all of this CSIRO research has been conducted by scientists in the Division of Tropical Pastures (1959-1972), Division of Tropical Agronomy (1972-1975), Division of Tropical Crops and Pastures (1975-1996) and CSIRO Tropical Agriculture (1996-2000). This work sometimes involved grazing experiments, where the impacts of different pasture species or management practices on cattle production and/or pasture productivity were measured. As CSIRO currently has no experiments of this type, it is an opportune time to summarise all the published information from such studies in terms of the treatments imposed and the attributes measured. With the increasing interest in the use of modelling, it is also important to alert scientists to sources of published data on animals and plants, which might be useful in the development or validation of models.

This paper provides details of all CSIRO trials where liveweight gain and/or reproduction of beef cattle and pasture composition were measured under controlled grazing. In the majority of cases, only 2-4 head, usually steers, grazed each treatment. Short-term trials carried out in the

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1970s using dairy cattle have not been included; a complete list of publications describing these trials can be found by looking under "Stobbs" in the list of CSIRO publications compiled by Thompson (1982). With one exception (Roe and Allen 1993), CSIRO has not reported on any grazing trials with sheep in northern Australia, apart from one instance where sheep were used in an endeavour to assess quality differences in different accessions of buffel grass (*Cenchrus ciliaris*) (Minson and Hacker 1995) and another where sheep were used as grazers in an evaluation study in the coastal lowlands (Bryan and Evans 1971a). Other state-based government departments, especially the Queensland Department of Primary Industries (now Queensland Primary Industries and Fisheries), and some universities have also made major contributions in the fields of pasture improvement and animal production, but their contributions were not included in this paper. However, some of the studies reported here were made by workers outside of CSIRO but were on CSIRO experiments (*e.g*. Orr *et al.* 2004a; 2004b).

Grazing trials with annual forage crops, such as those with forage sorghum or oats in the Ord River valley (Blunt and Fisher 1973; 1976) or with oats in central Queensland (Coaldrake and Smith 1967) have not been included. The experiments carried out on Townsville stylo (*Stylosanthes humilis*) at Katherine Research Station during the 1960s have not been included. Most were short-term trials, lasting less than 2 years and/or grazed for only part of the year. For further information on these trials, refer to Norman and Phillips (1970) and Norman and Begg (1973).

This paper outlines what treatments were imposed and then lists the types of data collected. It does not give actual results, but refers to publications where these data are presented. In the vast majority of the experiments considered, the data are available in published papers. A few of the experiments listed have not been formally written up, but some of the key data have been summarised in annual reports and conference papers, so they have been included in this paper. Three Ph.D. thesis studies, conducted within listed long-term grazing trials, have been included, even though the results of these studies have not been published. This paper complements the publication of Hasker (2000) that presents information from trials and producer-demonstration-sites under headings such as weaners, supplementation etc. within northern Australia. Day *et al*. (1997) have also summarised the results of 10 grazing trials on native pastures within Queensland.

Methods

The published papers were examined to determine what treatments were imposed, and which attributes were measured other than animal production and basic pasture yield and composition.

Results

Location of trials and treatments imposed

Details of the trial sites, including location, rainfall and soil type are listed in Table 1. Soil types have been listed using the terms in the relevant published papers, so several different forms of nomenclature have been used. In some cases, where no soil type is given in the original publication, soils have been described using general terms such as "clays", based on personal knowledge of the site.

Table 2 gives details of each trial, which is allocated a number. Where a trial ran for a number of years but was then appreciably modified, the different phases have been indicated by use of the letters a, b and c after the same trial number. In cases where the same experimental site has been re-used, but with completely different treatments in the second trial, the second trial has been given a new number. Table 2 lists the site name and the duration of the trial in years, and the pasture types, designated by an 'x', have been grouped into 3 classes: native pasture, oversown native pasture and fully improved pasture. The table then uses an "x" to indicate the types of treatments imposed in each trial, under the following column headings:

SR Stocking rates - the trial included 2 or more stocking rates

Gs Grazing systems - the trial compared 2 or more grazing systems. Most trials had continuous grazing only.

N Nitrogen - there were 2 or more levels of nitrogen fertilisation

P Phosphorus - there were 2 or more levels of phosphorus fertilisation

K Potassium - there were 2 or more levels of potassium fertilisation

Ca Calcium - there were 2 or more levels of lime or calcium fertilisation
Gr Grass - 2 or more grasses were compared as different treatments
Le Legumes - 2 or more legumes were compared as different treatments
Tr Trees – the effects of tree killing were examined
Ha Hay - 1 treatment included conserving excess feed during the growing season and feeding this in winter
Bc Breed comparison - productivity of 2 or more cattle breeds was compared
Su Supplements - the effects of nutritional supplements such as P and N were examined
Bu Burning - the effects of burning stand-over feed were compared with not burning

A very brief description of each trial is given, with the key reference to that trial. The only exception is that the key reference to trial 36 is a particular issue of *Tropical Grasslands*. This is because the results of that trial were presented, along with the results from other grazing trials on the same topic, in 6 different papers within the one journal issue.

Attributes measured

Trials 1-82b all contain some data on animal production, although the level of detail varies widely. Almost all of these trials have some data on pasture yield and botanical composition. Trials 101-112 contain data on yield and composition only. The plot sizes in these trials were adequate to give controlled grazing but not large enough to enable measurement of animal production.

Table 3 lists attributes *other than* liveweight gain, pasture yield and botanical composition data that have been measured in these trials. It refers to trials by the same numbering system used in Table 2. In some instances, where many extra attributes have been measured, 2 or more lines have been used in Table 3 to list all the attributes measured in the 1 experiment.

Other attributes measured in these trials are listed under the following column headings:
Sf Soil fertility - includes attributes such as pH, available P, total N, total C
Ro Run-off - includes measurements of run-off and soil loss
De Demography - includes plant survival, seedset, seed banks, seedling recruitment
Fs Faecal seed - seed levels in cattle faeces
Bi Biodiversity - plant biodiversity or species richness
Ec Economics - economic analyses were carried out comparing different treatments
Pq Pasture quality - measurements such as N%, P% and digestibility
Cg Carcase grade - carcase grades of animals from different treatments
Am Animal measurements - includes P in blood and bone, thyroxine in blood
Dc Dietary composition - from oesophageal fistula or analysis of C isotopes of faeces
Gr Grass - includes measurements of grass leaf/stem and green/dry components, etc.
Re Reproduction - includes pregnancy %, calving %, calf growth rates, semen quality
Pe Pests - includes ratings of insect damage

Following the individual columns for these attributes, the next column gives very brief details of what was measured. Phrases in this column separated by a semicolon indicate they relate to different areas of study. For example, the first phrase may relate to measurements of demography and faecal seed, whereas the next phrase relates to measurements of animal reproduction. The order of phrases is, as far as possible, the same as in the headings Sf to Pe, as given above. Appropriate references follow. If there are 2 references separated by a semicolon, the first refers to the first phrase in the previous column.

Obviously, not all entries have the same amount of information about that attribute. For example, one of the entries with an 'x' for biodiversity could have a large amount of information with complete listing of all species present. Others might have much less information, yet still present enough to warrant inclusion. In contrast, papers that had only a sentence or two about "other important species" were not given an 'x' for biodiversity.

Details on pasture quality

Further details of any pasture quality and animal measurements are given in Table 4. Using the same trial numbers as previously, the first 2 columns indicate whether measurements were made on cut samples, which were usually taken from herbage samples cut to 10 cm above ground level, or were plucked by hand to simulate what animals might eat. The next 4 columns indicate if samples were from native grass, sown grass, legume or a mixture. The following 12 columns

describe what elements (N to Mn) were measured in at least some of the samples, while the next column indicates if measurements of *in vitro* digestibility were taken. The final column of plant attributes indicates that some measurements were made of leaf:stem ratios or of green and dry leaf in at least some of the samples. The next 9 columns relate to measurements of animal bone P, blood, faeces or saliva. Appropriate references are then listed, using semicolons as described previously.

Discussion

It is not the purpose of this memorandum to present or review data. However, some general observations can be made about the types of experiments used and on the attributes measured.

Firstly, there is an interesting difference between the pasture types used for experimentation in southern Queensland and those used in north Queensland and the Northern Territory. In southern Queensland, most experiments have been on fully sown pastures rather than on oversown or undisturbed native pastures. This is presumably partly due to historical changes in thinking and partly to practical considerations. When many of the grazing trials were set up in the 1960s, it was assumed that pasture improvement would be more important than it has actually been. For example, Davies and Eyles (1965) estimated that ≈ 58 M ha of Queensland could be improved, whereas more recent estimates (Walker and Weston 1990) suggest a figure of 22 M ha. Similarly, native pastures were perhaps undervalued by CSIRO policy makers, so it is not surprising that there was less emphasis on native pastures in the 1960s. Furthermore, much of this early research work was done in the coastal and brigalow areas, where there were usually no or insufficient useful native grasses to quickly colonise the newly cleared areas. Consequently, the emphasis was on sown pastures. Despite this, there was some work on native pastures in southern and central Queensland in the 1950s-1970s, primarily at Narayen, Westwood and Rodds Bay. In contrast to southern Queensland, experiments in northern tropical Australia, with the exception of those under irrigation at Kununurra in Western Australia, focussed on undisturbed or oversown native pasture.

Secondly, there has been little research on burning, although burning is a topic of considerable interest in relation to pasture composition (Winter 1987; Orr *et al.* 1991). Burning was a variable in one trial in the northern Territory (70d), and in two medium-term experiments at Narayen Research Station (34b; 37) and some opportunistic observations were made after an accidental burn in sown pastures in experiment 33 at Narayen. In addition, the effects of tree clearing have been investigated in only 4 experiments.

Thirdly, very few trials have looked at grazing management other than set-stocked year-long grazing. While this form of management has the distinct advantage of reproducible simplicity and is well suited for initial grazing studies, there has been very little attempt to move further. This would involve the examination of the effects of short- or long-term resting, deferred grazing or even seasonal changes in grazing pressure (column Gs or grazing system in Table 3). This is despite the early scientific demonstration of the major impacts that these factors can have on pasture composition (*e.g.* Jones 1933) and of the improvements claimed by graziers who have used these strategies on their own properties (*e.g.* Lansberg 1993). It is also interesting to reflect that, while many of the treatments imposed have resulted in overgrazed pastures at the heaviest stocking rate, little effort has been made to investigate how to restore these overgrazed pastures. Even the simple use of small exclosures or cages on such pastures can provide very useful information on recovery (Jones 1992). There are very few instances of where grazing treatments have been deliberately imposed on poor or degraded pastures with the objective of restoring them (*e.g.* Jones 1984; Ash *et al.* 2001; Jones and Jones 2003).

Fourthly, a considerable amount of information has been collected on nutrient concentrations in forage. This was collected to provide data to enable better interpretation of results of animal growth. With the exception of the detailed work on P in plants, soils and animals (*e.g.* experiments 36, 53 and 70c), it is questionable how much of this has been useful, particularly from cut samples. It is very difficult to relate the data from the many 'whole plant' samples (cut to ground level) to material being selected by grazing animals. There is abundant evidence of the ability of animals to select a higher quality diet than the mean

of the pasture on offer, even in intensively grazed and high quality temperate pastures (Jacobs *et al.* 1999), where selection is unlikely to be as critical as it is in extensively grazed tropical pastures. While the whole plant analyses describe broad changes in overall pasture quality with season or species, they may be of little practical use. The data on plucked samples, taken to simulate what animals are actually eating, are more likely to be of use in explaining results or in modelling studies. However, it is uncertain how representative plucked samples are of the material that animals are ingesting. Similarly, caution is needed in extrapolating measurements of diet selection, as measured by oesophageal-fistulated animals, to free-grazing animals (Coates *et al.* 1987b; Clements *et al.* 1996). While there is considerable value in measuring nutrient content if this can be related to true pasture yield, and then to nutrient status of the pasture system, these parallel measurements were not made in any CSIRO trials.

Fifthly, comparatively few studies have taken advantage of the opportunity that is afforded to take extra measurements of other variables such as species diversity, plant demography and soil fertility that can be measured in grazing trials. The advantage of taking such measurements is that they can be placed in the context of controlled variables such as fertiliser and stocking rates and known rainfall and pasture composition. It is then possible to gain insight into how the different management treatments affect the ecology of the whole grazing system. For example, some environmentalists argue that sowing of species such as buffel grass reduces species diversity. Yet, in the many experiments sown to buffel grass, records have been taken of the complete species list of associated species only in experiment 34 (although they are as yet largely unpublished) and, to a much lesser extent, experiment 35. Thus, the opportunity to ascertain how species florisitics have been affected by the use of buffel grass has been lost. There was not even one instance of where measurements were made of how treatments affected below- or above-ground grassland invertebrates. Similarly, there has been very little use of exclusion cages to measure how applied grazing treatments have affected true pasture growth and decay. Such measurements are particularly useful in pasture modelling. Likewise, there have been only rare instances, such as McIvor *et al*. (1995) and Orr *et al.* (2004a), where the basal area of perennial grasses has been measured, although this can be a very useful attribute in rangeland research. These statements, however, are not to imply that such extra measurements (O'Reagain *et al.* 2008) should be taken in all trials, as the merit of taking them depends on many factors, such as the importance of the pasture types being investigated. This concept of making more use of grazing experiments by measuring extra variables has been discussed in more detail by Jones *et al.* (1995a).

Sixthly, valuable information on pastures has been obtained by using small paddocks that enabled different stocking rates to be imposed, yet were not large enough to measure animal production. This applied to trials 101-112, particularly to 107 and 108, where many ecological processes, such as colonisation and tree regrowth, were investigated. There is good evidence that such small plots can give realistic stocking rate effects, as shown by the comparable effects of heavy grazing on *Setaria sphacelata* pastures in very small paddocks (<0.1 ha) (Jones 1979) and larger paddocks of 1-3 ha (Jones and Jones 2003) and on commercial pastures in the same region. In all cases, the tussock grass setaria was replaced by prostrate grasses such as *Digitaria didactyla*. However, caution may be needed in using small plots to compare different grazing systems owing to the small number of animals used in small plot studies (Norton 1998). The limitations of small plots may also be greater in rangeland research as compared with intensively grazed improved pastures, owing to greater spatial and temporal variability (Ash and Smith 1996).

Finally, many of the grazing trials carried out in the 1960s-80s collected vast amounts of data on pastures and animal liveweight changes at regular 4-8 weekly intervals. These data could be of considerable use in model development and validation, but with two exceptions (McCaskill 1992; McDonald *et al.* 1995) were not published. As published data on long-term trials are often presented on an annual basis, or even as the mean of a number of years, this detailed information is lost unless it is specially presented in another form. However, it must also be acknowledged that much of the regular information collection occurred in the early years of the trials, before many of the important changes in botanical composition took place (*e.g*. Jones *et al*. 1995b; Jones and Jones 2003; Jones 2003). This highlights a potential problem in short-term grazing studies, particularly if carried out for less than 5 years;

it is quite likely that such studies could provide a misleading indication of long-term pasture persistence. The difficulties associated with documenting long-term botanical changes in grazing studies and possible ways of overcoming them have been discussed in more detail by Jones *et al.* (1995a).

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References

Andrew, M.H. (1986a) Use of fire for spelling monsoon tallgrass pasture grazed by cattle. *Tropical Grasslands*, **20**, 69-78.

Andrew, M.H. (1986b) Selection of plant species by cattle grazing native monsoon tallgrass pastures at Katherine, N.T. *Tropical Grasslands,* **20**, 120-127.

Anon (1996) Sustainable and profitable native grass-legume pastures for southern speargrass lands. *Final Report, Project CS195. Australian Meat Corporation*.

Ash, A.J., McIvor, J.G., Corfield, J.P. and Winter, W.H. (1995) How land condition alters plant-animal relationships in Australia's tropical rangelands. *Agriculture, Ecosystems and Environment*, **56**, 77-92.

Ash, A.J. and Smith, D.M.S. (1996) Evaluating stocking rate impacts in rangelands: animals don't practice what we preach. *The Rangeland Journal*, **18**, 216-243.

Ash, A.J. and Corfield, J.P. (1998) Influence of pasture condition on plant selection patterns by cattle: its implications for vegetation change in a monsoon tallgrass rangeland. *Tropical Grasslands*, **32**, 178-187.

Ash, A.J. and McIvor, J.G. (1998a) Forage quality and feed intake responses of cattle to improved pastures, tree killing and stocking rate in open eucalypt woodlands of north-eastern Australia. *Journal of Agricultural Science, Cambridge,* **131**, 211-219.

Ash, A.J. and McIvor, J.G. (1998b) How season of grazing and herbivore selectivity influence monsoon tall-grass communities of northern Australia. *Journal of Vegetation Science*, **9**, 123-132.

Ash, A., Corfield, J. and Ksiksi, T. (2001) The Ecograze Project: developing guidelines to better manage grazing country. *CSIRO Sustainable Ecosystems and Queensland Department of Primary Industries Report.*

Ash, A.J., Corfield, J.P., McIvor, J.G. and Ksiksi, T.S. (in press) Grazing management in tropical savannas: utilisation and rest strategies for rangeland health and recovery. *Rangeland Ecology and Management*, xx, 000-000.

Blunt, C.G. (1976) Preliminary cattle grazing trials on irrigated *Leucaena leucocephala* and pangola grass in the Ord Valley, N.W. Australia. *Proceedings of the Australian Society of Animal Production,* **11**, 10P.

Blunt, C.G. (1978) Production from steers grazing nitrogen fertilized irrigated pangola grass in the Ord Valley. *Tropical Grasslands,* **12**, 90-96.

Blunt, C.G. and Fisher, M.J. (1973) Production and utilization of fodder and grain sorghum as forage for cattle in the Ord River valley, Western Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **13**, 234-237.

Blunt, C.G. and Fisher, M.J. (1976) Production and utilization of oats as forage for cattle in the Ord River Valley, Western Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **16**, 88-93.

Blunt, C.G. and Jones, R.J. (1977) Steer liveweight gains in relation to the proportion of time on *Leucaena leucocephala* pastures. *Tropical Grasslands***, 11**, 159-164.

Bryan, W.W. (1968a) Grazing trials on the Wallum of south-eastern Queensland. 1. A comparison of four pastures. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **8**, 512-520.

Bryan, W.W. (1968b) Grazing trials on the Wallum of south-eastern Queensland. 2. Complex mixtures under common grazing. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **8**, 683-690.

Bryan, W.W. and Evans, T.R. (1971a) Grazing trials on the Wallum of south-eastern Queensland. III. A nursery grazed by sheep. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **11**, 633-639.

Bryan, W.W. and Evans, T.R. (1971b) A comparison of beef production from nitrogen fertilized pangola grass and from a pangola grass-legume pasture. *Tropical Grasslands*, **5**, 89-98.

Bryan, W.W. and Evans, T.R. (1973) Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of south-eastern Queensland. 1. Botanical composition and chemical effects on plants and soils. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **13**, 516-529.

Charles-Edwards, D.A., Tow, P. and Evans, T.R. (1987) An analysis of the growth rates of pasture and animal production. *Agricultural Systems,* **25**, 245-259.

Christian, C.S. and Shaw, N.H. (1952) A study of two strains of rhodes grass (*Chloris gayana* Kunth.) and of lucerne (*Medicago sativa* L.) as components of a mixed pasture at Lawes in south-east Queensland. *Australian Journal of Agricultural Research*, **3**, 277-299.

Clements, R.J., Jones, R.M., Valdes, L.R. and Bunch, G.A. (1996) Selection of *Chamaecrista rotundifolia* by cattle. *Tropical Grasslands*, **30**, 389-394.

Coaldrake, J.E. and Smith, C.A. (1967) Estimates of animal production from pastures on brigalow land in the Fitzroy basin, Queensland. *Journal of the Australian Institute of Agricultural Science*, **33**, 52-54.

Coaldrake, J.E., Smith, C.A., Yates, J.J. and Edye, L.A. (1969) Animal production on sown and native pastures on brigalow land in southern Queensland during drought. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **9**, 47-56.

Coates, D.B. (1994) The effect of phosphorus as fertiliser or supplement on pasture and animal productivity in the semi-arid tropics of north Queensland. *Tropical Grasslands*, **28**, 90-108.

Coates, D.B. (1995) The effect of phosphorus as fertiliser or supplement on the forage intake of heifers grazing stylo-based pastures. *Australian Journal of Experimental Agriculture,* **35**, 181-188.

Coates, D.B. (1996) Diet selection by cattle grazing *Stylosanthes*-grass pastures in the seasonally dry tropics: effect of year, season, stylo species and botanical composition. *Australian Journal of Experimental Agriculture,* **36**, 781-789.

Coates, D.B. and Bean, K.G. (1978) Post-weaning growth rates of Belmont Red and Hereford steers. *Proceedings of the Australian Society of Animal Production,* **12**, 218.

Coates, D.B., Mannetje, L.'t and Seifert, G.W. (1987a) Reproductive performance and calf growth to weaning of Hereford and Belmont Red cattle in subtropical, subcoastal Queensland. *Australian Journal of Experimental Agriculture*, **27**, 1-10.

Coates, D.B., Schachenmann, P. and Jones, R.J. (1987b) Reliability of extrusa samples collected from steers fistulated at the oesophagus to estimate the diet of resident steers in grazing experiments. *Australian Journal of Experimental Agriculture*, **27**, 739-745.

Coates, D.B. and Mannetje L. 't (1990) Productivity of cows and calves on native and improved pastures in subcoastal, subtropical Queensland. *Tropical Grasslands*, **24**, 46-54.

Coates, D.B. and Murray, R.M. (1994) Tail-bone density compared with other indicators of phosphorus deficiency in cattle. *Proceedings of the Australian Society of Animal Production*, **20**, 329-332.

Coates, D.B. and Le Feuvre, R.P. (1998) Diet composition of cattle grazing *Stylosanthes*-grass pastures in the seasonally dry tropics: the effect of phosphorus as fertilizer or supplement. *Australian Journal of Experimental Agriculture*, **38**, 7-15.

Davies, J.G. and Eyles, A.G. (1965) Expansion of Australian agricultural production. *Journal of the Australian Institute of Agricultural Science*, **31**, 77-93.

Day, K.A., McKeon, G.M. and Carter, J.O. (1997) Evaluating the risks of pasture and land degradation in native pasture in Queensland. *Final report for Rural Industries and Research Development Corporation Project DAQ124A. Queensland Department of Natural Resources, Brisbane.*

Edye, L.A., Ritson, J.B., Haydock, K.P. and Davies, J.G. (1971) Fertility and seasonal changes in liveweight of Droughtmaster cows grazing a Townsville stylo-spear grass pasture. *Australian Journal of Agricultural Research*, **22**, 963-977.

Edye, L.A., Ritson, J.B. and Haydock, K.P. (1972) Calf production of Droughtmaster cows grazing a Townsville stylo-speargrass pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **12**, 7-12.

Evans, T.R. (1969) Beef production from nitrogen fertilized pangola grass (*Digitaria decumbens*) on the coastal lowlands of southern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **9**, 282-286.

Evans, T.R. (1970) The effect of time and frequency of nitrogen application on animal production from pangola grass. *Annual Report 1969-70, Division of Tropical Pastures, CSIRO, Australia.* pp. 29-30.

Evans, T.R. (1972) Animal production from nitrogen fertilised pangola and Nandi setaria pastures. *Annual Report 1971-72, Division of Tropical Pastures, CSIRO, Australia.* pp. 9-10.

Evans, T.R. and Bryan, W.W. (1973) Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of south-eastern Queensland. 2. Liveweight change and beef production. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **13**, 530-536.

Evans, T.R. and Peake, D.C.I. (1976) Animal production from nitrogen fertilized grass pastures. *Annual Report 1975-76, Division of Tropical Pastures, CSIRO, Australia.* p. 6.

Evans, T.R. and Biggs, J. (1979) Breeding performance of Hereford cows grazing tropical pastures at Beerwah, south-east Queensland. *Tropical Grasslands*, **13**, 129-134.

Evans, T.R. and Wilson, J.R. (1984) Some responses of grasses to water stress and their implications for herbage quality and animal liveweight gain. *Proceedings of the 10th General Meeting of the European Grassland Federation, Norway, June 1984.* pp. 372-376.

Evans, T.R. and Hacker, J.B. (1992a) An evaluation of the production potential of six tropical grasses under grazing. 2. Assessment of quality using variable stocking rates. *Australian Journal of Experimental Agriculture*, **32**, 29-37.

Evans, T.R. and Hacker, J.B. (1992b) An evaluation of the production potential of six tropical grasses under grazing. 3. Responses to set stocking rates under continuous grazing. *Australian Journal of Experimental Agriculture*, **32**, 693-699.

Filet, P.G. (1990) *The distribution of biomass, nitrogen, and phosphorus in grazed* Heteropogon contortus *((L.) Roem. & Schult.) pastures*. Ph.D. Thesis. University of Queensland.

Firth, J.A., Evans, T.R. and Bryan, W.W. (1975) Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of south-eastern Queensland. 4. Budgetary appraisals of fertilizer and stocking rates. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **15**, 531-540.

Gardener, C.J. (1980) Diet selection and liveweight performance of steers on *Stylosanthes hamata* –native grass pastures. *Australian Journal of Agricultural Research*, **31**, 379-392.

Gardener, C.J. (1982) Population dynamics and stability of *Stylosanthes hamata* cv. Verano in grazed pastures. *Australian Journal of Agricultural Research*, **33**, 63-74.

Gardener, C.J., McCaskill, M.R. and McIvor, J.G. (1993) Herbage and animal production from native pastures and pastures oversown with *Stylosanthes hamata* 1. Fertiliser and stocking rate effects. *Australian Journal of Experimental Agriculture*, **33**, 561-570.

Gardener, C.J. and Ash, A.J. (1994) Diet selection in six *Stylosanthes*-grass pastures and its implications for pasture stability. *Tropical Grasslands*, **28**, 109-119.

Gillard, P. (1979) Improvement of native pasture with Townsville stylo in the dry tropics of sub-coastal northern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 325-336.

Gillard, P., Edye, L.A. and Hall, R.L. (1980) Comparison of *Stylosanthes humilis* with *S. hamata* and *S. subsericea* in the Queensland dry tropics: Effects on pasture composition and cattle liveweight gain. *Australian Journal of Agricultural Research*, **31**, 205-220.

Hacker, J.B. and Evans, T.R. (1992) An evaluation of the production potential of six tropical grasses under grazing. 1. Yield and yield components, growth rates and phenology. *Australian Journal of Experimental Agriculture*, **32,** 19-27.

Hasker, P.J.S. (2000) Beef cattle performance in northern Australia: a summary of recent research. *Information Series QI00054, Queensland Department of Primary Industries*. 377 pp.

Heida, R. and Jones, R.M. (1988) Seed reserves of barrel medic (*Medicago truncatula*) and snail medic (*M. scutella*) in the topsoil of pastures on a brigalow soil in southern Queensland. *Tropical Grasslands*, **22**, 16-21.

Izac, A-M.N., Anaman, K.A. and Jones, R.J. (1990) Biological and economic optima in a tropical grazing ecosystem in Australia. *Agriculture, Ecosystems and Environment*, **30**, 265-279.

Jacobs, J.L., McKenzie, F.R. and Ward, G.N. (1999) Changes in the botanical composition and nutritive characteristics of pasture, and nutrient selection by dairy cows grazing rainfed pastures in western Victoria. *Australian Journal of Experimental Agriculture*, **39**, 419-428.

Jones, M.G. (1933) Grassland management and its influence on the sward. I Factors affecting the growth of pasture plants. *Empire Journal of Experimental Agriculture,* **1**, 43-56.

Jones, R.J. (1966) The effect of urea-salt-molasses supplements on the winter performance of beef cattle on improved pastures at Samford, south-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **6**, 145-149.

Jones, R.J. (1974) The relation of animal and pasture productivity to stocking rate on legume based and nitrogen fertilized subtropical pastures. *Proceedings of the Australian Society of Animal Production*, **10**, 340-343.

Jones, R.J. (1976) Grass species, fodder conservation and stocking rate effects on nitrogen fertilized sub-tropical pastures. *Proceedings of the Australian Society of Animal Production*, **11**, 445-448.

Jones, R.J. (1988) The effect of pasture management on grass and animal production following frosting of nitrogen fertilized sub-tropical grass pastures. *Tropical Grasslands*, **22**, 57-62.

Jones, R.J. (1989) Nitrogen-fertilized pastures of Narok setaria and Samford rhodes grass give similar beef production in S.E. Queensland. *Tropical Grasslands*, **23**, 65-74.

Jones, R.J. (1990) Nitrogen rate and stocking rate effects on steer gains from grazed irrigated pangola grass in the Ord Valley, Western Australia. *Australian Journal of Experimental Agriculture*, **30**, 599-605.

Jones, R.J. (1997) Steer gains, pasture yield and pasture composition on native pasture and on native pasture oversown with Indian couch (*Bothriochloa pertusa*) at three stocking rates. *Australian Journal of Experimental Agriculture*, **37**, 755-765.

Jones, R.J. (2003) Effects of sown grasses and stocking rate on pasture and animal production from legume-based pastures in the seasonally dry tropics. *Tropical Grasslands*, **37**, 129-150.

Jones, R.J. (2004) Steer gains on Verano-improved pastures in north Queensland compared with those at Katherine, Northern Territory – is there a deficiency of nitrogen at Katherine? *Tropical Grasslands*, **38**, 42-46.

Jones, R.J. and Jones, R.M. (1982) Observations on the persistence and potential for beef production of pastures based on *Trifolium semipilosum* and *Leucaena leucocephala* in subtropical coastal Queensland. *Tropical Grasslands*, **16**, 24-29.

Jones, R.J. and Jones, R.M. (1989) Liveweight gain from rotationally and continuously grazed pastures of Narok setaria and Samford rhodes grass fertilized with nitrogen in south-east Queensland. *Tropical Grasslands*, **23**, 135-142.

Jones, R.J., Coates, D.B. and McCaskill, M.R. (1990) Pasture and climatic effects on cattle liveweight gain from stylo-based pastures in the seasonally dry tropics. *Proceedings of the Australian Society of Animal Production*, **18**, 260-263.

Jones, R.J. and Minson, D.J. (1990) Responses to monensin and oestradiol in steers grazing two tropical pastures in N.E. Queensland. *Asian-Australasian Journal of Animal Science*, **3**, 183-186.

Jones, R.J. and Coates, D.B. (1992) The effect of age on steer liveweight gain on continuously stocked tropical pastures. *Proceedings of the Australian Society of Animal Production*, **19**, 39-42.

Jones, R.J., Galgal, K.K., Castillo, A.C., Palmer, B., Deocareza, A. and Bolam, B. (1998) Animal production from five species of *Leucaena*. In: Shelton, H.M. *et al.* (eds) *Leucaena – Adaptation, Quality and Farming Systems.* pp. 247-252. *ACIAR Proceedings* No. 86. (ACIAR: Canberra).

Jones, R.J. and Palmer, B. (1998) A comparison of steer gains on Cunningham Leucaena and some alternative psyllid-tolerant shrub legumes. *Proceedings of the XVII International Grassland Congress, Winnipeg and Saskatoon, Canada.* Session **23**, pp. 35-36.

Jones, R.J. and Jones, R.M. (2001) Variation in yield and mimosine concentration of *Leucaena leucocephala* at three sites in northern Australia. *Leucnet News* No. 8, 3-5.

Jones, R.J. and Hu, F.D. (2006) Diet selection of steers grazing *Stylosanthes hamata* cv. Verano-grass pastures in north Queensland and its potential influence on botanical composition. *Tropical Grasslands*, **40**, 65-69.

Jones, R.J. and Le Feuvre, R.P. (2006) Pasture production, pasture quality and their relationships with steer gains on irrigated, N-fertilised pangola grass at a range of stocking rates in the Ord Valley, Western Australia. *Tropical Grasslands*, **40**, 1-13.

Jones, R.M. (1979) Effect of stocking rate and grazing frequency on a siratro (*Macroptilium atropurpureum*)/*Setaria anceps* cv. Nandi pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 318-324.

Jones, R.M. (1982a) White clover (*Trifolium repens*) in subtropical south-east Queensland. I. Some effects of site, season and management practices on the population dynamics of white clover. *Tropical Grasslands*, **16,** 118-127.

Jones, R.M. (1982b) White clover (*Trifolium repens*) in subtropical south-east Queensland II. Effect of lime application on nutrient concentrations in soil and in white clover. *Tropical Grasslands*, **16**, 127-130.

Jones, R.M. (1984) White clover (*Trifolium repens*) in subtropical south-east Queensland. III. Increasing animal production by use of lime and flexible stocking rates. *Tropical Grasslands*, **18**, 186-194.

Jones, R.M. (1988) The effects of stocking rate on the population dynamics of siratro in siratro (*Macroptilium atropurpureum*) - setaria (*Setaria sphacelata*) pastures in south-east Queensland. III. Effects of spelling on restoration of siratro in overgrazed pastures. *Tropical Grasslands*, **22**, 5-11.

Jones, R.M. (1989) Productivity and population dynamics of silverleaf desmodium (*Desmodium uncinatum*), greenleaf desmodium (*D. intortum*) and two *D. intortum* X *D. sandwicense* hybrids at two stocking rates in coastal south-east Queensland. *Tropical Grasslands*, **23**, 43-55.

Jones, R.M. (1992) Resting from grazing to reverse changes in sown pasture composition: application of the 'state and transition' model. *Tropical Grasslands*, **26**, 97-99.

Jones, R.M. and Evans, T.E. (1977) Soil seed levels of *Lotononis bainesii, Desmodium intortum* and *Trifolium repens* in subtropical pastures. *Journal of the Australian Institute of Agricultural Science*, **43**, 164-166.

Jones, R.M. and Evans, T.R. (1984) Problems associated with grazing experiments involving the integration of different pastures - a case study in south-east Queensland. *Tropical Grasslands*, **18**, 39-45.

Jones, R.M., Johansen, C. and Little, D.A. (1984) Effect of omission of annual superphosphate applications on desmodium-pangola grass pastures. *Tropical Grasslands*, **18**, 205-215.

Jones, R.M. and Jones, R.J. (1984) The effect of *Leucaena leucocephala* on liveweight gain, thyroid size and thyroxine levels of steers in south-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **24**, 4-9.

Jones, R.M. and Mannetje, L.'t (1986) A comparison of bred *Macroptilium atropurpureum* lines and cv. Siratro in subcoastal south-east Queensland with particular reference to legume persistence. *Tropical Agronomy Technical Memorandum No. 47, CSIRO, Australia.*

Jones, R.M. and Bunch, G.A. (1988a) The effects of stocking rate on the population dynamics of siratro in siratro (*Macroptilium atropurpureum*) - setaria (*Setaria sphacelata*) pastures in south-east Queensland. I Survival of plants and stolons. *Australian Journal of Agricultural Research*, **39**, 209-219.

Jones, R.M. and Bunch, G.A. (1988b) The effects of stocking rate on the population dynamics of siratro in siratro (*Macroptilium atropurpureum*) - setaria (*Setaria sphacelata*) pastures in south-east Queensland. II Seed set, soil seed reserves, seedling recruitment and seedling survival. *Australian Journal of Agricultural Research*, **39**, 221-234.

Jones, R.M. and Evans, T.R. (1989) Liveweight gain from four nitrogen fertilized grasses grazed over the growing season in coastal south-east Queensland. *Tropical Grasslands*, **23**, 75-79.

Jones, R.M., McLennan, M.W. and Dowsett, K.F. (1989) The effect of *Leucaena leucocephala* on the reproduction of beef cattle grazing leucaena/grass pastures. *Tropical Grasslands,* **23**, 108-114.

Jones, R.M., Noguchi, M. and Bunch, G.A. (1991) Levels of germinable seed in topsoil and cattle faeces in legume-grass and nitrogen-fertilized pastures in south-east Queensland. *Australian Journal of Agricultural Research*, **42**, 953-968.

Jones, R.M., Kerridge, P.C. and McLean, R.W. (1993) Population dynamics of Siratro and shrubby stylo in south-east Queensland as affected by phosphorus, soil type, stocking rate and rainfall. *Tropical Grasslands*, **27**, 65-74.

Jones, R.M. and Bunch, G.A. (1995a) Long-term records of legume persistence and animal production from pastures based on Safari Kenya clover and leucaena in subtropical coastal Queensland. *Tropical Grasslands*, **29**, 74-80.

Jones, R.M. and Bunch, G.A. (1995b) Yield and population dynamics of *Chamaecrista rotundifolia* cv. Wynn in coastal south-eastern Queensland as affected by stocking rate and rainfall. *Tropical Grasslands*, **29**, 65-73.

Jones, R.M., Jones, R.J. and McDonald, C.K. (1995a) Some advantages of long-term grazing trials, with particular reference to changes in botanical composition. *Australian Journal of Experimental Agriculture*, **35**, 1029-1038.

Jones, R.M., McDonald, C.K. and Silvey, M.W. (1995b) Permanent pastures on a brigalow soil: the effect of nitrogen fertiliser and stocking rate on pastures and liveweight gain. *Tropical Grasslands*, **29**, 193-209.

Jones, R.M. and Mannetje, L.'t (1997) Long term records of legume persistence and animal production from six legume-based pastures in subcoastal southeast Queensland. *Tropical Agriculture Technical Memorandum No. 1, CSIRO, Australia.*

Jones, R.M. and Bunch, G.A. (1999) Levels of seed in faeces of cattle grazing speargrass (*Heteropogon contortus*) pastures oversown with legumes in southern subcoastal Queensland. *Tropical Grasslands*, **33**, 11-17.

Jones, R.M., McDonald, C.K., Clements, R.J. and Bunch, G.A. (2000) Sown pastures in subtropical south-eastern Queensland: pasture composition, legume persistence and cattle liveweight gain. *Tropical Grasslands,* **34***,* 21-37.

Jones, R.M. and Jones, R.J. (2003) Effect of stocking rates on animal gain, pasture yield and composition, and soil properties from pastures of siratro-setaria and nitrogen-fertilized setaria in coastal south-east Queensland. *Tropical Grasslands*, **37**, 65-83.

Lansberg, R. (1993) The benefits of sustainable management: A producer's view. In: *Will Cells Sell*. (University of southern Queensland: Toowoomba).

Little, D.A. and Shaw, N.H. (1979) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 5. Bone phosphorus levels in grazing cattle. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 645-651.

MacLeod, N.M. and Cook, S.J. (2004) The economic performance of steers grazing black speargrass pastures oversown with legumes in south Queensland, Australia. *Tropical Grasslands*, **38,** 140-153.

MacLeod, N.M. and McIntyre, S. (1997) Stocking rate impacts on the production and economic performance of steers grazing black speargrass pastures. *Rangeland Journal*, **19**, 174-189.

McCaskill. M.R. (1992) Detailed data from a long-term grazing trial comparing native and Verano pastures at Lansdown. *Tropical Agronomy Technical Memorandum No. 74, Division of Tropical Crops and Pastures, CSIRO, Australia.*

McCaskill, M.R. and McIvor, J.G. (1993) Herbage and animal production studies from native pastures and pastures oversown with *Stylosanthes hamata*. 2. Modelling studies. *Australian Journal of Experimental Agriculture*, **33**, 571-579.

McCown, R.L., Winter, W.H., Andrew, M.W., Jones, R.K. and Peake, D.C.I. (1986) A preliminary evaluation of legume ley farming in the Australian semi-arid tropics. In: Haque, I., Jutzi, S. and Neate, P.J.H. (eds) *Potentials of Forage Legumes in Farming Systems of Sub-Saharan Africa.* (ILCA: Ethiopia).

McDonald, C.K. (1999) *Impact of plant age and biomass distributions on seed production of tropical legumes in grazed pastures.* M.Agr.Sc. Thesis. University of Queensland.

McDonald, C.K., Jones, R.M. and Silvey, M.W. (1995) Detailed pasture and animal data from a long-term grazing trial on brigalow soil. *Tropical Agronomy Technical Memorandum No. 86, CSIRO, Australia.*

McDonald, C.K., Jones, R.M. and Silvey, M.W. (1996) Effect of seasonal soil moisture, nitrogen fertiliser and stocking rate on unsown species in a sown subtropical pasture. *Tropical Grasslands*, **30**, 319-329.

McDonald, C.K., Jones, R.M. and Tothill, J.C. (1998) Growth and spread of *Digitaria eriantha* cv. Premier and *Urochloa mosambicensis* cv. Nixon oversown into native speargrass (*Heteropogon contortus*) pasture in south-east Queensland. *Tropical Grasslands*, **32**, 41-49.

McDonald, C.K. and Jones, R.M. (2002a) Relationships between age and biomass of individual plants and seed production in two grazed tropical legumes. 1. Derivation of relationships. *Australian Journal of Agricultural Research*, **53**, 91-105.

McDonald, C.K. and Jones, R.M. (2002b) Relationships between age and biomass of individual plants and seed production in two grazed tropical legumes. 2. Validation of models. *Australian Journal of Agricultural Research*, **53**, 107-114.

McDonald, C.K., Jones, R.M. and Silvey, M.W. (2009) Crop-pasture rotations on a brigalow soil: effects of season and type of rotation on pasture and animal production **(In press)**

McIntyre, S., MacLeod, N.D. and Taylor, J.A. (1996) Landscape position as a determinant of floristic change and animal production in subtropical *Heteropogon contortus* pastures of eastern Australia. In: West, N.E. (ed.) *Rangelands in a Sustainable Biosphere.* pp. 354-355. (Society for Range Management: Denver, USA).

McIvor, J.G. (1998) Pasture management in semi-arid tropical woodlands: effects on species biodiversity. *Australian Journal of Ecology*, **23**, 349-364.

McIvor, J.G. (2002) Pasture management in semi-arid tropical woodlands: effects on ground cover levels. *Tropical Grasslands*, **36**, 218-226.

McIvor, J.G. (2004) Pasture management in semi-arid tropical woodlands: levels of germinable seed in soil and faeces of cattle grazing *Stylosanthes* pastures. *Tropical Grasslands*, **38**, 129-139.

McIvor, J.G. (2006a) Pasture management in semi-arid tropical woodlands: effects on tree regrowth. *Tropical Grasslands*, **40**, 14-23.

McIvor, J.G. (2006b) Pasture management in semi-arid tropical woodlands: colonisation by introduced pasture species. *Tropical Grasslands*, **40**, 137-144.

McIvor, J.G. (2007) Pasture management in semiarid tropical grasslands: improving the herbage quality of stylos and grasses. *Australian Journal of Experimental Agriculture,* **47**, 1359-1367.

McIvor, J.G. and Gardener, C.J. (1991) A description of the ECOSSAT experimental site at Cardigan near Charters Towers, north Queensland. *Tropical Agronomy Technical Memorandum No. 68, Division of Tropical Crops and Pastures, CSIRO, Australia.*

McIvor, J.G., Gardener, C.J. and Spain, A.V. (1991) A description of the ECOSSAT experimental site at Hillgrove near Charters Towers, north Queensland. *Tropical Agronomy Technical Memorandum No. 70, Division of Tropical Crops and Pastures, CSIRO, Australia.*

McIvor, J.G. and Gardener, C.J. (1995) Pasture management in semi-arid tropical woodlands: effects on herbage yields and botanical composition. *Australian Journal of Experimental Agriculture*, **35**, 705-715.

McIvor, J.G. and Moneypenny, R. (1995) Evaluation of pasture management systems for beef production in the semi-arid tropics: model development. *Agricultural Systems*, **49**, 45-67.

McIvor, J.G., Williams, J. and Gardener, C.J. (1995) Pasture management influences runoff and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture,* **35**, 55-65.

McIvor, J.G. and Gardener, C.J. (1998) Population dynamics of *Stylosanthes hamata* and *S. scabra* in north-eastern Queensland: effects of superphosphate application, timber

treatment, and stocking rate. *Australian Journal of Agricultural Research*, **49**, 1027-1037.

Mannetje, L.'t (1991) Studies on buffel grass pastures with siratro, lucerne or nitrogen fertilizer 2. Nutritive value of the herbage and beef production. *Tropical Agronomy Technical Memorandum No. 67, CSIRO, Australia.*

Mannetje, L.'t and Coates, D.B. (1976) Effects of pasture improvement on reproduction and pre-weaning growth of Hereford cattle in central sub-coastal Queensland. *Proceedings of the Australian Society of Animal Production*, **11,** 257-260.

Mannetje, L.'t, Cook, S.J. and Wildin, J.H. (1983) The effects of fire on a buffel grass and siratro pasture. *Tropical Grasslands*, **17**, 30-39.

Mannetje, L.'t and Jones, R.M. (1990) Pasture and animal productivity of buffel grass with Siratro, lucerne or nitrogen fertiliser. *Tropical Grasslands*, **24**, 269-281.

Mannetje, L.'t and Butler, K.L. (1991) Studies on buffel grass pastures with siratro, lucerne or nitrogen fertiliser. 1. Herbage production, botanical composition, legume demography and changes in soil fertility. *Tropical Agronomy Technical Memorandum No. 66, CSIRO, Australia.*

Minson, D.J. and Hacker, J.B. (1995) Production by sheep grazing six *Cenchrus ciliaris* accessions. *Tropical Grasslands*, **29**, 34-39.

Mitchell, T.E., Bryan, W.W. and Evans, T.R. (1972) Budgetary comparisons between pangola grass/legume pasture and nitrogen fertilized pangola pasture for beef production in the southern Wallum. *Tropical Grasslands*, **6**, 177-190.

Mott, J.J., Winter, W.H. and McLean, R.W. (1989) Evaluation of management options for increasing the productivity of tropical savanna pastures. IV. Population biology of introduced *Stylosanthes* spp. *Australian Journal of Agricultural Research*, **40**, 1227-1240.

Norman, M.J.T. and Phillips, L.J. (1970) Wet season grazing of Townsville stylo pastures at Katherine, N.T. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **10**, 710-715.

Norman, M.J.T. and Begg, J.E. (1973) Katherine Research Station: a review of published work 1965-72. *Technical Paper No. 33, Division of Land Research, CSIRO.*

Norton, B.E. (1998) The application of grazing management to increase sustainable livestock production. *Proceedings of the Australian Society of Animal Production*, **22**, 15-26.

O'Reagain, P.J., Bushell, J.J. and Holloway, C.H. (2008) Testing and developing grazing principles and management guidelines for the seasonally variable tropical savannas. *Final Report, Meat and Livestock Australia, Sydney*. 266 pp.

Orr, D.M. (2004) Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 4. The effects of burning on *H. contortus* and *Aristida* spp. populations. *Tropical Grasslands*, **38,** 77-87**.**

Orr, D.M., McKeon, G.M. and Day, K.A. (1991) Burning and exclosure can rehabilitate degraded black speargrass (*Heteropogon contortus*). *Tropical Grasslands*, **25**, 333-336.

Orr, D.M., Paton, C.J. and Reid, D.J. (2004a) Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 1. Dynamics of *H. contortus* populations. *Tropical Grasslands*, **38**, 17-30.

Orr, D.M., Paton, C.J. and Playford, C. (2004b) Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 2. Seed production and soil seed banks of *H. contortus*. *Tropical Grasslands*, **38**, 31-41.

Orr, D.M., Paton, C.J. and Playford, C. (2004c) Dynamics of plant populations in *Heteropogon contortus* (black speargrass) pastures on a granite landscape in southern Queensland. 3. Dynamics of *Aristida* spp. populations. *Tropical Grasslands*, **38**, 65-76.

Ritson, J.B. (1968a) Two year-old cattle on fertilised Townsville lucerne/spear grass pastures. *Annual Report 1967-68, Division of Tropical Pastures, CSIRO, Australia*. pp. 107-108.

Ritson, J.B. (1968b) Weaner cattle on fertilised Townsville lucerne/spear grass pastures. *Annual Report 1967-68, Division of Tropical Pastures, CSIRO, Australia*. pp. 107-109.

Ritson, J.B., Edye, L.A. and Robinson, P.J. (1971) Botanical and chemical composition of a Townsville stylo-spear grass pasture in relation to conception rate of cows. *Australian Journal of Agricultural Research*, **22**, 993-1007.

Roe, R. (1962) Mitchell grass pasture – Gilruth Plains. Report of sampling, February 1961. *Field Station Record, Division of Plant Industry, CSIRO.* **1**, 21-28.

Roe, R. and Allen, G.H. (1945) Studies on the Mitchell grass association in south-western Queensland. 2. The effect of grazing on the Mitchell grass pasture. *CSIR Bulletin 185, Council for Scientific and Industrial Research, Australia*.

Roe, R. and Davies, H.I. (1985) Long-term variation in the density of *Astrebla* species in the Warrego region of Queensland. *Tropical Grasslands*, **19**, 87-95.

Roe, R. and Allen, G.H. (1993) Studies on the Mitchell grass association in south-western Queensland. 3. Pasture and wool production under different rates of stocking and continuous or rotational grazing. *Rangeland Journal*, **15**, 302-319.

Russell, J.S. (1985a) Soil treatment, plant species and management effects on improved pastures on a solodic soil in the semi-arid subtropics. 1. Dry matter and botanical composition. *Australian Journal of Experimental Agriculture*, **25**, 367-379.

Russell, J.S. (1985b) Soil treatment, plant species and management effects on improved pastures on a solodic soil in the semi-arid subtropics. 2. Cattle liveweight gains. *Australian Journal of Experimental Agriculture,* **25**, 380-391.

Russell, J.S. (1994) Soil treatment, plant species and management effects on improved pastures on a solodic soil in the semi-arid subtropics. 3. Improving cool season plant and animal productivity. *Australian Journal of Experimental Agriculture*, **34**, 145-152.

Sallaway, M.M., Waters, D., Bridge, B. and Wandera, F.P. (1993) Variations in hydrological characteristics of the soils associated with grazed patches in granitic landscapes in northern Australia. *Proceedings of the XVII International Grassland Congress, Rockhampton, 1993.* pp. 1900-1902.

Shaw, N.H. (1961) Increased beef production from Townsville lucerne (*Stylosanthes sundaica* Taub.) in the spear grass pastures of central coastal Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **1**, 73-80.

Shaw, N.H. (1978a) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. I. Pasture production. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **18**, 788-799.

Shaw, N.H. (1978b) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 2. Animal production. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **18**, 800-807.

Shaw, N.H. and Mannetje, L. 't (1970) Studies on a spear grass pasture in central coastal Queensland- the effect of fertilizer, stocking rate and oversowing with *Stylosanthes humilis* on beef production and botanical composition. *Tropical Grasslands*, **4**, 43-56.

Shaw, N.H. and Dale, M.B. (1978) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 3. The balance of native species in the pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **18**, 808-816.

Shaw, N.H. and Andrew, C.S. (1979) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 4. Phosphate and potassium sufficiency. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 426-436.

Silvey, M.W. and Ferraris, R. (1988) Sward productivity and animal production from perennial forage sorghums grazed at four stocking rates. *Tropical Agriculture Technical Memorandum No. 56, CSIRO, Australia.*

Silvey, M.W. and Jones, R.M. (1990) Permanent pastures on a brigalow soil: changes in pasture yield and composition during the first five years. *Tropical Grasslands*, **24**, 282-290.

Silvey, M.W., Coaldrake, J.E., Haydock, K.P., Ratcliff, D. and Smith, C.A. (1978) Beef cow performance from tropical pastures on semi-arid brigalow lands under intermittent drought. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **18**, 618-629.

Stobbs, T.H. (1977) Seasonal changes in the preference by cattle for *Macroptilium atropurpureum* cv. Siratro. *Tropical Grasslands*, **11**, 87-91.

Ternouth, J.H., Bortolussi, G., Coates, D.B., Hendricksen, R.E. and McLean, R.W. (1996) The phosphorus requirements of growing cattle consuming forage diets. *Journal of Agricultural Science*, *Cambridge*, **126**, 503-510.

Thompson, P.A.C. (1982) CSIRO Division of tropical crops and pastures, scientific publications 1959-1980. *Tropical Agronomy Technical Memorandum No. 33, Division of Tropical Crops and Pastures, CSIRO, Australia.*

Thornton, R.F. and Minson, D.J. (1973) Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of south-eastern Queensland. 3. Relation of liveweight changes to chemical composition of blood and pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **13***,* 537-543.

Tothill, J.C. (1974a) Catchment grazing experiment. *Annual Report 1973-74, Division of Tropical Agronomy, CSIRO, Australia*. pp. 27-30.

Tothill, J.C. (1974b) Experiences in sod-seeding siratro into native speargrass pastures on granite soils near Mundubbera. *Tropical Grasslands*, **8**, 128-131.

Tothill, J.C. (1974c) The effect of grazing, burning and fertilizing on the botanical composition of a natural pasture in the sub-tropics of south-east Queensland. *Proceedings of the XII International Grassland Congress, Moscow.* **2,** 515-521.

Tothill, J.C. (1976) Sequential effects of grazing, burning and fertilizing on a native pasture in south-east Queensland. In: Williams, W.T. (ed.) *Pattern Analysis in Agricultural Science.* (CSIRO:Melbourne and Elsevier:Amsterdam).

Tothill, J.C. (1983) Optimum levels for use of speargrass grazing lands. *Annual Report 1982-83, Division of Tropical Crops and Pastures, CSIRO, Australia*. pp. 104-107.

Tothill, J.C. (1984) Floristic analysis in understanding interactions between species in native pasture. In: Liddle, M.J. and Tothill, J.C. (eds) *The Ecological Basis of Interactions between Organisms*. *AES Monograph 1/84, School of Environmental Studies, Griffith University, Brisbane.*

Tothill, J.C. and Jones, R.M. (1977) Stability in sown and oversown Siratro pastures. *Tropical Grasslands*, **11**, 55-65.

Tothill, J.C. and Berry, J. (1981) Cool season weed invasion of improved subtropical pastures. *Proceedings of the 6th Australian Weeds Conference.* **1**, 29-33.

Tothill**,** J.C., McDonald, C.K., McHarg, G.W. and Hargreaves, J.N.G.H. (2008a) Development options in *Heteropogon contortus* grasslands in south-east Queensland: tree killing, legume oversowing and pasture replacement. 1. Pasture production and composition. *Tropical Grasslands*, **42**, 129-151.

Tothill**,** J.C., McDonald, C.K., McHarg, G.W. and Hargreaves, J.N.G.H. (2008b) Development options in *Heteropogon contortus* grasslands in south-east Queensland: tree killing, legume oversowing and pasture replacement. 2. Animal production. *Tropical Grasslands*, **42**, 152-159.

Tothill, the late J.C., McDonald, C.K. and McHarg, the late G.W. (2009) Effect of wet season rotational grazing on pasture and animal production in buffel (*Cenchrus ciliaris*) – siratro (*Macroptilium atropurpureum*) pastures in south-east Queensland. *Tropical Grasslands*, **43**, 162-170.

Tothill, the late J.C., McDonald, C.K. and McHarg, the late G.W. (2010) Management options in *Heteropogon contortus* grasslands in south-east Queensland: burning, high stocking rate with dry season supplementation and pasture oversowing. *Tropical Grasslands*, **44**, 000-000.

Vallis, I. and Jones, R.J. (1973) Net mineralization of nitrogen in leaves and leaf litter of *Desmodium intortum* and *Phaseolus atropurpureus* mixed with soil. *Soil Biology and Biochemistry*, **5**, 391-397.

Walker, B. and Weston, E.J. (1990) Pasture development in Queensland – a success story. *Tropical Grasslands*, **24**, 257-268.

Wandera, F.P. (1993) *Patches in a* Heteropogon contortus *dominated grassland in southeast Queensland – their characteristics, probable causes, implications and potential for rehabilitation*. Ph.D. Thesis. University of Queensland.

Wandera, F.P., Kerridge, P.C., Taylor, J.A. and Shelton, H.M. (1993) Changes in productivity associated with replacement of *Heteropogon contortus* by *Aristida* species and *Chrysopogon fallax* in the savannas of south east Queensland. *Proceedings of the XVII International Grassland Congress, Palmerston North, New Zealand*, *1993.* pp. 352-353.

Williams, O.B. and Roe, R. (1975) Management of arid rangelands for sheep: plant demography of six grasses in relation to climate and grazing. *Proceedings of the Ecological Society of Australia, Brisbane, 1975.* **9**, 142-156.

Williams, W.T., Haydock, K.P., Edye, L.A. and Ritson, J.B. (1971) Analysis of a fertility trial with Droughtmaster cows. *Australian Journal of Agricultural Research*, **22**, 979-991.

Wilson, J.R. and Mannetje, L. 't (1978) Senescence, digestibility and carbohydrate content of buffel grass and green panic leaves in swards. *Australian Journal of Agricultural Research*, **29**, 503-516.

Winter, W.H. (1987) Using fire and supplements to improve cattle production from monsoon tallgrass pastures. *Tropical Grasslands*, **21**, 71-80.

Winter, W.H. (1988) Supplementation of steers grazing *Stylosanthes hamata* pastures at Katherine, Northern Territory. *Australian Journal of Experimental Agriculture*, **28**, 669-682.

Winter, W.H. (1989) Removing limitations to cattle production in the semi-arid tropics. *Proceedings of the XVI International Grassland Congress, Nice, France, 1989.* pp. 1175-1176.

Winter, W.H. and Evans, T.R. (1984) Grazing systems on Caribbean stylo-sown grass pastures. *Annual Report 1983-84, Division of Tropical Crops and Pastures, CSIRO, Australia.* pp. 126-128.

Winter, W.H. and Evans, T.R. (1985) Grazing systems on Verano stylo-sown grass pastures. *Annual Report 1984-85, Division of Tropical Crops and Pastures, CSIRO, Australia*. pp. 117-118.

Winter, W.H. and McLean, R.W. (1988) Sodium supplementation of steers grazing *Stylosanthes*-native grass pastures in northern Australia. *Proceedings of the Australian Society of Animal Production*, **17,** 485.

Winter, W.H., Edye, L.A., Megarrity, R.G. and Williams, W.T. (1977a) Effects of fertilizer and stocking rate on pasture and beef production from sown pastures in northern Cape York Peninsula 1. Botanical and chemical composition of the pastures. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **17**, 66-74.

Winter, W.H., Edye, L.A. and Williams, W.T. (1977b) Effects of fertilizer and stocking rate on pasture and beef production from sown pastures in northern Cape York Peninsula 2. Beef production and its relation to blood, faecal and pasture measurements. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **17**, 187-196.

WINTER, W.H., SIEBERT, B.D. and KUCHEL, R.E. (1977c) Cobalt deficiency of cattle grazing improved pastures in northern Cape York Peninsula. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **17**, 10-15.

WINTER, W.H., MOTT, J.J., MCLEAN, R.W. and RATCLIFF, D. (1989a) Evaluation of management options for increasing the productivity of tropical savanna pastures. 1. Fertiliser. *Australian Journal of Experimental Agriculture*, **29**, 613-622.

WINTER, W.H., MOTT, J.J. and MCLEAN, R.W. (1989b) Evaluation of management options for increasing the productivity of tropical savanna pastures. 2. Legume species. *Australian Journal of Experimental Agriculture*, **29**, 623-630.

WINTER, W.H., MOTT, J.J. and MCLEAN, R.W. (1989c) Evaluation of management options for increasing the productivity of tropical savanna pastures. 3. Trees. *Australian Journal of Experimental Agriculture*, **29**, 631-634.

YATES, J.J., EDYE, L.A., DAVIES, J.G. and HAYDOCK, K.P. (1964) Animal production from a *Sorghum almum* pasture in south-east Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **4**, 326-335.

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