Tropical Grasslands (1991) Volume 25, 145-152

Sustaining productive pastures in the tropics
10. Forage and feeding systems for cattle

W.H. WINTER,[1] L. WINKS[2] AND
R.M. SEEBECK[3]
[1]*Division of Tropical Crops and Pastures and* [3]*Division of Tropical Animal Production, CSIRO; and* [2]*Queensland Department of Primary Industries; Brisbane, Queensland, Australia.*

Abstract

This paper discusses options available, and projected to be available, to producers in the subtropics and tropics to manipulate beef production and quality. The requirements of future beef markets regarding uniformity, tenderness and juiciness will mainly be achieved by increasing growth rate via managing the feed supply in conjunction with the appropriate animal genotype, and by using chemical growth or digestion modifiers.

Native pastures are the predominant forage, but animal production is highly variable. Generally they provide useful grazing during summer and, with strategic supplementation, may be adequate for breeding cows and for maintaining liveweight of slaughter animals during the cooler months.

Cattle may need to be finished on sown pastures to meet specific market requirements. Growth rates on these pastures are low in comparison to temperate pastures, with maximum rates rarely exceeding 1kg/d during spring and summer. Options to improve productivity include use of legumes and direct supplementation to overcome nutrient limitations. The greatest nutrient limitations occur in autumn and winter on mature and frosted tropical forages.

The economic benefit of improving branding percentage by 15% (an achievable improvement in most situations) and growth by 60 kg/annum (to enable a reduction in turnoff age by a year) are assessed.

Correspondence: Dr W.H. Winter, CSIRO, 306 Carmody Rd, St Lucia, Qld 4067, Australia.

Paper presented at the Fourth Australian Conference on Tropical Pastures, held at Toowoomba, Queensland, in November 1990.

Resumen

Se discuten las opciones disponibles, y las proyectadas para ser disponibles, a los productores de los sub-trópicos y trópicos para manipular la producción y calidad del ganado bovino de carne. Los requerimientos del futuro mercado de carne bovina tales como la ternura, uniformidad y jugosidad serán alcanzados principalmente con un apropiado genotipo animal y con el uso de modificadores químicos del crecimiento o de la digestión.

Las pasturas nativas son los forrajes predominantes, pero la producción animal es muy variable. Por lo general ellas pueden ser pastoreadas provechosamente durante el verano y, con una suplementación estratégica, podrían ser adecuadas para vacas de cría y para mantener durante los meses fríos el peso vivo del los animales para el sacrificio.

A fin de cubrir lo requerimientos específicos del mercado, el ganado bovino debiera ser finalizado en pasturas introducidas. Las tasas de crecimiento en estas pasturas son bajas en comparación a las obtenidas en pasturas de zonas templadas. Durante la primavera y el verano raramente se logra una tasa máxima de 1 kg/d. Las opciones para mejorar la productividad involucran el uso de leguminosas y la suplementación directa para superar las limitaciones de nutrientes. Las mayores limitaciones de nutrientes en los forrajes tropicales maduros y congelados ocurren en el otoño y en el invierno.

Se evalúa el beneficio económico de incrementar el porcentaje de marcaje al nacimiento en un 15% (mejoramiento factible de ser alcanzado en la mayoría de las situaciones) y de aumentar el crecimiento a 60 kg/año (para obtener una reducción de un año en la edad al sacrificio).

Introduction

Over 90% of the beef produced from the 10.5 million (M) head in northern Australia is derived from native pastures. Generally, producers have placed little emphasis on management of these native pastures and, with the exception of the recent trade in carcasses of specified age, weight and fat cover to Japan and Korea, on the production of beef of specified quality. Two consequences of this low level of management are the degradation of large areas of native pastures and the export of half of the beef into the relatively low value markets.

Producers face a growing social pressure to develop sustainable management systems, and need to become more efficient to survive the ongoing rural cost/price squeeze. In the next few years producers can partly offset these problems by producing more beef of specified quality (and premium price) for the expanding Western Pacific Rim (WPR) market.

This paper outlines the options available, now and in the near future, to exploit the opportunities and redress the problems of producing and marketing beef from northern Australia. Integration of these options will be discussed in this paper, with a particular emphasis on meeting the market requirements by reducing age of turnoff and genotype selection, and of developing sustainable and viable systems by improving herd efficiency.

Markets

In 1989/90 79% of the 700K tonnes of beef produced in northern Australia was exported. This compares with 59% of the 1600K tonnes for the whole of Australia. About 46% of the total production went to the USA market, with an increasing proportion to Western Pacific Rim (WPR) markets, Japan and Korea. Unlike the USA market, the WPR markets have demanded and paid a premium for beef of specific quality. Most of the beef sold into the WPR and domestic markets is grass fed, with the possibility of 40-70 days of grain feeding pre-slaughter. Long-term feedlot beef currently accounts for about 5% of the market and is projected to double in the next 5 years. An identified requirement from the expanding sections of the market is for more consistency of quality. This can best be accomplished by increasing growth rate, which will be reflected by a reduction in turnoff age. If the potential WPR markets are to be satisfied most northern producers will need to modify their production systems to meet these specific quality demands.

Current trends in the important markets, as forecast by the Australian Meat and Livestock Corporation (AMLC) and Australian Bureau of Agricultural and Resource Economics (ABARE), are listed below, but presently there is a high degree of uncertainty, particularly for Japan.

USA: This market will continue to be important, particularly for cull stock and older animals. Beef of varying quality will be accepted, but the average price will remain relatively low.

Japan: Exports have the potential to double to 400K tonne by 1995 (Blyth and Mues 1990). The preference is for juicy and tender beef (AMLC 1990), and a possible wider range of carcass weights (200-300 + kg), and age requirement of <3 years.

Korea: This steady market of 65K tonne is for carcasses of 180-340 kg from animals <3 years old. As for Japan there is a demand for consistency of product, which, to some degree, is being met from grain-fed beef at present.

Domestic: The 20% of northern beef consumed locally constitutes a major market. The preference is for carcasses of 180-220 kg and 5-7 mm backfat from animals <18 months old.

Live exports: In 1989/90 97K live store animals (usually 250-350 kg and <2 years) were exported to Japan, Malaysia and other Asian destinations. This market will probably increase if the prices become more competitive with carcass beef.

Forage systems

Native pastures constitute the most important source of forage for northern beef producers, but generally animal production is limited by forage quality. Production can be enhanced from sown grass and legume pastures. Scope for using sown pastures is high in the more fertile and better watered areas of SE and central Queensland and the coastal and tableland areas of north Queensland, moderate in the humid tropical areas of north Queensland and low in the semi-arid areas of NE and NW Australia. The current distribution of the 5.5M ha of improved pastures reflects this schema: 90% are in Queensland, the majority are in the subtropics, and 70% are sown to grass alone (Gramshaw and Walker 1988; Walker and Weston 1990). The current annual sowing rate is about 0.3M ha.

Table 1. Frequency distribution of growth rates from tropical pastures as reported in Australian literature in the regions south and north of latitude 22°S. Data for the wet season are mainly from long-term experiments, while data for specific periods are generally from experiments which considered these periods separately. The number of experiment/years used to derive the frequency distribution are shown in the last column.

Growth rate (g/day)	<200	2-400	4-600	6-800	8-1000	>1000	No. of periods
			%				
			Peak period: spring/summer/autumn				
North							
Native pasture	6	19	27	36	10	2	142
Sown grass	17	28	17	11	11	16	18
N.p./legume	3	3	8	48	16	22	63
Sown grass/legume	8	15	30	30	9	8	66
South							
Native pasture	14	19	51	14	2	0	63
Sown grass	5	8	20	42	22	3	97
N.p./legume	0	0	18	73	0	9	11
Sown grass/legume	3	13	27	38	8	11	37
Sorghum	0	18	46	27	9	0	22
Leucaena	3	10	3	45	18	21	29
			Peak period: winter/spring				
Oats/barley	0	0	14	33	29	24	21
			Off-peak period: autumn/winter				
Leucaena	29	19	36	10	3	3	31
			Off-peak period: spring or autumn				
North							
Native pasture	54	23	5	14	4	0	22
N.p./legume	48	19	21	10	0	2	48
Sown grass/legume	70	5	10	15	0	0	20
South							
Native pasture	45	31	11	9	1	3	75
Sown grass	10	3	36	27	7	17	30
Sown grass/legume	4	16	14	20	20	26	50

Growth rate (g/day)	< −200	−200-0	0-200	>200	No. of periods
		%			
		Low period: winter			
North					
Native pasture	10	37	28	25	104
Sown grass	7	7	53	33	15
N.p./legume	10	33	24	33	63
Sown grass/legume	0	10	16	74	49
South					
Native pasture	35	21	37	7	43
Sown grass	7	22	18	53	45
N.p./legume	0	0	67	33	3
Sown grass/legume	0	11	29	60	45

Growth rates of cattle grazing tropical pastures in northern Australia were reviewed in order to provide an overview of the value of pastures, in generic terms. Over 140 published experiments provided over 1600 grazing periods. Some of those data are presented here (Table 1), where growth rates were separated into *peak rates*, usually during spring/summer/autumn or for specific shorter periods for special purpose pastures, *off-peak rates* which occurred either before and/or after the peak rates during spring or autumn, and *low rates* during the cooler months of winter. The demarcation for the northern and southern regions was the Tropic of Capricorn. Growth rates rarely exceeded 1000g/d from most forages, which is 20-30% below the potential production levels of the stock used in the region (t'Mannetje 1984).

Native pastures

Forage production and ultimately animal production from native pastures depends primarily upon the natural soil fertility (particularly nitrogen and phosphorus supply), water supply and grass species (Mott *et al.* 1984). Generally, the quality of tropical forages, expressed in energy, protein and mineral supply terms, declines with plant maturity, causing sub-optimal animal growth during the spring/summer/autumn period and, in most situations, weight loss during the winter period. Quality limitations can be ameliorated with strategic supplementation (with one or more of urea or by-pass protein, phosphorus, sodium and sulphur) which has been demonstrated to reduce mortality, reduce dry season weight loss, increase wet season weight gains and improve post partum conception rate and milk production (e.g. Saadullah 1984; Winks 1984; Hennessy 1986; Winter 1987; Leng 1989). A cautionary note about supplementary feeding is that it invariably increases forage intake, so it should not be used without adjustment of other property management strategies.

The higher peak animal growth rates from native pastures (Table 1) in northern areas are probably due to some degree of compensatory growth. In the south the slightly lower growth rates were maintained for a longer period. Annual production from native pastures can fluctuate dramatically from year to year (e.g. as much as 100 kg/head at one site McLennan *et al.* 1988), due primarily to variable climatic conditions as they effect the length of the growing season and the condition of dry season feed (McCown 1981). This general model may be further complicated by the stocking rate effects on the availability of forage. Graziers can increase forage supply by reducing stocking rate and/or tree killing (Burrows *et al.* 1988), while strategic pasture burning can improve pasture quality and animal growth (Ash *et al.* 1982; Tothill 1983; Winter 1987). In some areas the negative effects of burning may outweigh the short-term benefits (Anderson *et al.* 1988).

Sown grass

The few data for sown grass pastures in the northern region are mostly for the wet tropical coast and tableland areas where N is applied. The low growth rates during the wet season are caused by very wet periods and high stocking rates, but growth is good during the mild winters. In the southern region sown grass pastures give higher growth rates over an extended period when compared with native pastures. However, productivity from these pastures may decline over time to less than 50% of original levels due to immobilisation of soil N (Robbins *et al.* 1987), and techniques need to be developed to reduce this effect. In the south, in particular, there are few examples of growth rates exceeding 1000g/d. This may be due to N limitations, but there may be scope for selection of grasses to produce higher rates of liveweight gain under these conditions, as achieved by Sollenberger and Jones (1989).

Native pasture and legume

Oversowing legumes into native pastures is the most common form of pasture development in the northern region. In most commercial situations these pastures are used for slaughter stock, but enhanced cow fertility and branding percentages has also been reported (Edye 1984). These pastures support higher stocking rates than native pastures and promote higher growth rates, with 38% of the peak growth rates being higher than 800g/d. In low soil fertility conditions the animals may require supplementary P to reach this level of production. When compared with native pastures, the period of peak growth rates may be extended 20-30 days. The few reported data for the southern region indicates similar performance to that from sown grass pastures during the peak period, but poorer performance during the off-peak and low periods. A common problem with these pastures is the loss of the grass component, which causes loss of animal production at the start of the wet season (Winter *et al.* 1990) and pasture instability and weed ingress (Winks *et al.* 1979). The methodology and value of grass introduction into these pastures is worthy of investigation.

Sown grass and legume

These pastures are most common in the intensively developed subtropics and wetter coastal and tableland areas in the tropics. Stocking rates are higher than for native grass and legume pastures and the period of good growth is usually extended by 30-40 days. In the south the profile of growth rates is similar or marginally better to that for sown grass in each period, while in the north these pastures offer the best option during the low period. Unfortunately, these pastures tend to grass dominance within a few years, usually after a period of good legume contribution. The effects of these changes on liveweight gain and stocking capacity are poorly understood as a small amount of legume in the pasture may support reasonable growth rates of cattle, but may be insufficient to sustain the growth and persistence of the sown grass. In some southern areas where moisture is available during the cooler months, annual temperate legumes such as serradellas and medics provide a valuable boost to production during these periods (Gramshaw and Walker 1988).

Special purpose pastures

These pastures fall into the categories of winter and spring grazing of temperate cereals (oats and barley) or pasture grasses (rye) in the subtropics using stored water, winter rainfall or irrigation, and the summer and autumn grazing of tropical forages in all regions. Over 50% of the reported growth rates from temperate species are >800 g/d, making this an attractive option for finishing slaughter cattle. In contrast, the growth rates from tropical forages only reached 800 g/d in 10% of the cases, so offering little advantage over other permanent pastures. However, they are a valuable source of forage where quantity is a limitation. In areas with reliable autumn/winter rainfall oversowing of sown grass pastures with rye grass or oats during the autumn for winter grazing is a potential option, as Roquette and Carpenter (1981) have achieved rates of liveweight gain of 800-1000 g/d with this system.

Ponded pastures

There are few data on liveweight gain available from ponded pastures, but gains of 400-600 g/d are considered normal for the autumn and early winter period (before frosts) and up to 1000 g/d during spring (J.H.Wildin, personal communication). The management flexibility these pastures provide is seen as their major benefit as, for example, they can be used as a supplement to dry feed for breeding cows and weaners or for finishing cattle for high value markets (Wildin and Chapman 1988).

Shrub legumes

At present, the only shrub legume adapted for commercial purposes is leucaena which gives the highest growth rates for legume-based pastures in the south, and for the longest periods. Most sowings are in central Queensland, but leucaena will grow under a wide range of soil and climatic conditions and could be used more extensively to enhance growth of slaughter stock and breeding cow efficiency. Wider use of leucaena is limited by the risk and cost of establishment.

Animal systems

Genotype

Production systems aimed at particular beef markets must take account of the genotype to be used. The choice requires consideration of factors such as (i) the adaptation to stress but reduced potential for growth and fertility from *Bos indicus* breeds, (ii) the poor tropical adaptation but good fertility and growth of the *B.taurus* breeds, and (iii) possible high maintenance costs and calving problems for cows if large European breeds are used to give high growth rates and lower fat levels. An appropriate combination of frame size and species will depend on the type of operation and the breeding practice. Improving or changing the genotype on a property is currently hindered by the lack of use of AI in the extensive beef situation. This impediment could be overcome by the successful development of a sperm capsule to facilitate the synchronisation of sperm release with oestrus.

Properties producing only store cattle for finishing elsewhere are economically risky because of fluctuations in demand and price, and, as a result of the high proportion of breeding females, are most susceptible to poor climatic conditions. Profitability of breeding cattle with a desirable genotype mix depends upon the willingness of buyers to pay a premium. To date the beef industry has not seen the development of an integrated breeder/finisher network like that for prime lambs in southern Australia.

In general, the most robust system to accommodate climatic and financial risk is to operate breeding and finishing enterprises (at the one location or on separate properties), and personally capitalise on the benefits of specifically bred stock. Graziers buying stock for finishing increase the risk of introducing diseases and parasites, but can improve their efficiency by careful selection of genotype to suit the local conditions.

Different breeding practices can be used with each management option. Straight bred or stabilised crossbred herds are the simplest to manage. However, they do not benefit from hybrid vigour associated with crossbreeding, which has the potential to increase efficiency through effects on growth rates, feed efficiency, fertility and milk production. A 3 or 4 breed rotational cross will retain more hybrid vigour than a stabilised cross, but would only be practical where animals are under good control. Graziers using terminal sires (typically large European breeds) use hybrid vigour efficiently, but unless it is a small part of the enterprise, replacement heifers need to be purchased.

Growth and fertility stimulants

Carcass quality and growth efficiency can be improved by several avenues. Hormonal growth promotants which act either at the cellular level to regulate protein synthesis and degradation and/or via circulating hormones are already in widespread use. Growth responses of 10-15% are achieved when growth rates exceed 500 g/d through increased intake and metabolic efficiency. Trenbolone acetate can reduce liveweight loss during the dry season by lowering basal metabolism (Hunter and Vercoe 1987). The future of hormonal growth promotants in the Australian industry is uncertain due to importation requirements of some markets.

Rumen modifiers improve digestive efficiency by altering the composition of the rumen microflora. They are used widely in the feedlot industry where marginal improvements in feed conversion are important. Recent research aims to produce modified rumen bacteria that will improve forage digestibility.

Repartitioning agents such as the *B*-adrenergic agonists clenbuterol and cimaterol and synthetic somatotropin have the potential to alter carcass composition by increasing muscle deposition and reducing fat deposition, but no products are available commercially.

Currently there are no immunological or hormonal methods available to improve fertility of cattle, but research is in progress using both avenues (M.J.D'Occhio, personal communication).

Nutrition

High growth rates and low levels of stress improve meat tenderness and juiciness, but also increase fat content (Seebeck 1984). Dietary effects on carcass composition, independent of growth rate, have not been demonstrated with cattle, as they have with pigs (Yen *et al.* 1986). The lack of response in cattle may be due to the narrow range of the protein/energy ratio of nutrients reaching the abomasum following microbial digestion (Poppi 1990), but higher levels of by-pass protein in the diet may result in greater muscle deposition.

Sex

Growth rate and leanness of males can be improved by late castration (15 months), without market discrimination. Alternatively, chemical castration can be used at an earlier age. Cull cows should be chemically or surgically spayed 4-6 months before slaughter to improve growth rates and carcass quality.

Integration

The integration of some of the forage and animal options outlined above can help realise the objectives of reducing turn-off age and improving herd efficiency within an economically and ecologically sustainable framework. The choice of options by graziers will depend on unique features, including personal attitudes and aspects of the physical and economic environment. Rather than deal with options on an individual basis, calculations have been made using a "static" herd simulation model on the potential net economic benefit of improving growth rates and fertility to levels considered possible with current technology. Table 2 shows these calculated benefits, which indicate the break-even level of expenditure that can be incurred to obtain the benefit at the raised production level, but does not take into account the costs and risks incurred in the transition to that level.

Weight gains

The mean net benefit of increasing annual weight gains by 60 kg is about $70 per annum for each slaughter animal.

North: 100 kg/annum is the accepted long-term level of production from native pastures. The target weight gain of 160 kg/year is about 25 kg higher than that regularly obtained from native grass/legume pastures or from native pastures with strategic supplementation, either of which cost $30-40/head annually. Strategic grazing of slaughter stock on higher fertility soils will give better baseline weight gains and will reduce the expenditure on pastures. Other forage options include special purpose pastures such as leucaena or deferred legume pastures to extend the growth period into the early dry season, at < $20/head.

South: At about 130 kg/annum, weight gains from native pastures are higher than in the north. The target weight of 190 kg/annum is 20-30 kg higher than that regularly achieved from sown

Table 2. The net benefits derived from changes in fertility or growth rates from a property with a 1000 AU herd. The herd with 55% branding and 100 kg annual growth represents northern properties within the tropical regions, and that with 65% branding and 130 kg gain represents southern herds. The improvements in fertility and growth are considered feasible using current technology.

Base production level Branding percentage	Annual gain kg/head	*New level*	Net benefit $/target animal /year	Total increment $,000
Growth[1]				
		Gain kg/hd		
55	100	160	74	36.8
70	100	160	72	47.5
65	130	190	64	36.5
80	130	190	75	45.5
Fertility[2]				
		Branding %		
55	100	70	68	22.2
55	160	70	84	33.0
65	130	80	60	22.8
65	190	80	74	31.8

[1]slaughter animals; [2]wet/pregnant breeders

grass pastures or native pastures oversown with legumes, at a cost of $30-40/head annually. Growth rates can be further improved with sown grass/legume or leucaena pastures used either strategically or year-round, with cost varying from $10-50/head depending on the time spent grazing these pastures. Special purpose pastures such as the temperate cereals and forage sorghums should only be used to finish stock, at $15-25/head. Southern graziers also have the option of feeding grain to finish animals during autumn and winter either at pasture or in small feedlots. The economics of this option depend primarily on the relative prices of grain and beef.

Crossbreeding and growth stimulants would each improve gains by 10%, at <$15/head annually. In the future modified rumen bacteria may be able to increase the digestibility of forages by 5% which could improve growth rates by up to 20% (R.M.Seebeck, unpublished data) for little or no cost. These low cost technologies are needed to supplement the forage supply strategies to achieve the aim of reducing age of turnoff by a year and to make the package economically beneficial.

Fertility

Methodology to improve fertility is less well understood because less research data are available at the herd scale over different land classes. All experimental and practical data have been collated by Holroyd and O'Rourke (1988). In the analysis presented here the average net benefit of $71 per wet and/or pregnant cow for a 15% improvement in branding rate gives adequate scope for management and nutritional intervention. Benefits from nutritional intervention depend upon improvements in herd management, which include early weaning, culling for infertility and the use of fertile bulls. If early weaning is used to improve cow fertility, additional costs will be incurred to ensure good calf growth post-weaning. Adoption of these management options in conjunction with a crossbreeding program could achieve 10% of the 15% target improvement in branding rate. The remainder will require a direct improvement in nutrition. The majority of breeding cows in the tropics graze native pastures and this scenario is likely to remain for the foreseeable future. The most practical option to improve conception and milk production is strategic supplementation, particularly by-pass protein (Hennessy 1986) and P (and possibly non-protein N) where soil P levels are low. For protein the key period is pre and post partum, while P will be most beneficial during the period of active pasture growth. Where breeding cows have grazed legume based pastures, or sown grass pastures in the south, the target fertility levels have been attained (Holroyd and O'Rourke 1988).

The relative benefits of improving either fertility or weight gains depend heavily upon beef price. In the simulation, animals were sold at a mean price of $1.15/kg live weight and the total net increment was higher for the improvement in weight gain. However, it should be noted that the highest net increments were obtained when fertility was improved in addition to annual weight gains.

Conclusions

There are proven technologies available to producers in northern Australia which would enable improvements in herd efficiency and production of beef to meet market demands for beef of specified quality, and further technologies are being developed. However, the integration of these options into sustainable management systems will depend upon the attitudes and management skills of individual graziers, together with the climatic and soil characteristics of their properties.

Acknowledgments

The authors wish to thank Tom Rudder for his economic analyses and helpful comments, and Ms Heidi Herzog for compiling the database of the results of grazing experiments used in Table 1.

References

AMLC (1990) Summary of Australian Livestock Statistics. (Australian Meat and Livestock Commission: Sydney.)

Anderson, E.R., Pressland, A.J., McLennan, S.R., Clem, R.L. and Rickert, K.G. (1988) The role of fire in native pasture management. In: Burrows, W.H., Scanlan, J.C. and Rutherford, M.T. (eds) *Native Pastures in Queensland.* pp. 112-124. (Department of Primary Industries: Brisbane.)

Ash, A., Prinsen, J.H., Myles, D.J. and Hendricksen, R.E. (1982) Short-term effects of burning native pasture in spring on herbage and animal production in south-east Queensland. *Proceedings of the Australian Society of Animal Production*, **14**, 377-380.

Blyth, M. and Mues, C. (1990) Australian Meat: a decade of opportunity. National Agricultural and Resources Outlook Conference 1990.

Burrows, W.H., Scanlan, J.C. and Anderson, E.R. (1988) Plant ecological relations in open forests, woodlands and shrublands. In: Burrows, W.H., Scanlan, J.C. and Rutherford, M.T. (eds) *Native Pastures in Queensland.* pp. 72-90. (Department of Primary Industries: Brisbane.)

Edye, L.A. (1984) Pasture improvement in semi-arid tropical savannas: a practical example in northern Queensland. In: Tothill, J.C. and Mott, J.J. (eds). pp.303-309. *Ecology and Management of the World's Savannas.* (The Australian Academy of Science: Canberra.)

Gramshaw, D. and Walker, B. (1988) Sown pasture development in Queensland. *Queensland Agricultural Journal*, **114**, 93-101.

Hennessy, D.W. (1986) Supplementation to reduce lactational anoestrus in first-calf heifers grazing native pastures in the subtropics. *Proceedings of the Australian Society of Animal Production*, **16**, 227- 230.

Holroyd, R.G. and O'Rourke, P.K. (1988) *Collation of basic biological data on beef cattle production in north Australia.* (AMLRDC: Sydney.)

Hunter, R.A. and Vercoe, J.E. (1987) Reduction of energy requirements of steers fed on a low-quality roughage diets using trenbolone acetate. *British Journal of Nutrition*, **58**, 477-483.

Leng, R. (1989) Recent Advances in Applied Aspects of Ruminant Physiology and Nutrition. In: Devendra, C. and Imaizumi, E. (eds) *Ruminant Physiology and Nutrition in Asia.* pp.1-23. (Japan Society of Zootechnical Science: Tokyo.)

t'Mannetje, L. (1984) Problems of animal production from tropical pastures. In: Hacker, J.B. (ed) *Nutritional Limits to Animal Production from Pastures.* pp.67-85. (Commonwealth Agricultural Bureau: Farnham Royal.)

McCown, R.L. (1981) The climatic potential for beef cattle production in tropical Australia. *Agricultural Systems*, **6**, 303-307.

McLennan, S.R., Hendricksen, R.E., Beale, I.F., Winks, L., Miller, C.P. and Quirk, M.F. (1988) Nutritive value of native pastures in Queensland. In: Burrows, W.H., Scanlan, J.C. and Rutherford, M.T. (eds) *Native Pastures in Queensland.* pp. 125-159. (Department of Primary Industries: Brisbane.)

Mott, J.J., Williams, J., Andrew, M.H. and Gillison, A.N. (1984) Australian savanna ecosystems. In: Tothill, J.C. and Mott, J.J. (eds). pp.303-309. *Ecology and Management of the World's Savannas.* pp. 56-82. (The Australian Academy of Science: Canberra.)

Poppi, D. (1990) Manipulation of nutrient supply to animals at pasture opportunities and consequences. *Proceedings of the 5th Asian-Australian Association of Animal Production Societies.* pp. 41-79.

Robbins, G.B., Bushell, J.J. and Butler, K.L. (1987) Decline in plant and animal production from ageing pastures of green panic (*Panicum maximum* var. *trichoglume*). *Journal of Agricultural Science; Cambridge*, **108**, 407-417.

Roquette, F.M. and Carpenter, Z.L. (1981) Carcass characteristics of weanling calves grazed at three levels of forage availability. *Journal of Animal Science*, **53**, 892-897.

Saadullah, M. (1984) *Studies on utilisation of rice straw by cattle.* Ph.D. Thesis, Royal Veterinary University, Copenhagen.

Seebeck, R.M. (1984) Body composition of British and Zebu x British cattle in northern Australia. 1. Breed and growth rate effects on yields of carcass, dressed carcass composition and offal composition. *Animal Production*, **39**, 177-193.

Sollenberger, L.E. and Jones, C.S. (1989) Beef production from nitrogen-fertilized Mott dwarf elephantgrass and Pensacola bahiagrass pastures. *Tropical Grasslands*, **23**, 129-134.

Tothill, J. (1983) Fire in black speargrass (*Heteropogon contortus*) — a ten year comparison of burnt and unburnt treatments. In: Roberts, B.R. (ed) *2nd Queensland Fire Research Workshop.* pp.77-85. (Darling Downs Institute of Advanced Education: Toowoomba.)

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

Wildin, J.H., and Chapman, D.G. (1987) Ponded pasture systems — capitalising on available water. Regional Bulletin Series. RQR87006. (QDPI: Rockhampton.)

Winks, L., Laing, A.R., O'Rourke, P.K. and Wright, G.S. (1979) Factors affecting responses to urea-molasses supplements by yearling cattle in tropical Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **19**, 522-529.

Winks, L. (1984) Cattle growth in the dry tropics of Australia. *Australian Meat Research Committee Review* **45**, pp. 1-43.

Winter, W.H. (1987) Using fire and supplements to improve cattle production from monsoon tallgrass pastures. *Tropical Grasslands* **21**, 71-81.

Winter, W.H., D.B. Coates, R.E. Hendricksen, P.C. Kerridge, R.W. McLean and Miller, C.P. (1990) Phosphorus and beef production in northern Australia. 4. The response of cattle to fertilizer and supplementary phosphorus. *Tropical Grasslands*, **24**, 170-184.

Yen, H.T., Cole, D.J.A. and Lewis, D. (1986) Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg live weight to dietary ideal protein. *Animal Production*, **43**, 141-154.