Australian Journal of Experimental Agriculture, 1996, **36**, 389–95

Creep feeding and prepartum supplementation effects on growth and fertility of Brahman-cross cattle in the dry tropics

G. Fordyce[A], *N. J. Cooper*[A], *the late I. E. Kendall*[A], *B. M. O'Leary*[AB] *and J. de Faveri*[C]

[A] Queensland Department of Primary Industries, Swan's Lagoon, Millaroo, via Ayr, Qld 4807, Australia.
[B] Present address: 'Lavera', Julia Creek, Qld 4823, Australia.
[C] Queensland Department of Primary Industries, PO Box 1054, Mareeba, Qld 4880, Australia.

Summary. Post-partum anoestrus is a primary contributor to low branding rates in *Bos indicus* cattle herds in the dry tropics of northern Australia [Entwistle, K. W. (1983). Australian Meat Research Committee Review No. 43]. To increase branding rates, it was hypothesised that creep feeding for a short period in mid–late lactation during the latter half of the growing season may trigger an earlier onset of post-partum oestrus cycling, just as short-term, high-level, prepartum supplementation can achieve.

Two experiments were conducted using F_n Brahman-cross cows (1/2, 5/8 and 3/4 crosses with Beef Shorthorn) which calved from late October to late January. Cows were mated from mid–late January to mid-April. Calves in one treatment in both experiments had *ad libitum* access to creep feed (calf pellets: 16% crude protein, 10 MJ ME/kg) for 40–42 days from late February to early April. In experiment 2, the effects on cow growth and fertility due to supplementation with either cottonseed meal (1.5 kg/day) or molasses with 7.4% (w/w) urea for 49 days late in the dry season before calving ('spike' feeding) were also evaluated. Control cattle were unsupplemented.

Creep feed was only consumed at 0.1 and 0.4 kg/day in experiments 1 and 2, respectively. Short-term creep feeding had no consistent effects on cow liveweights, condition, or fertility, or on calf growth and temperaments under extensive grazing conditions during the tropical wet season.

Spike feeding reduced weight loss by 0.2–0.4 kg/day ($P<0.01$). The effects on liveweights did not persist into the wet season. There were no effects on cow fertility in this year of extreme weather conditions, when 4 months of nutritional and climatic stress followed supplementation.

Introduction

Post-partum anoestrus (PPA) is a primary contributor to low branding rates in *Bos indicus* cattle herds in the dry tropics of northern Australia (Entwistle 1983). Reducing the PPA interval increases branding rates by increasing the proportion of cows which conceive before weaning, which commences about April–May at the end of the pasture growing season. It also enables weaning of calves at the first weaning round in the following year, thereby reducing the proportion of cows lactating in the dry season, and the cow and calf mortalities which result from this.

Suckling in cows has a potent suppressant effect on resumption of cycling after calving; many cows are able to recommence cyclic ovarian activity in response to weaning due to relief from suckling stimuli and the energy drain of lactation (Williams 1990). Our hypothesis was that creep feeding for a short period in mid–late lactation during the latter half of the growing season may reduce milk intake by calves; this may reduce the suckling stimulus and trigger an earlier onset of post-partum ovarian and oestrus activity. Previous studies have reported that creep feeding for 2.5–4.5 months may improve conception rates (Stricker *et al.* 1979; Lishman *et al.* 1984*b*; Schlink *et al.* 1988) or may have no effect on cow growth and fertility (Lishman *et al.* 1984*a*). Jolly (1992) reported a study where suckling intensity was substantially greater when *Bos indicus*-cross cows fed poorer quality diets produced less milk (milk yields: 3.6 *v.* 4.8 kg/day; suckling episodes/day: 13.7 *v.* 9.5; total suckling time: 127 *v.* 92 min/day). He suggested that increasing intensity of suckling enhanced the negative feedback of the suckling stimulus on gonadotrophin secretion, thus being a major contributor to the delay in resumption of post-partum ovarian cyclicity.

This paper reports 2 experiments on short-term creep feeding during mid–late lactation and its effects on dam and calf performance. In addition, in the second experiment the efficacy of creep feeding in lactating cows was compared with that of short-term, high-level, prepartum supplementation (so called 'spike' feeding), previously reported by Fordyce *et al.* (1989).

Materials and methods

Location

The experiments were conducted at Swan's Lagoon Beef Cattle Research Station (20°05'S, 147°14'E) in subcoastal North Queensland. The climate is dry tropical and characterised by a distinct hot, wet summer period (wet season) and a warm, dry winter period followed by a hot, dry period (dry season). Distribution and amount of annual rainfall (July–June average 862 mm) is highly variable (range 296–1951 mm). In the years of the experiments reported, season breaks were average (21 November 1989) and late (26 December 1990), with total rainfall above average in both years (1112 and 1552 mm, respectively). The first 2 months of the 1990–91 wet season were extremely wet, with an average 24 mm/day. Vegetation, is open woodland (primarily *Eucalyptus* spp.) with an unimproved native pasture which is predominantly black speargrass (*Heteropogon contortus*). The experimental area is flat with low-fertility soil. A more detailed description of the climate, vegetation and soils is given by Fordyce *et al.* (1996).

Cattle and their management

In both experiments, pregnant, F_n Brahman-cross cows (1/2, 5/8 and 3/4 crosses with Beef Shorthorn) were allocated using stratified randomisation on estimated stage of pregnancy within genotype, age and body condition to treatments and replicates. Each treatment replicate was allocated to a 100 ha paddock (1.35 by 0.75 km). Calving occurred from early November to late January, with an average calving date of early December. All calves were 5/8 Brahman crosses. Two reproductively-sound Brahman-cross bulls were put into each paddock in late January for 84–85 days. Calves were weaned early in June.

Treatments

Four treatments were used: (i) NOSUP, no supplementation of cows or calves; (ii) CREEP, calves (starting age 1–4 months) were creep fed *ad libitum* commercial calf pellets [comprising 16% crude protein (CP), 10 MJ ME/kg, constituted from wheat, bran, pollard, meat and bone meal, blood meal, peanut hulls, molasses, lime, monoammonium phosphate (MAP), bentonite, urea, salt, and a vitamin and mineral mix] from late February–early April; (iii) SFCSM, cows were supplemented with an average 1.5 kg/day of cottonseed meal (CSM; 40% CP) for 49 days prepartum fed twice weekly as a 3-day and 4-day ration; and (iv) SFM8U, cows were offered *ad libitum* molasses with 7.4% urea (w/w) for 49 days prepartum.

The latter 2 treatments are referred to as 'spike' feeding. Twice-weekly supplementation with CSM has the same efficacy as daily feeding when fed at the same average daily intake (Hennessey *et al.* 1981). Residues of all cow and calf supplements in each paddock were measured twice weekly when troughs were refilled. No attempt was made to measure intakes of individual animals.

Experiment 1

Cows aged between 3.5 and 5.5 years were allocated to 3 replicates of 2 treatments (NOSUP and CREEP) with 30–34 cows per replicate. In the creep feeding paddocks, an area of about 1 ha was fenced to enclose the water trough which was at the end of the paddock. A 1-way inlet (spear gate; Anon. 1987) and adjacent outlet cow–calf separator (Hirst and Wicksteed 1989) were incorporated. At the separator, calves were automatically and efficiently drafted off into a feeding yard from which they exited through an outlet spear gate to the paddock. Creep feeding using covered feed troughs commenced on 28 February and continued for 40 days. Cows had no access to creep feed at any stage.

Experiment 2

Cows aged 2.5 years and on their first pregnancy were allocated to 2 replicates of 4 treatments (NOSUP, CREEP, SFCSM, SFM8U) with 34–36 cows per replicate. Spike feeding commenced on 7 September 1990 and ceased just before calving. Creep feeding was achieved in a similar fashion to experiment 1. However, calves were able to exit the feeding yard either through a spear gate to the watering enclosure or through a creep panel (vertical bars with 400 mm inside spacing) to the paddock (Fig. 1). Creep feeding lasted for 42 days starting on 25 February 1991. As cattle were not watering at the trapping enclosure due to the very wet conditions at the start of supplementation, an additional creep feeding enclosure per paddock was constructed at camping sites and used for the first 11 days. These were 10 m^2 with 2 rails which were 800 and 1300 mm above ground level. A tarpaulin at a height of 1.5–2.0 m covered each enclosure.

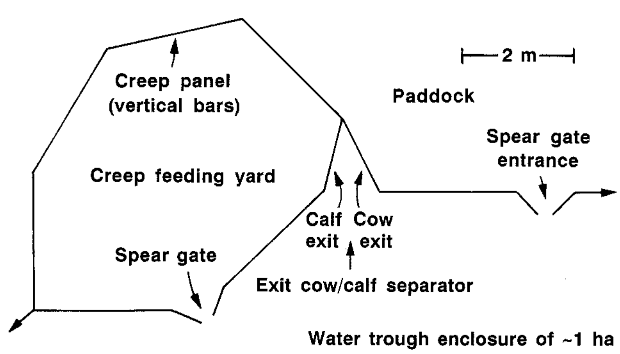

Figure 1. Schematic representation of the creep feeder.

Measurements

All cows and calves were weighed (early-morning before drinking) and condition scored (9-point scale, Holroyd 1978) at the start and end of the experiments, treatments, calving, and mating. Dates of conception before allocation and during the experiments were estimated from manual rectal pregnancy diagnoses at the end of mating and at weaning.

During creep feeding, observations were made up to 5 times weekly of cattle behaviour during daylight hours by an observer on a motor bike. As well, a video camera was regularly set with 4 h tapes to observe calf behaviour in the absence of man in and around the creep feeder during daylight hours.

Fifty days after weaning in experiment 1, flight distances (minimum tolerated approach distance in a yard) of heifer progeny (Fordyce and Goddard 1984) were measured as an assessment of temperament.

At the end of spike feeding in experiment 2, jugular blood samples were taken mid-morning, immediately after mustering, from NOSUP, SFCSM and SFM8U cows into tubes containing oxalate and immediately chilled. Plasma samples were stored frozen and subsequently assayed for glucose and insulin. The glucose oxidase method of Gochman and Schmitz (1972) was used to determine plasma glucose (absorbance measured at 600 nm). Plasma insulin concentrations were estimated using a standard, double-antibody, solid-phase, insulin radioimmunoassay kit (IM 78; Amersham Australia Pty Ltd) which contained antiserum raised in guinea pigs against bovine insulin, ^{125}I-labelled bovine insulin tracer, and human insulin standards. The standard protocol was modified to improve assay sensitivity and precision by diluting tracer and antiserum in assay buffer to activities of about 10000 cpm/100 μL and 40% tracer binding in the zero standard, and by extending primary incubation from 3 to 18 h. The assay sensitivity was 0.850 ± 0.086 μU/L. Intra- and inter-assay coefficients of variation were 7.96 and 13.27%, respectively, at the average concentration (14.5 μU/mL) of insulin in a reference plasma sample.

At the conclusion of creep feeding, 24 h milk yield of all NOSUP and CREEP cows was estimated using the weigh–suckle–weigh method (Neville 1962). Cows were drafted into 6 groups of about 20. Calves were weighed before and after 20 min of suckling at 17 and 24 h after the initial 20 min sucking-out period.

Statistical analyses

Only data from cows which reared a calf to the end of data collection were included in the analyses. Full weights were initially adjusted for stage of pregnancy using the method of O'Rourke *et al.* (1991).

All variables were analysed by the method of least squares for unequal subclass numbers using LSMLMW (Harvey 1975). Animal to animal variation within cells was used to estimate experimental error. Initially, models included all 2-factor interactions and relevant covariates. Models were then reduced by step-wise elimination of non-significant terms. Least square means and standard errors were estimated for all effects in the final models.

For experiment 1, models for the analyses of cow liveweights, body condition scores, and percentage pregnant included the effects of treatment, cow genotype, and cow age as factors, and day of calving as a covariate. Changes in liveweight and condition score were analysed using a similar model with liveweight and condition at the beginning of each period also included as a factor and covariate, respectively. Liveweights and growth rates of calves were analysed after addition to the initial model of calf sex and the covariate of calf weight either at the start of mating (for weight analyses) or start of the period (for growth rate analyses).

Models for analyses of the same variables in experiment 2, with the addition of milk yield, plasma glucose and plasma insulin, were similar to those for experiment 1 but excluded cow age.

Results

Supplement intake

From observations using remote-controlled video, most calves had learned to accept the creep feed within a week in both experiments. Calves actively sought pellets if they were in the vicinity of the creep feeder, often camping in the feeding yard. Despite this, average daily

Table 1. Experiment 1. Effects of no supplement (NOSUP; n = 91) and short-term creep feeding (CREEP; n = 86) on growth and fertility

Values are least square means

Means within each row followed by the same letter are not significantly different at P = 0.01

	Date or days	NOSUP	CREEP	s.e.m.
	Cows			
Liveweight (kg)				
Allocation	5.vi.89	421a	421a	3.6
Precalving	16.x.89	424a	427a	3.2
Start of creep feeding	28.ii.90	427a	428a	3.1
Growth rate (kg/day) over creep feeding	40 days	0.15a	0.07a	0.03
Condition score				
Allocation	5.vi.89	6.9a	6.9a	0.11
Precalving	16.x.89	7.0a	7.0a	0.11
Start of creep feeding	28.ii.90	6.1a	6.0a	0.10
Change over creep feeding	40 days	0.7a	0.6a	0.08
Pregnancy rate (%)				
Start of creep feeding	28.ii.90	70a	63a	5
End of creep feeding	9.iv.90	88a	90a	4
End of mating	17.iv.90	90a	94a	3
	Calves			
Liveweight (kg)				
Start of creep feeding	28.ii.90	113a	115a	1.4
Growth rate (kg/day) over creep feeding	40 days	0.96a	0.93b	0.01

intake of supplement (based on paddock intakes) was only 100 g/calf (range 20–200 g/calf) in experiment 1 and 400 g/calf (range 70–1260 g/calf) in experiment 2.

In experiment 2, spike-fed cows consumed an average 2.3 kg/cow.day of molasses–urea which did not vary significantly over feeding. The 3- and 4-day rations of CSM were consumed by cows within an hour of feeding.

Responses to creep feeding

Creep feeding had no effect on cow liveweight, condition score, pregnancy rate or milk yield (Tables 1 and 2). There was no effect of creep feeding on calf growth in experiment 1 (Table 1) but a small increase in calf growth in experiment 2 ($P<0.05$; Table 2). In experiment 2, there were also significant ($P<0.01$) treatment x dam genotype interactions for calf liveweights and calf growth rates, though the effects appeared random.

Post-weaning temperament was unaffected by previous creep feeding in experiment 1. Flight distance averaged 2.2 m for both NOSUP and CREEP progeny.

Responses to spike feeding

Spike feeding reduced weight loss by 0.2–0.4 kg/day ($P<0.01$) and condition score loss by 0.3–0.4 units ($P<0.01$), with the greatest response to CSM (Table 2). Treatment interacted with genotype in its effect on growth rate ($P<0.05$); this appeared primarily due to 1/2 Brahmans having relatively high growth rate in the NOSUP and SFM8U treatments and relatively low growth rate in other treatments.

At the end of spike feeding, plasma insulin was unaffected by treatment, but plasma glucose was higher in spike-fed cows ($P<0.05$; Table 2).

The small weight advantage gained by spike feeding was not retained through to mating (Table 2). Pregnancy rates were not affected by spike feeding (Table 2);

Table 2. Experiment 2. Effects of no supplement (NOSUP; n = 64), spike feeding with cottonseed meal (SFCSM; n = 64) or molasses with 7.4% urea (SFM8U; n = 63), and short-term creep feeding (CREEP; n = 65) on growth and fertility

Values are least square means

Means within each row followed by the same letter are not significantly different at P = 0.05

	Date or days	NOSUP	SFCSM	SFM8U	CREEP	s.e.m.
		Cows				
Liveweight (kg)						
Allocation	10.v.90	396a	395a	396a	400a	1.8
Start of spike feeding	6.ix.90	410a	412a	411a	418b	1.5
End of spike feeding	26.x.90	379a	401c	391b	394bd	1.6
Start of creep feeding	5.iii.91	369a	369a	366ab	361b	2.0
Growth rate (kg/day)						
During spike feeding	49 days	–0.66a	–0.25c	–0.44bd	–0.48d	0.03
During creep feeding	42 days	0.22	0.18	0.19	0.16	0.06
Condition score						
Allocation	10.v.90	7.9a	7.9a	7.9a	8.0a	0.03
Start of spike feeding	6.ix.90	7.8a	7.8a	7.7a	7.8a	0.05
End of spike feeding	26.x.90	6.5a	6.9b	6.8b	6.3a	0.08
Start of creep feeding	5.iii.91	4.8a	4.8a	4.6a	4.5a	0.10
Condition score change						
During spike feeding	49 days	–1.1a	–0.7b	–0.8b	–1.2a	0.07
During creep feeding	42 days	0.1a	0.2a	0.2a	0.1a	0.06
Plasma parameters at end of spike feeding						
Glucose (mg/dL)	26.x.90	69a	74b	74b	—	1.5
Insulin (μU/mL)	26.x.90	18a	18a	16a	—	1.2
Milk yield (kg/day)						
End of creep feeding	8.iv.91	3.6a	—	—	3.6a	0.3
Pregnancy rates (%)						
Start of creep feeding	5.iii.91	25a	9a	14a	21a	5
End of creep feeding	8.iv.91	50a	34a	33a	38a	6
End of mating	16.iv.91	52a	39a	35a	39a	6
		Calves				
Liveweight (kg)						
Start of creep feeding	5.iii.91	105a	101ab	100b	97b	1.6
Growth rate (kg/day)						
over creep feeding	42 days	0.74a	0.79ab	0.79b	0.82b	0.02

conception patterns and average conception dates were similarly unaffected.

Discussion

Creep feeding

At the very low intake of creep feed achieved, the general lack of response was expected. However, had creep-feed intakes been higher in experiment 1, significantly higher pregnancy rates could not have been achieved as pregnancy rates in cows whose calves did not receive creep feed were very high due to excellent seasonal conditions.

The opportunity to achieve a response appeared excellent in experiment 2. Cows had experienced considerable wet weather stress in the preceding 2 months. They were in backward-store condition and their pregnancy rate by the end of mating was only 40–50%. During creep feeding, the weather was mostly fine and cattle generally watered or camped adjacent to the creep-feeding yard. Milk yield was relatively low compared with about 5 kg/day obtained for Brahman crosses on tropical native pasture in the wet season (Holroyd *et al.* 1979), and about 6 kg/day obtained for Brahman-cross cows on maintenance diets (Hunter and Magner 1988). However, based on the finding of Jolly (1992) that the suckling stimulus is greater in nutritionally-depleted cows with low milk yields, the potential to reduce suckling stimulus by substituting creep feed for pasture and milk was probably quite high.

Low creep-feed intakes were primarily considered a function of grazing behaviour of breeding herds. Our experience is that grazing weaned calves of the same age consume up to 2 kg/day of these pellets in contrast to <0.5 kg/day consumed by unweaned calves. No detailed records were kept, but observations showed that calves in this study moved with their dams and grazed pasture as well as suckled. The main grazing periods each day are usually early morning and late afternoon, and the calves suckled before returning to water after grazing in the morning. Groups of calves then often separated themselves from their dams and came into water with 'nurse' cows after their dams. Upon reuniting with dams at the trapping enclosure, their first instinct was to suckle and then drink water from the trough before being separated into the creep yard. The grazing, suckling and drinking may have together suppressed the calves' appetite for creep feed, possibly through a substitution (gut fill) effect. During rain periods, in both experiments, the situation was partially exacerbated because the cattle camped and watered away from the creep feeder. Under these conditions, cattle were moved steadily, by a person on a motorbike, once a day from their camp area to the creep feeder where they recamped.

Unsupplemented calves in experiment 2 would have gained an estimated 11.0 MJ/day of empty liveweight, with a net efficiency of ME utilisation for gain (k_g) of 0.48 (Standing Committee on Agriculture 1990). Therefore, creep-fed calves would have gained an estimated extra 0.13 kg/day if there was no substitution effect. The actual growth increment of 0.08 kg/day indicates a partial feed substitution effect.

Previous research, where the effects of creep feeding on cow fertility were assessed, was generally conducted under more intensive management; daily creep-feed intake was much higher and feeding was for much longer periods, thus explaining why both cow and calf responses were sometimes achieved. When Stricker *et al.* (1979) creep fed calves of mature Hereford cows from birth to weaning, calf growth increased by 0.1 kg/day. Though cow growth was not affected, conception rates increased from 55 to 74%; however, cows did have some access to the creep feed, particularly in the first year of the study. Lishman *et al.* (1984*a*) in a multifactorial experiment using 151 Africander cows in South Africa, provided 0.9 kg/day of creep feed to their calves between about 4 and 7 months of age. The same treatment was applied during the final 4.5 months of lactation in a subsequent study using 99 first-calf Africander, Africander cross and Hereford heifers (Lishman *et al.* 1984*b*). Creep feeding increased calf growth in both studies by 0.1 kg/day, but there was no effect on cow weight (426 and 401 kg, respectively). In the first study, calving rates were not affected (57%). However, in the second study, calving rates were increased from 32 to 60%. In an observation at a dry tropical North Queensland site using 104 Droughtmaster cattle, creep feeding calves (1.8 kg/day for 2.4 months) had no effect on growth but was related to a 13% increase ($P>0.05$) in conception rates (Schlink *et al.* 1988); however, creep-feeding effects were confounded with paddock nutrition and bull fertility in this study.

Spike feeding

Spike feeding developed from extensive research showing that precalving energy levels have a significant effect on rebreeding (Wiltbank *et al.* 1962; Dunn *et al.* 1969; Corah *et al.* 1975; Bellows and Short 1978; Selk *et al.* 1988; Fordyce *et al.* 1989; Marston *et al.* 1995). This effect has been related to changes in ovarian follicular activity following feeding for a minimum 42-day period in the late dry season immediately before calving (Fordyce *et al.* 1989). Following a series of 12 experiments and observations, Entwistle *et al.* (1994) concluded that other than in years of climatic extremes, spike feeding increases pregnancy rates in lactating cows by an average 15%. Similar responses were achieved when cows were in both backward and forward body condition at the start of mating.

In experiment 2, strong homeostatic mechanisms (Randel 1990) would have maintained dry season plasma glucose in pregnant cows within the normal range (Coles

1974; Bastidas *et al.* 1990) despite cows losing weight at 0.5–0.6 kg/day on the poor quality, dry season diet. Cows were unlikely to have consumed supplement within 20 h of sampling and had been grazing a poor quality pasture between then and mustering. This, combined with the homeostatic mechanisms, were the most likely reasons why supplementation only slightly elevated plasma glucose levels. Plasma insulin levels, as measured, were not affected by spike feeding, probably also because of the extended time since supplement intake. Both Hunter and Magner (1988) and Marston *et al.* (1995) have shown increased insulin levels in response to prepartum concentrate supplementation; in both reports this was related to increased growth, and in the latter report, where supplementary feeding continued in the post-partum period, to higher post-partum pregnancy rates (+11%).

Any advantages in ovarian function achieved by spike feeding in experiment 2 appeared to have been countered by the extended extreme seasonal conditions which ensued. At the end of spike feeding, dry season nutritional stress continued for 2 months followed by persistent rain (average 24 mm/day) for a further 2 months; the latter caused direct stress as well as nutrient dilution in pastures. The mechanism for the nutritional stress effect was not investigated in this experiment. Jolly *et al.* (1994) in their review, indicated that nutritional stress may suppress folliculogenesis via direct and indirect effects on both the hypothalamo-pituitary axis and the ovary.

In a practical situation under severe nutritional conditions late in the dry season, spike feeding is likely to be extended beyond the minimum requirement of 50 days, primarily to prevent cow and calf mortalities which, without crisis supplementation, can easily be greater than 20% of the herd in some years (Fordyce *et al.* 1990). Extension of energy supplementation until the arrival of wet season rains would most probably sustain advantages in ovarian folliculogenesis and achieve typical increases in lactating cow fertility. Anecdotal evidence from the higher-than-expected 1983–84 branding rates following extended molasses-based supplement feeding for survival in the severe 1982–83 drought in the region supports this.

Conclusions

The main practical conclusions from these experiments are: (i) short-term creep feeding is unlikely to successfully improve cow or calf performance if attempted under extensive grazing conditions during the wet season in the tropics; and (ii) spike feeding will not improve fertility in cows if the supplementation period is followed by several months of continued nutritional stress, i.e. in years of extreme weather conditions.

Acknowledgments

This research was partially funded by the Meat Research Corporation under NAP2:DAQ.062. We thank David Hirst and other colleagues at Swan's Lagoon for their assistance in conducting the research, and Dr Lee Fitzpatrick and his James Cook University laboratory staff for performing the glucose and insulin assays. Comments on this paper from Dr Richard Holroyd and Dr Rob Dixon are also gratefully acknowledged.

References

Anon. (1987). The Hirst spear gate is simple to construct. *Queensland Agricultural Journal* **113**, 327–8.

Bastidas, P., Forrest, D. W., Del Vecchio, R. P., and Randel, R. D. (1990). Biological and immunological luteinizing hormone activity and blood metabolites in postpartum Brahman cows. *Journal of Animal Science* **68**, 2771–8.

Bellows, R. A., and Short, R. E. (1978). Effects of precalving feed level on birth weight, calving difficulty and subsequent fertility. *Journal of Animal Science* **46**, 1522–8.

Coles, E. H. (1974). 'Veterinary Clinical Pathology.' 2nd Edn. (W. B. Saunders: Philadelphia.)

Corah, L. R., Dunn, T. G., and Kaltenbach, C. C. (1975). Influence of prepartum nutrition on the reproductive performance of beef females and the performance of their progeny. *Journal of Animal Science* **41**, 819–24.

Dunn, T. G., Ingalls, J. E., Zimmerman, D. R., and Wiltbank, J. N. (1969). Reproductive performance of 2-year-old Hereford and Angus heifers as influenced by pre- and post-calving energy intake. *Journal of Animal Science* **29**, 719–26.

Entwistle, K. W. (1983). Factors influencing reproduction in beef cattle. Australian Meat Research Committee Review No. 43, Sydney.

Entwistle, K. W., Fitzpatrick, L. A., and Fordyce, G. (1994). Strategic supplementation and hormonal feedback controls to reduce the postpartum anoestrus interval in Brahman cross cows. *In* 'Developing Cost-effective Strategies for Improved Fertility in *Bos indicus* Cross Cattle'. Final Report, Project NAP2:DAQ.062/UNQ.009. pp. 67–83. (Meat Research Corporation: Sydney.)

Fordyce, G., Fitzpatrick, L. A., Mullins, T. J., and Entwistle, K. W. (1989). Pre-partum supplementation effects on cow fertility. *Proceedings of the Australian Society for Reproductive Biology* **21**, 101.

Fordyce, G., and Goddard, M. E. (1984). Maternal influence on the temperament of *Bos indicus* cross cows. *Proceedings of the Australian Society of Animal Production* **15**, 345–8.

Fordyce, G., Howitt, C. J., Holroyd, R. G., O'Rourke, P. K., and Entwistle, K. W. (1996). The performance of Brahman–Shorthorn and Sahiwal–Shorthorn beef cattle in the dry tropics of northern Queensland. 5. Scrotal circumference, temperament, ectoparasite resistance, and the genetics of growth and other traits in bulls. *Australian Journal of Experimental Agriculture* **36**, 9–17.

Fordyce, G., Tyler, R., and Anderson, V. J. (1990). Effect of reproductive status, body condition and age of *Bos indicus* cross cows early in a drought on survival and subsequent reproductive performance. *Australian Journal of Experimental Agriculture* **30**, 315–22.

Gochman, N., and Schmitz, J. M. (1972). Application of a new peroxidase indicator reaction to the specific automated determination of glucose with glucose oxidase. *Clinical Chemistry* **18**, 943–50.

Harvey, W. R. (1975). Least squares analysis of data with unequal subclass numbers. United States Department of Agriculture, Agricultural Research Service, ARS H-5.

Hennessey, D. W., Williamson, P. J., Lowe, R. F., and Baigent, D. R. (1981). The role of protein supplements in nutrition of young grazing cattle and their subsequent productivity. *Journal of Agricultural Science, Cambridge* **96**, 205–12.

Hirst, D. J., and Wicksteed, L. T. (1989). Livestock drafting equipment. Australian Patent 616559 (The State of Queensland), Australian Industrial Property Organisation, Canberra.

Holroyd, R. G. (1978). Methods of investigating beef cattle fertility. *In* 'Beef Cattle Production in the Tropics'. (Eds R. M. Murray and K. W. Entwistle.) pp. 233–46. (James Cook University Press: Townsville.)

Holroyd, R. G., O'Rourke, P. K., and Allan, P. J. (1979). Effect of pasture type and supplementary feeding on the milk yield of Shorthorn and Brahman cross cows and the growth rate of their progeny in the dry tropics of north Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 389–94.

Hunter, R. A., and Magner, T. (1988). The effect of supplements of formaldehyde-treated casein on the partitioning of nutrients between cow and calf in lactating *Bos indicus* x *Bos taurus* heifers fed a roughage diet. *Australian Journal of Agricultural Research* **39**, 1151–62.

Jolly, P. D. (1992). Physiological and nutritional aspects of postpartum acyclicity in *Bos indicus* cows. Ph.D. Thesis, James Cook University of North Queensland, Townsville.

Jolly, P. D., Fitzpatrick, L. A., McDougall, S., Macmillan, K. L., and Entwistle, K. W. (1994). Physiological effects of undernutrition on postpartum anoestrum in cows. *In* 'Reproduction in Domestic Ruminants III'. *Journal of Reproduction and Fertility* **49** (Suppl.), 477–92.

Lishman, A. W., Lyle, A. D., Smith, V. W., and Botha, W. A. (1984*a*). Conception rate of beef cows and growth of suckling calves as influenced by date of calving and supplementary feeding. *South African Journal of Animal Science* **14**, 10–9.

Lishman, A. W., Snyman, J. W., and Moolman, J. Z. (1984*b*). Reconception and body-mass changes of energy supplemented first-calver beef cows and growth of their creep-fed calves. *South African Journal of Animal Science* **14**, 20–5.

Marston, T. T., Lusby, K. S., Wettemann, R. P., and Purvis, H. T. (1995). Effects of feeding energy or protein supplements before or after calving on performance of spring-calving cows grazing native range. *Journal of Animal Science* **73**, 657–64.

Neville, W. E. Jr (1962). Influence of dam's milk production and other factors on 120-day and 240-day weight of Hereford calves. *Journal of Animal Science* **21**, 315–20.

O'Rourke, P. K., Entwistle, K. W., Arman, C., Esdale, C. R., and Burns, B. M. (1991). Fetal development and gestational changes in *Bos taurus* and *Bos indicus* genotypes in the tropics. *Theriogenology* **36**, 839–53.

Randel, R. D. (1990). Nutrition and postpartum rebreeding in cattle. *Journal of Animal Science* **68**, 853–62.

Schlink, A. C., Gibson, D. S., Liang, Z. J., and Dixon, R. (1988). Calf management strategies and reproductive performance in a northern Australian cattle herd. *Proceedings of the Australian Society of Animal Production* **17**, 326–9.

Selk, J. E., Wettemann, R. P., Lusby, K. S., Oltjen, J. W., Mobley, S. L., Rasby, R. J., and Garmendia, J. C. (1988). Relationships among weight change, body condition and reproductive performance of range beef cows. *Journal of Animal Science* **66**, 3153–9.

Standing Committee on Agriculture (1990). 'Feeding Standards for Australian Livestock. Ruminants.' (CSIRO: Melbourne.)

Stricker, J. A., Matches, A. G., Thompson, G. B., Jacobs, V. E., Martz, F. A., Wheaton, H. N., Currence, H. D., and Krause, G. F. (1979). Cow–calf production on tall fescue–ladino clover pastures with and without nitrogen fertilization or creep feeding: spring calves. *Journal of Animal Science* **48**, 13–25.

Williams, G. L. (1990). Suckling as a regulator of postpartum rebreeding in cattle: a review. *Journal of Animal Science* **68**, 831–52.

Wiltbank, J. N., Rowden, W. W., Ingalls, J. E., Gregory, K. E. and Koch, R. M. (1962). Effect of energy level on reproductive phenomena of mature Hereford cows. *Journal of Animal Science* **21**, 219–25.

Received 25 August 1995, accepted 29 February 1996