CSIRO PUBLISHING

Australian Journal of Experimental Agriculture

Volume 37, 1997

… a journal publishing papers (in the soil, plant and animal sciences)
at the cutting edge of applied agricultural research

www.publish.csiro.au/journals/ajea

All enquiries and manuscripts should be directed to
Australian Journal of Experimental Agriculture
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood
Vic. 3066
Australia

Telephone: 61 3 9662 7614
Facsimile: 61 3 9662 7611
Email: chris.anderson@publish.csiro.au
lalina.muir@publish.csiro.au

Published by
CSIRO PUBLISHING
in co-operation with the
Standing Committee on Agriculture
and Resource Management (SCARM)

Australian Journal of Experimental Agriculture, 1997, **37**, 399–405

An evaluation of growth and adaptive traits of different cattle genotypes in a subtropical environment

B. M. Burns[AB], *D. J. Reid*[C] *and J. F. Taylor*[D]

[A] Queensland Department of Primary Industries, MS 586, Theodore, Qld 4719, Australia.
[B] Present address: Queensland Department of Primary Industries, Tropical Beef Centre, PO Box 5545, Rockhampton, Qld 4702, Australia; e-mail: burnsb@dpi.qld.gov.au
[C] Queensland Department of Primary Industries, PO Box 6014, Rockhampton Mail Centre, Qld 4702, Australia.
[D] Department of Animal Science, Texas A & M University, College Station, Texas 77843-2471, USA.

Summary. The ability of the large, late maturing, high grade Simmental (HGS), purebred Hereford (H), Hereford x Shorthorn crossbred (HSH) and grade Belmont Red (BR) genotypes to withstand both tick and intestinal helminth burdens and high ambient temperatures and to grow in a subtropical environment was investigated.

Compared with the H, HSH and BR genotypes the HGS was the least heat tolerant and tick resistant, while there was no difference among genotypes in helminth resistance. The HGS had the heaviest weaning (228 kg *v*. average of 186 kg for the other breeds) and 12 month of age (235 kg *v*. average of 210 kg for the other breeds) weights, however, by 18 months of age there was little difference in the weights of the HGS and BR genotypes (323 *v*. 317 kg, respectively), with the HSH intermediate (302 kg) and the H the lightest (288 kg).

When compared with H, HSH and HGS genotypes, the BR genotype is the recommended breed for this subtropical environment because it demonstrated superior adaptive trait performance and, as high, or higher growth performance at 18 months of age.

Introduction

The introduction of the large, late maturing European breeds (e.g. Charolais and Simmental) has added an additional choice for cattlemen to the traditional early maturing British breeds (e.g. Hereford and Shorthorn) and tropically adapted breeds (e.g. Belmont Red and Brahman–British crossbreds) in the southern areas of the Brigalow belt of Central Queensland. Favourable growth performance results have been reported for the Simmental in both the semi-arid subtropical and harsher areas of South Africa (Joubert *et al.* 1977). Apart from studies in subtropical northern New South Wales (Thompson *et al.* 1981; Darnell *et al.* 1987), there is a paucity of information reporting the effect of the environmental stresses on growth for this breed in tropical and subtropical regions of Australia.

At the Brigalow Research Station, in the southern Brigalow belt of Central Queensland, the large, late maturing Simmental breed is being compared with the early maturing Hereford and a Hereford–Shorthorn crossbred and the tropically adapted grade Belmont Red under a semi-intensive grazing regime. As part of the research program to evaluate the relative productivity of these 4 genotypes in this environment, a study was conducted to investigate the growth performance of these genotypes in the presence of tick and helminth burdens, and high ambient temperatures. This paper reports the results of this study.

Materials and methods

Environment

The study was conducted at the Brigalow Research Station, Theodore, which is located 190 km south-west of Rockhampton in the Brigalow belt of Central Queensland (latitude 24°50'S; longitude 149°48'E). This region has a subtropical climate with an annual rainfall averaging 726 mm with about 55% falling during November–February, inclusive. This rainfall generally results in excellent pasture growth which allows cattle to achieve good liveweight gains over a 7–8 month period (October–November to April–May), and to maintain liveweight during winter, except under extremely dry conditions following a poor summer rainfall. Seasonal and annual rainfall at the Brigalow Research Station during the experimental period and long-term means are presented in Table 1. Mean monthly ambient temperatures range from 32°C maximum and 21°C minimum in January to 21°C maximum and 6°C minimum in July.

The experimental animals grazed improved pastures of green panic (*Panicum maximum* var. *trichoglume*), buffel (*Cenchrus ciliaris*) and rhodes (*Chloris gayana*)

10.1071/EA96092

Table 1. Seasonal and annual rainfall at the Brigalow Research Station during the experimental period and long-term means (± s.d.)

Year	May–October	November–April	Annual
1983–84	505	419	924
1984–85	512	353	865
1985–86	307	348	655
1986–87	434	427	861
Long term (21 years to April 1988)	256 ± 122	470 ± 116	726 ± 137

grasses growing on cracking clays and duplex soils in the Highworth land system (Speck *et al.* 1968). Stocking rates ranged from 1 to 2 ha per growing animal.

Constraints to animal production in the Brigalow belt include the cattle tick (*Boophilus microplus*) which is endemic, gastro-intestinal helminths (*Haemonchus placei*, *Cooperia* spp., *Trichostrongylus axei* and *Oesphagostomum radiatum*), high ambient temperatures (Burns *et al.* 1986) and Bovine Infectious Keratoconjunctivitis (BIK) (Burns *et al.* 1988*b*). Buffalo fly (*Haematobia irritans exigua*) has not been considered a problem, as large population numbers are evident for only a few weeks of each year. Occasional outbreaks of ephemeral fever occur.

Animals

The experimental animals were heifers bred over 3 consecutive years from single sire matings. There were a total of 172 240 and 216 heifers branded in 1984, 1985 and 1986, respectively. All heifers were of known parentage (Table 2) from which heifer breed composition was calculated. Heifers belonged to 1–4 genotype categories: high grade Simmental (HGS), purebred Hereford (H), Hereford x Shorthorn (HSH), and grade Belmont Red (BR), according to their respective sire breed.

Table 3 presents the number of sires used and the number of progeny generated in each genotype category for each heifer year group. In general, sires were not represented in more than 1 year. However, 2 Simmental and 2 Africander x Hereford sires were present in both 1985 and 1986. There were no comparative performance data available for the commercial or stud Hereford sires or for the F5 *et seq.* generation Hereford x Shorthorn sires. Simmental sires used to produce 1984, 1985 and 1986 branded heifers had liveweight for age ratios in their herds of origin ranging from 93 to 111, 84 to 117 and 90 to 110, respectively. The BR sires used to produce the 1984, 1985 and 1986 heifer groups had yearling liveweight for age ratios in their herd of origin ranging from 91 to 106, 96 to 117 and 96 to 107, respectively.

Vaccination against babesiosis and anaplasmosis was carried out at weaning and 6 weeks post-weaning. Calves were vaccinated against blackleg (*Clostridium chauvoei*) and tetanus (*C. tetani*) at branding and again at weaning.

Experimental measurements

In this study 3 adaptive traits (tick and helminth burdens, and rectal temperature) and 1 productive trait (growth) were measured for each of the experimental heifers. Data for heifers from each year group were collected from birth to about 18 months of age. Birth dates and liveweights were recorded. Unfasted liveweights were measured at 4–6 weekly intervals from weaning to 18 months of age.

During summer, when the heifers' (12–15 months of age) resistance to ticks is the greatest (Wharton *et al.* 1970), heifers were artificially infested with 1 g of tick larvae (about 20 000 larvae) on 2 separate occasions, using tick collars. Engorging female ticks between 4.5 and 8.0 mm in length on the left side of each animal were counted 20 and 21 days after each infestation.

Helminth burdens of the heifers were based on counts of helminth eggs from 4 grab samples taken at 4–6 weekly intervals from early spring to summer (7–12 months of age), using a modification of the McMaster technique (Whitlock 1948). Each of the 4 samples was expressed as the number of eggs per gram of faeces (EPG).

Rectal temperature was measured to assess the effect of environmental temperature on heat tolerance and growth performance. Heat tolerance may be defined as the ability to maintain normal body temperature in a hot environment (Turner 1984). Although rectal temperature is used as a measure of heat tolerance, it is a measure of

Table 2. Parental genotypes used to generate experimental heifers

Parental genotypes		Experimental heifers
Sire	Dam	
Purebred Simmental	1/2 Simmental x 1/2 Hereford 3/4 Simmental x 1/4 Hereford 7/8 Simmental x 1/8 Hereford	HGS (high grade Simmental; i.e. ≥3/4 Simmental with residual Hereford)
Purebred Hereford	Purebred Hereford	H (purebred Hereford)
F5 *et seq.* Hereford x Shorthorn	Purebred Hereford	HSH (3/4 Hereford x 1/4 Shorthorn)
F2 *et seq.* Africander x Hereford	F1 *et seq.* Africander x Hereford F2 *et seq.* Africander x Hereford (majority)	BR (grade Belmont Red)

Table 3. Number of sires used and number of progeny generated in each genotype category for each heifer group

Genotype	1984 heifers		1985 heifers		1986 heifers	
	No. of sires	No. of progeny	No. of sires	No. of progeny	No. of sires	No. of progeny
HGS	6	50	8	72	5	50
H	4	39	3	42	4	44
HSH	2	20	2	30	2	26
BR	6	63	6	96	8	96
Total	18	172	19	240	19	216

overall thermal tolerance; heat production and absorption as well as heat dissipation. To ensure that heifers (12–15 months of age) were adequately heat stressed at the time of measurement, temperatures were recorded during the hottest months of summer (November–February) and during the hottest period of the day (1300–1500 hours). As body temperature is greatly influenced by metabolism, which has a residual effect for 4–6 h (Turner 1982), heifers were mustered early in the day and held off feed and water for about 5 h before recording temperatures.

Rectal temperatures were measured using a Bailey's (Model BAT-12) Microprobe Electronic Thermometer with a short response time at a rate of about 120 heifers/h. The order in which heifers were measured was recorded to detect environmental differences between heifers associated with time of measurement and the waiting time until measurement.

Rectal temperatures were measured on 10 occasions for the 1984 branded heifers, on 5 occasions for the 1985 heifers and on 7 occasions for the 1986 heifers. The average (over all recording dates within each year group) of the ambient temperature (mean ± s.e.) at the yards at the start of data recording was 35.6 ± 0.42°C, 34.9 ± 0.51°C, and 35.3 ± 0.17°C for the 1984, 1985 and 1986 heifer groups, respectively.

Statistical analyses

Dam age was categorised into 3 groups: 2- and 3-year-olds (young), 4–6-year-olds (mature) and 7–10-year-olds (old). This grouping was chosen to give similar numbers in each cell for breed of sire by dam age classes, and to ensure there were always animals present for each class.

As each sire was generally present for only 1 year, sires were almost completely confounded with year (i.e. heifer group). For simplicity, the 2 Simmental and 2 Africander sires that were used in both 1985 and 1986 were treated as if they were different sires and therefore completely confounding years with sires.

The tick counts made on days 20 and 21 post-infestation were totalled for each of the 2 infestations made on each of the heifer groups. These totals were $\log_e(x + 1)$ transformed and then averaged across the 2 infestations (MLTKS, mean $\log_e$ tick counts). The data were $\log_e$ transformed to remove the dependency of the variance on the mean.

A $\log_e$ transformation was applied to the helminth data of each of the 4 samples taken for each heifer group so as to control heterogeneity of variance. The mean of the transformed data of the 4 samples was then calculated (MLEPG, mean $\log_e$ EPG).

Rectal temperatures at each recording occasion for each year group were linearly regressed on crush order to adjust for the length of time a heifer had to wait before measurement. Rectal temperatures have been shown not to be normally distributed, with variance increasing with mean temperature (Turner 1982, 1984). The transformations $\log_e$(temperature – 37°C) and $\log_e$(temperature – 38°C) were found to control heterogeneity of variance in the data sets that were discussed by Turner (1982, 1984). Preliminary analyses of rectal temperature, adjusted for crush order, at each sampling occasion revealed that the $\log_e$(temperature – 38°C) transformation controlled heterogeneity of variance in the present data set. The transformed temperatures were then averaged across all recording occasions within each year group (MLTEMP, mean $\log_e$ rectal temperature).

Age-corrected liveweights at weaning (7 months of age, i.e. ACW 7), 12 months of age (ACW 12) and 18 months of age (ACW 18) were defined as:

$$\text{Age-corrected liveweight} = \left(\frac{\text{weight} - \text{birth weight}}{\text{age at weighing}}\right) \times \left(\begin{matrix}\text{average age of}\\ \text{group at weighing}\end{matrix}\right) + \left(\begin{matrix}\text{birth}\\ \text{weight}\end{matrix}\right)$$

Average daily gains from weaning to 12 months (ADG 7–12) and 12–18 months (ADG 12–18) were also calculated.

The growth variables (ACW 7, ACW 12, ACW 18, ADG 7–12 and ADG 12–18) and the adaptive traits (MLEPG, MLTKS and MLTEMP) were modelled by residual maximum likelihood (REML) using the GENSTAT statistical package (Genstat 5 Committee, 1993). All models included the fixed effects of breed, dam age and the breed x dam age interaction and the random effects of year (i.e. heifer group), breed x year, sire within breed x year and the residual error. Models for the adaptive traits of ticks and helminths also included the effects of weight at weaning (wt-wean) and age at weaning (age-wean) as covariates and their corresponding interactions with the main effects of breed and dam age. A stepwise procedure was used to eliminate non-significant (P>0.05) interactions and covariates using the REML likelihood ratio test of Welham and Thompson (1992) to assess the significance of terms in the model.

Results and discussion

There was significant genotype × year (i.e. heifer group) variation for all growth variables and for MLTEMP. This variation appeared to be due to the BR being less influenced by year (i.e. across heifer groups) than other genotypes. There was no significant genotype × dam age interaction for any of the growth or adaptive trait variables so the interaction was excluded from all models.

Tick resistance

The HGS were the most susceptible to ticks and the BR the least susceptible (P<0.01; Table 4). The lower tick burdens of the BR compared with the HSH, H and HGS genotypes partially accounts for this genotype's better growth (Burns *et al*. 1988*a*). Interestingly, the HSH had lower tick burdens than the HGS, which is possibly a consequence of the selection of the HSH for growth in a tick infested environment with no control of ticks.

Age at weaning was significantly (P<0.01) correlated with tick burdens with older calves having greater tick counts. Sularsasa (1985) observed that an association between tick counts and age was influenced by seasonal tick burdens, as tick counts increased with age only at times of high levels of tick infestation. This is not consistent with the results of this study, as an association between age at weaning and tick count was detected even though tick burdens were never very severe. This association between age at weaning and tick count may be explained by younger calves still receiving maternal antibodies from their dams compared with older calves which would be partially weaned before weaning and therefore largely independent of their dam's milk supply.

Tick burdens were also influenced (P<0.01) by the age of the dam with heifers from young dams having lower tick burdens than those of mature or old dams (4.44 *v*. 4.74). Similar results were observed by Frisch and O'Neill (pers. comm.) in beef cattle breeds of African (Belmont Red and Boran and Tuli crossbreds), European and Indian origins at Belmont Research Station, Rockhampton. However, we can find no obvious reason for this observation.

Helminth resistance

No significant difference (P>0.05) in MLEPG, and hence in EPG counts, was observed among genotypes (Table 4). This is in agreement with the findings of other studies (Turner and Short 1972; Seifert 1977). However, Frisch and Vercoe (1984), and Entwistle and Goddard (1984) have reported significant breed differences for post-weaning EPG counts in Hereford × Shorthorn, Brahman and Brahman × Hereford–Shorthorn animals at Rockhampton, Central Queensland, and in F2 generation 3/4 Africander-cross, F1 generation 3/4 Sahiwal × 3/4 Africander-cross and F2 generation 3/4 Brahman-cross animals in North Queensland, respectively. Our comparison lacked a *Bos indicus* genotype which was the source of improved resistance in other studies. The Africander is similar in helminth resistance to other *Bos taurus* genotypes, hence the similar results observed between the genotypes in this study. EPG counts are

Table 4. Overall means (± s.e.) and significance of effects for helminth burdens (MLEPG), tick burdens (MLTKS) and rectal temperature (MLTEMP) across the three heifer groups

HGS, high grade Simmental; H, Hereford; HSH, Hereford × Shorthorn; BR, Belmont Red
Numbers in parentheses are back-transformed means
Means within columns followed by the same letter are not significantly different at P = 0.05

	Ticks		Helminths		Temperature	
	n	Mean	*n*	Mean	*n*	Mean
Overall mean ± s.e.	628	4.64 ± 0.131(103)	618	5.00 ± 0.260 (149)	604	0.495 ± 0.109 (39.6)
Breed						
HGS	172	5.48a (239)	172	5.04 (153)	166	0.645a (39.9)
H	125	5.14b (170)	124	5.03 (152)	121	0.633a (39.9)
HSH	76	4.62c (100)	75	4.91 (135)	72	0.520a (39.7)
BR	255	3.33d (27)	247	5.04 (153)	245	0.180b (39.2)
Average s.e.		0.163		0.267		0.122
Significance		**		n.s.		**
Covariate						
Age-7 ± s.e.		0.004579 ± 0.001885		–0.007692 ± 0.001649		
Significance		**		**		

* P<0.05; ** P<0.01; n.s. not significant.

influenced by the age of the animal at sampling with different breeds developing resistance at different ages, level of helminth infestation and nutritional status of the pasture (Turner and Short 1972). These factors may also contribute to the different experimental results with different genotypes, and need to be considered when attempting to differentiate between breeds.

The lower (*P*<0.01) MLEPG counts recorded in older heifers (Table 4) is in agreement with the findings of Sularsasa (1985), and reflects an increased immunity with age and exposure. At pre-weaning, the older calves grazed pasture as well as suckling, compared with the younger calves which were suckling only. Therefore, through grazing, the older animals were exposed to helminths and may have developed some immunity resulting in lower EPG counts.

Heat tolerance

The HGS recorded similar rectal temperatures to both the H and HSH while the BR had lower (*P*<0.01) rectal temperatures than the other genotypes (Table 4). The lower rectal temperatures reported for the BR in this experiment is a reflection of their evolution in, and hence their adaptation to, hot environments (Burns *et al*. 1988*a*).

Across all breeds a negative relationship between weight at weaning and MLTEMP was observed (*P*<0.01) with MLTEMP being lower for heavier heifers (i.e. the greater the mass of an animal, the longer it takes to heat up). Small calves have a high surface area relative to mass and therefore heat up more rapidly and cool more rapidly in response to environmental changes in ambient temperature.

Selection for low rectal temperature, if it reflects a low heat production, may have a negative effect on production. However, combined selection for low rectal temperature and high growth rate in tropical and subtropical environments, should progress both traits; i.e. heat tolerance and growth rate.

Growth

At weaning, the HGS were heavier (*P*<0.01) than the other 3 genotypes considered in the study. However, by 18 months of age there was little difference in the weights of the HGS and BR. The HSH were heavier than the H which recorded the lightest weights (Table 5). The heavier (*P*<0.01) weaning weights (ACW 7) observed for the HGS compared with the other genotypes in this experiment concurs with previous research in less stressful environments (Mason 1971; Thompson *et al*. 1981; Darnell *et al*. 1987). This superior pre-weaning growth of the HGS is, in fact, a reflection of the high mature size (growth potential) and the high milking ability of the HGS dams (Mason 1971). Post-weaning, dam effects evident at weaning are overridden by other environmental influences. This period is therefore more indicative of the individual’s and genotype’s ability to perform in the subtropical environment of the Brigalow Research Station. During the first dry season following weaning (heifers at 7–12 months of age), the HGS had lower (*P*<0.01) growth (ADG 7–12) than the other 3 genotypes indicating the relatively large maternal influence on the pre-weaning performance. There was also a compensatory effect for heifers from younger dams (*P*<0.05). During the following wet season (heifers at 12–18 months of age), when pasture growth was good but tick and helminth burdens were heaviest and high ambient temperatures were experienced, the more tick resistant and heat tolerant BR had higher (*P*<0.05) growth than the other genotypes. By 18 months of age

Table 5. Overall means (± s.e.) and significance of effects for weight and growth across the three heifer groups

ACW, age-corrected weight; ADG, average daily gain; HGS, high grade Simmental; H, Hereford; HSH, Hereford x Shorthorn; BR, Belmont Red
Means within columns followed by the same letter are not significantly different at *P* = 0.05

	n	ACW 7	ACW 12	ACW 18	ADG 7–12	ADG 12–18
Overall mean ± s.e.	628	196.5 ± 9.9	215.9 ± 9.5	307.3 ± 12.7	0.123 ± 0.034	0.530 ± 0.077
Breed						
HGS	172	227.6a	234.7a	322.7a	0.049a	0.511a
H	125	182.0b	203.9b	287.9c	0.135b	0.488a
HSH	76	188.7b	212.3b	302.1bc	0.144b	0.521a
BR	255	187.7b	212.6b	316.5ab	0.162b	0.601b
Average s.e.		10.8	10.2	13.6	0.036	0.079
Significance		**	*	*	**	*
Age of dam						
Young	154	190.3a	214.3a	306.5a	0.143a	0.535a
Mature	259	200.0b	218.9b	310.1a	0.122b	0.529a
Old	215	199.2b	214.4a	305.4a	0.103c	0.527a
Average s.e.		10.0	9.5	12.8	0.035	0.077
Significance		**	*	n.s.	**	n.s.

* *P*<0.05; ** *P*<0.01; n.s. not significant.

the liveweight advantage of the HGS at weaning compared with the BR was no longer evident. It is speculated that in subsequent wet seasons the more tick resistant and heat tolerant BR genotype should show a similar growth advantage over the HGS genotype, as was demonstrated in growth from 12 to 18 months of age. This should result in BR genotypes attaining target market weights at younger ages.

The patterns of growth observed in this study are consistent with those of Thompson *et al*. (1981) and Darnell *et al*. (1987) who also found that the higher growth rates of high grade large European or large European crossbreds were not fully expressed when compared with tropically adapted genotypes, such as the BR, under more stressful environmental conditions. Furthermore, the significantly lighter 18-month-old weights of the unadapted H and HSH genotypes compared with the HGS and BR reflects both the inability of these genotypes to cope with this subtropical environment and their lower mature size (growth potential).

Conclusions

In this study, the HGS recorded heavier weaning and 12-month-old weights compared with the other genotypes, however, by 18 months of age there was no difference in the weights of the HGS and BR genotypes, with the HSH intermediate and the H the lightest. On the other hand, the HGS were the least heat tolerant and tick resistant, with all genotypes displaying similar helminth resistance. Because of their higher mature size, the HGS was still capable of competing with smaller breeds for growth despite being relatively tick and heat susceptible. The southern Brigalow belt of Central Queensland can be considered to be relatively benign in terms of nutritional and other components of environmental stresses compared with the harsher coastal tropical environments of Australia. In environments with higher parasite and heat loads than those experienced in this study the HGS could be expected to grow slower than better adapted breeds.

The large, late maturing HGS genotype demonstrated its inherently higher mature size by its growth in this environment compared with other genotypes of lower mature size (H and HSH). Although BR and HGS had similar weights at 18 months of age, it is speculated that the BR genotype's ability to cope with environmental stress in subsequent wet seasons should result in the BR genotype reaching target market weights at younger ages.

While the modification of this environment would enable high mature size, unadapted genotypes, particularly the HGS, to further express their growth potential, in practice the cost of labour and other operating costs would make this option less attractive. Because the BR demonstrated superior adaptive trait performance and as high or higher growth performance at 18 months of age than the HGS (and the other British *Bos taurus* genotypes), it would be the more efficient option in this subtropical environment as far as growth is concerned.

Acknowledgments

The authors acknowledge the efforts of R. Webber, C. Esdale and T. James in the collection of the data for this experiment and also K. Pattel for her preparation of this paper.

References

Burns, B. M., Howitt, C. J., and Esdale, C. R. (1986). Relationships between adaptive traits and weight in different cattle breeds. *Proceedings of the Australian Society of Animal Production* **16**, 163–6.

Burns, B. M., Vercoe, J. E., and Holmes, C. R. (1988*a*). Productive and adaptive trait differences of Simmental, Hereford and Africander x Hereford cattle. *Journal of Agricultural Science, Cambridge* **III**, 475–80.

Burns, B. M., Howitt, C. J., and Esdale, C. R. (1988*b*). Bovine Infectious Keratoconjunctivitis in different cattle breeds. *Proceedings of the Australian Society of Animal Production* **17**, 150–3.

Darnell, R. E., Hearnshaw, H., and Barlow, R. (1987). Growth and carcass characteristics of crossbred and straightbred Hereford steers. III. Post-weaning growth in seven environments in New South Wales. *Australian Journal of Agricultural Research* **38**, 941–55.

Entwistle, K. W., and Goddard, M. E. (1984). Productivity of some *Bos indicus* cross genotypes in sub-coastal northern Queensland. *In* 'ACIAR Proceedings No. 5, Evaluation of Large Ruminants for the Tropics'. (Ed. J. W. Copland.) pp. 156–60. (Australian Centre for International Agricultural Research: Canberra.)

Frisch, J. E., and O'Neill, C. J. (1997). Comparative evaluation of beef cattle breeds of African, European and Indian origins. II. Resistance to cattle ticks and gastrointestinal nematodes. *Animal Science* (in press).

Frisch, J. E., and Vercoe, J. E. (1984). An analysis of growth of different cattle genotypes reared in different environments. *Journal of Agricultural Research, Cambridge* **103**, 137–53.

Genstat 5 Committee (1993). 'Genstat 5 Release 3 Reference Manual.' (Clarendon Press: Oxford.)

Joubert, D. M., Eloof, H. P., Lindemann, C. J. F., Eden, D. W., and Badenhorst, J. F. G. (1977). On the performance of Simmental cattle in South African livestock research programmes. *World Review of Animal Production* **13**, 63–74.

Mason, I. L. (1971). Comparative beef performance of the large cattle breeds of western Europe. *Animal Breeding Abstracts* **39**, 1–29.

Seifert, G. W. (1977). The genetics of helminth resistance in cattle. *In* 'Proceedings of the 3rd International Congress of the Society of Advancement of Breeding Research in Asia and Oceania'. pp. 7-4–8. (SABRAO: Canberra.)

Speck, N. H., Wright, R. L., Sweeney, F. C., Nix, H. A., and Perry, R. A. (1968). Part III. Land Systems of the Dawson–Fitzroy Area. *In* 'Lands of the Dawson–Fitzroy Area, Queensland. Land Research Series No. 21'. pp. 17–25. (CSIRO: Australia.)

Sularsasa, D. (1985). Genetic variation and correlations between bodyweights, growth, adaptive and reproductive traits in tropical beef cattle. PhD Thesis, James Cook University of North Queensland, Townsville.

Thompson, J. M., Barlow, R., Johnston, B., and Nicholls, P. J. (1981). Growth and carcass characteristics of crossbred and straightbred Hereford steers. 1. Post-weaning growth. *Australian Journal of Agricultural Research* **32**, 161–70.

Turner, H. G. (1982). Genetic variation of rectal temperatures in cows and its relationship to fertility. *Animal Production* **35**, 417–27.

Turner, H. G. (1984). Variation in rectal temperature of cattle in a tropical environment and its relationship to growth rate. *Animal Production* **38**, 417–27.

Turner, H. G., and Short, A. J. (1972). Effects of field infestations of gastro-intestinal helminths and of the cattle tick (*Boophilus microplus*) on growth of three breeds of cattle. *Australian Journal of Agricultural Research* **23**, 177–93.

Welham, S. J., and Thompson, R. (1992). REML likelihood ratio tests for fixed model terms. *In* ‘Royal Statistical Society Conference’. University of Sheffield, 9–11 September 1992. Abstracts of papers.

Wharton, R. H., Utech, K. B. W., and Turner, H. G. (1970). Resistance to the cattle tick, *Boophilus microplus* in a herd of Australian Illawarra Shorthorn cattle: its assessment and heritability. *Australian Journal of Agricultural Research* **21**, 163–81.

Whitlock, H. V. (1948). Some modifications of the McMaster helminth egg-counting technique and apparatus. *Journal of the Council of Scientific and Industrial Research Australia* **21**, 177–80.

Received 16 September 1996, accepted 9 April 1997