The influence of stocking rate, range condition and rainfall on seasonal beef production patterns in the semi-arid savanna of KwaZulu-Natal

G.P. Hatch* and N.M. Tainton
Department of Range and Forage Resources, University of Natal, P.O. Box X01, Scottsville 3209, South Africa

Received 13 October 1995; accepted 8 August 1997

Grazing trials were established at two sites in the semi-arid savanna (Lowveld) of KwaZulu-Natal. The sites differed initially in range composition. Llanwarne was dominated by *Themeda triandra*, *Panicum maximum* and *P. coloratum*, and Dordrecht by *Urochloa mosambicensis, Sporobolus nitens* and *S. iocladus*. Three treatments at each site were stocked with Brahman-cross cattle to initially represent 'light' (0.17 LSU.ha^{-1}) 'intermediate' (0.23 LSU.ha^{-1}) and 'heavy' (0.30 LSU.ha^{-1}) stocking. Cattle mass data collected over 116 three-week periods were used to develop a step-wise multiple linear regression model where summer mass gain (kg.ha^{-1}) was significantly related ($p < 0.01$) to total seasonal rainfall (mm) (measured 1 July to 30 June) and stocking rate (LSU.ha^{-1}). Winter mass loss (kg.ha^{-1}) was related to residual herbage mass at the end of summer (kg.ha^{-1}) and the length of winter (days). Although range condition did not significantly influence summer mass gain, winter mass loss was inversely related to residual herbage at the end of summer, which suggested that grass species in the Lowveld may differ in production potential rather than in quality.

Weidingsproewe is op twee terreine in die semi-droë savanna (Laeveld) van KwaZulu-Natal uitgevoer. Die terreine het aanvanklik verskillende spesiesamestellings gehad. Llanwarne is gekenmerk deur *Themeda triandra, Panicum maximum* en *P. coloratum*, en Dordrecht deur *Urochloa mosambicensis*, *Sporobolus nitens* en *S. iocladus*. Op beide terreine is Brahmaankruise gebruik om drie veebeladings te verkry, 'n 'ligte' (0.17 GVE. ha^{-1}), 'intermediêre' (0.25 GVE. ha^{-1}) en 'n 'hoë' (0.30 GVE.ha^{-1}) veelading. Liggaamsmassa is oor 116 drieweek periodes gemeet en gebruik om 'n stapsgewyse, veelvuldige lineêre regressiemodel te ontwikkel. Massatoename in die somer (kg.ha^{-1}) was betekenisvol afhanklik van totale seisoenale reënval (mm) (gemeet tussen 1 Julie en 30 Junie) en veelading (GVE.ha^{-1}). Massaverlies gedurende die winter (kg.ha^{-1}) was afhanklik van residuele plantmateriaal (kg.ha^{-1}) aan die einde van die somer en die lengte (dae) van die winter. Alhoewel veldtoestand nie massatoename gedurende die somer beduidend beïnvloed het nie, was massaverlies gedurende die winter deur residuele plantmateriaal aan die einde van die somer beïnvloed. Dit mag aandui dat grasspesies in die Laeveld in produksiepotensiaal eerder as in kwaliteit verskil.

Keywords: summer livemass gain, winter livemass loss, modelling

* To whom correpondence should be addressed at: CSIR Division of Water, Environment and Forestry Technology, P.O. Box 17001, Congella, 4013. E-mail: ghatch@csir.co.za

Introduction

Although stocking rate influences individual animal performance (Mott, 1960; Riewe, 1961; Jones & Sandland, 1974), livestock production in semi-arid systems is strongly influenced by temporal rainfall variability (McDonald, 1982; O'Connor, 1985; Ellis & Swift, 1988; Hatch & Tainton, 1995). This paper examines the relationship between rainfall, range condition, stocking rate and livestock production patterns in the semi-arid savanna, with the aim of developing a model to predict seasonal patterns of livemass change.

Procedure

Grazing trials were established at two adjacent sites in the semi-arid savanna (Lowveld) of KwaZulu-Natal. Data were collected over a seven-year period (1986–1993). The sites differed in range composition. Llanwarne (27°35'S; 31°45'E, 320 m a.s.l.) was dominated by *Themeda triandra, Panicum maximum* and *P. coloratum* and considered to be in good condition for cattle production. Dordrecht (27°36'S; 31°46'E, 320 m a.s.l.), was initially dominated by *Urochloa mosambicensis, Sporobolus nitens* and *S. ioclados*, and was considered to be in poor condition for cattle production. Soils of the Komatipoort System, predominantly of the Swartland form with Clovelly, Hutton, Mispah, Glenrosa and Bonheim forms, occurred at the sites (Soil Classification Working Group, 1991).

Three treatments at each site were stocked at the start of each season (October) with 250 kg Brahman-cross cattle to represent 'light' (0.17 LSU.ha^{-1}), 'intermediate' (0.23 LSU. ha^{-1}) and 'heavy' (0.30 LSU.ha^{-1}) stocking. [LSU denotes large stock unit as defined by Meissner, et al. (1983).] Seven and eight steers were allocated to the light and intermediate treatments, and eight and nine to the heavy treatments, at Dordrecht and Llanwarne respectively. The area of land allocated to each treatment was varied to provide the required range in stocking rates. Game, primarily impala (*Aepyceros melampus*), nyala (*Tragelaphus angasii*), kudu (*Tragelaphus strepsiceros*) and warthog (*Phacochoerus aethiopicus*), occurred at both sites. The actual cattle stocking rates applied in each season were calculated for the summer and winter using the animal unit equivalents approach of Aldermann & Barber (1973). A two-paddock rotational grazing system for each stocking rate treatment gave a total of six paddocks per site. Paddocks received alternate spring and autumn rests. The period of stay depended on the season and was therefore variable. Cattle were weighed at three-weekly intervals (from November 1986 to June 1993) after being starved overnight. Herbage mass was estimated at each recording date as the mean of 50 readings, recorded with a pasture disc-meter

(Bransby & Tainton, 1977), on a fixed diagonal transect in each camp. Mean disc-meter heights for each camp were converted to an estimate of herbage mass (kg.ha^{-1}) using the generalised calibration equation developed for the two sites by Turner (1990), where herbage mass (kg.ha^{-1}) = 882 + 271* (mean disc height in cm). Patterns in herbage mass consequently followed mean disc-meter heights.

Range condition was assessed in 1986, 1988, 1990, 1993 and 1994 using the nearest-plant method (Foran *et al.*, 1978) to collect 150 points at 3-m intervals on each of two fixed transects, from which proportional species composition was calculated for each paddock following the nomenclature of Gibbs Russell, *et al.* (1990). Range condition was indexed as the sum of the proportions of three key forage species, *T. triandra, P. maximum* and *P. coloratum* (Table 1). Daily rainfall (mm) records were kept for each site and total seasonal rainfall was calculated from 1 July to 30 June.

A step-wise multiple linear regression approach (Steel & Torrie, 1981) was used to reflect the influence of stocking treatment (LSU.ha^{-1}), range condition and total seasonal rainfall (mm) (recorded from 1 July to 30 June) on summer mass gain (kg.ha^{-1}). A winter loss model examined the influence of residual summer herbage mass (kg.ha^{-1}) and the length of the winter period (days) (defined as the number of days between the last rainfall event of >15 mm in summer and the first rainfall event of an equivalent amount in the following spring) on winter livemass loss (kg.ha^{-1}). The period over which herbage accumulation continued after the last date in summer on which >15 mm of rain was recorded, and the delay before recorded herbage accumulation occurred after the date on which >15 mm of rain was recorded in spring, were therefore assumed to be equal.

Table 1 The sum of proportions of three key forage species (*T. triandra, P. maximum* and *P. coloratum*) in each of the light (L), intermediate (M) and heavily (H) stocked paddocks during the 1986, 1988, 1990, 1993 and 1994 surveys at Llanwarne and Dordrecht

	Llanwarne						Dordrecht					
Survey	L1	M1	H1	L2	M2	H2	L1	M1	H1	L2	M2	H2
1986	52	36	49	42	43	40	5	22	8	15	26	24
1988	54	53	34	45	40	27	18	15	29	32	39	
1990	56	57	48	52	39	36	64	39	35	45	39	51
1993	45	50	56	63	50	37	52	60	47	39	23	51
1994	56	52	51	70	58	47	44	72	21	40	39	34

Results and discussion

Total seasonal rainfall patterns reflected considerable spatial and temporal variability (Figure 1), where the mean for the seven-year period was 569 mm and 612 mm at Llanwarne and Dordrecht respectively. Rainfall was slightly below the long-term mean of 518 mm at each site during the 1986/87 season, consistently higher for the 1987/88 to 1990/91 seasons and considerably below the mean during the 1991/92 season (Figure 1). Rainfall patterns within seasons are presented in detail by Hatch & Tainton (1995).

Livemass gain per individual animal (kg.LSU^{-1}) tended to decrease and gain per unit area (kg.ha^{-1}) increase as stocking

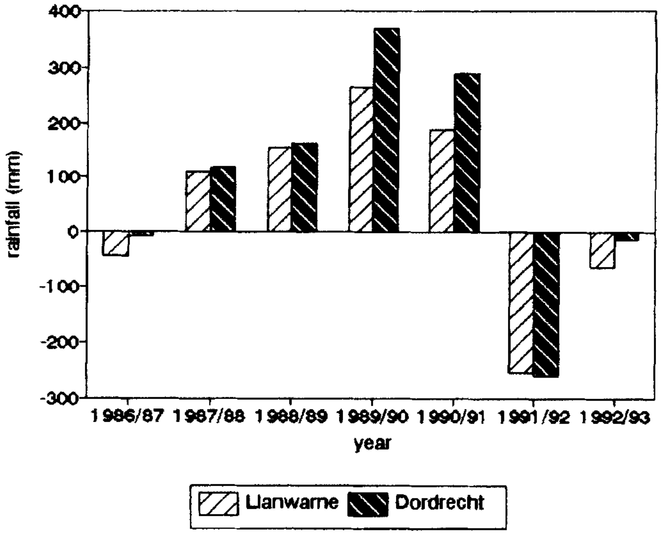

Figure 1 Variation in total seasonal rainfall (mm) about the long-term mean of 518 mm at Llanwarne and Dordrecht.

Table 2 Summer livemass gain and winter mass loss per individual animal (kg.LSU^{-1}) and per hectare (kg.ha^{-1}) for 'light' (L) (0.17 LSU.ha^{-1}), 'intermediate' (M) (0.23 LSU.ha^{-1}) and 'heavy' (H) (0.30 LSU.ha^{-1}) stocking at Llanwarne and Dordrecht

		Llanwarne				Dordrecht			
		Summer		Winter		Summer		Winter	
Season[1]	Treat.	/LSU	/ha	/LSU	/ha	/LSU	/ha	/LSU	/ha
1986/87	L	174	29.6	11	1.9	173	26.0	3	0.5
	M	161	40.3	15	3.8	158	30.0	4	0.8
	H	158	47.4	17	5.1	148	38.5	21	5.5
1987/88	L	231	34.7	11	1.7	225	42.8	13	2.5
	M	233	53.6	21	2.5	247	64.2	19	4.9
	H	246	78.8	33	10.6	229	71.0	21	6.5
1988/89	L	224	33.6	0	0.0	201	28.1	1	0.1
	M	207	43.5	0	0.0	198	33.7	1	0.2
	H	199	55.7	0	0.0	193	42.5	1	0.2
1989/90	L	182	27.3	10	1.5	197	33.5	4	0.7
	M	176	38.7	14	3.1	188	39.5	18	3.8
	H	153	39.8	21	5.5	177	47.8	18	4.9
1990/91	L	226	33.9	4	0.6	213	32.0	1	0.2
	M	221	48.6	1	0.2	215	40.9	4	0.8
	H	220	61.6	3	0.8	212	53.0	3	0.8
1991/92	L	154	23.1	38	5.7	200	36.0	72	13.0
	M	136	28.6	41	8.6	167	36.7	51	11.2
	H	147	42.6	36	10.4	150	40.5	62	16.7
1992/93	L	215	30.1	0	0.0	224	38.1	0	0.0
	M	224	49.3	8	1.8	188	37.6	52	12.0
	H	202	54.5	29	8.7	192	50.5	45	13.5

rates increased across treatments. Livemass gain was influenced by rainfall patterns (Hatch & Tainton, 1995) and decreased summer gains were evident for drier seasons (1986/87, 1991/92) (Table 2). Patterns of winter mass loss (kg.LSU^{-1}) reflect little difference between stocking treatments and sites, with the exception of the 1991/92 season where losses were substantial. Losses invariably increased as stocking rates were increased at both sites. Supplementary feeding (sugar-cane tops at 20 kg.LSU^{-1}.d^{-1}) for all stocking treatments during the winter of 1992 and for the intermediate and heavy stocking treatments at Dordrecht during the winter of 1993, restricted mass loss at these times.

The length of the period (days) over which cattle gained mass tended to be longer at Llanwarne (302 ± 65) than at Dordrecht (269 ± 33) (Table 3), so that the length of the period of mass loss was shorter at Llanwarne (51 ± 44) than at Dordrecht (86 ± 32). Average daily gains (ADG) were consequently lower at Llanwarne than at Dordrecht given similar mass gain for the summer, but cattle continued to gain mass for a longer period in each season at Llanwarne.

Table 3 The length of the period (days) of summer mass gain and winter loss at Llanwarne and Dordrecht (November 1996 to June 1993)

	Site			
	Llanwarne		Dordrecht	
Season	Gain	Loss (days)	Gain	Loss (days)
1986/87	189	85	253	63
1987/88	357	21	252	105
1988/89	357	0	273	84
1989/90	294	63	252	121
1990/91	348	42	327	42
1991/92	231	126	231	126
1992/93	336	126[a]	294	126[a]

[a] Period of winter mass loss in 1993 ends outside of study period (November 1996 to June 1993)

Development of a summer mass gain model

Summer livemass gain per hectare (kg.ha^{-1}) was significantly related ($p < 0.01$) to rainfall (mm) and stocking rate (LSU. ha^{-1}) (Table 3), but was not significantly related to range composition.

Predicting summer livemass gain

Summer livemass gain per hectare (kg.ha^{-1}) was related ($p <$ 0.01) to rainfall (mm) and stocking rate (LSU.ha^{-1}) (Table 4), but was not related to range composition (p>0.05). This suggested that a change from a *Themeda-Panicum* dominated to a *Urochloa-Sporobolus* dominated state may not be associated with reduced summer livemass gain, provided the amount of herbage does not become limiting. Importantly, the amount of residual summer herbage (kg.ha^{-1}) was directly related to the proportion of *T. triandra, P. maximum* and *P. coloratum* (Hatch & Tainton, 1995). Grass species in the semi-arid savanna may therefore differ in terms of production potential rather than quality. Changes in range composition may consequently influence patterns of winter mass loss rather than summer mass gain, provided intake is not restricted during the summer.

Table 4 A step-wise multiple linear regression model relating rainfall (mm) and stocking rate (LSU.ha^{-1}) to livemass gain per hectare (kg.ha^{-1})

Variables in model	Coefficient	t-value	r^2
Constant	–25.317706	–3.10 **	0.75 **
Rainfall	0.095159	3.42 **	
Rainfall^2	–0.000073	–2.88 **	
Stocking rate	180.861889	10.48 **	

** $p < 0.01$

The quadratic relationship between livemass gain per hectare and rainfall in this study implied that livemass gain would increase at a decreasing rate as rainfall increased, attain a maximum (at 700 mm) and then decline. This may be the consequence of an increased growth rate and hence increased stemminess of *T. triandra* and *P. maximum* during higher rainfall seasons. This would have acted to reduce the quality of intake and hence animal performance. In practice, range managers may increase stocking pressure to compensate for increased herbage production during wetter seasons by reducing the area grazed. This would reduce the extent of stem accumulation and allow utilisation of younger stem material. Accumulated herbage in ungrazed paddocks may then provide a drought reserve or be burnt to restrict bush thickening.

Despite considerable evidence to suggest that the relationship between stocking rate and livemass gain per unit area is quadratic (Mott, 1960; Cowlishaw, 1969; Conway, 1974; Jones & Sandland, 1974), at least until maximum gain is attained (Heitschmidt & Taylor, 1991), this tendency was not evident in this study. This was related to the restriction of stocking treatments to a range of likely economic stocking rates in this study (Hatch, 1994) which did not result in summer forage limitations. The stocking rate at which maximum gain per hectare would be reached was therefore calculated from the slope (a) and intercept (b) coefficients of the linear relationship between stocking rate and individual animal performance (Edwards, 1981) (Table 4).

The stocking rate at which maximum summer livemass gain per hectare would be attained (G_{max}) would be considerably higher at Dordrecht than at Llanwarne (Table 5). This difference may be attributed to the dominance of *S. iocladus* and *S. nitens* at the former, where the intake on less productive (and less stemmy) species may be higher during the summer than for more productive (and more stemmy) species such as *T. triandra* and *P. maximum*. Greater summer individual animal performance during drier seasons (1991/92) at Dordrecht than at Llanwarne (Table 2) may be the consequence of greater accessibility to higher quality forage at Dordrecht while cattle at Llanwarne were forced to select lower quality stem material. Importantly, despite higher summer production, even during drier seasons, little forage is likely to remain at the end of summer on range dominated pioneer species (Hatch & Tainton, 1995). This may account for the longer periods of winter mass loss at Dordrecht, which will influence the period over which supplementary feeding may be required to maintain animal condition.

Predicting winter livemass loss

Winter mass loss (kg.ha^{-1}) was negatively related ($p < 0.01$) to residual summer herbage mass (kg.ha^{-1}) and positively

Table 5 Calculation of the stocking rate ($LSU.ha^{-1}$) at which maximum gain per hectare (G_{max}) would be attained at Llanwarne and Dordrecht (based on the slope (a) and intercept (b) coefficients of significant ($p < 0.01$) linear relationships between stocking rate and average daily gain)

	Llanwarne				Dordrecht			
Season	a	b	r^2	G_{max}	a	b	r^2	G_{max}
1987	–0.84	1.13	0.99	0.37	–0.77	0.32	0.77	0.50
1988	–	–	–	*	–0.05	0.32	0.06	–
1989	–1.18	1.64	0.96	0.36	–2.25	2.66	0.99	0.39
1990	–0.80	1.02	0.82	0.39	–1.18	1.30	0.99	0.45
1991	–0.67	0.13	0.80	0.33	–1.17	2.02	0.85	0.29
1992	–0.59	0.59	0.12	–	–0.50	0.37	0.89	0.68
1993	–2.21	2.35	0.55	0.47	–0.58	0.41	0.47	0.71
Mean				0.37				0.50

* No negative relationship between stocking rate and average daily gain detected – data excluded.

Table 6 A step-wise multiple linear regression model relating residual summer herbage mass ($kg.ha^{-1}$) and the length of the winter (days) (from the last date in summer to the first date in the subsequent spring on which >15 mm of rain was recorded) to winter mass loss ($kg.ha^{-1}$)

Variables in model	Coefficient	*t*-value	r^2
Constant	8.209615	2.29 **	0.51 **
Winter length	0.037206	4.03 **	
Residual summer herbage mass	–0.002806	–2.43 **	

** $p<0.01$

related ($p < 0.01$) to winter length (days) (Table 6). Cumulative winter grazing days ($LSU.gd.ha^{-1}$) did not influence the extent of mass loss. This may be the consequence of rainfall and hence some growth during winter, supplementation during periods of forage deficit and the ability of the cattle to browse during adverse conditions. Residual herbage mass and the length of the winter would be unaffected by these factors.

As residual herbage mass was a function of cumulative summer grazing days ($LSU.gd.ha^{-1}$), rainfall (mm) and range condition (indexed as the sum of the proportions of *T. triandra, P. maximum* and *P. coloratum*) (Hatch & Tainton 1995), it can be implied that winter mass loss would be related to each of these factors. Although summer mass gain was not significantly related to range composition, the extent of winter mass loss may be strongly influenced by range condition through its effect on residual summer herbage mass (Figure 2).

Conclusions

Although winter mass loss was related to residual summer herbage and winter length, the relationship was confounded by winter rainfall, supplementation during drier seasons and the ability of the cattle to browse during adverse conditions. Although the winter model provides an indication of the factors which influence winter mass loss, it may be limited in its application. Addition of the amount of available browse during periods of forage deficit and estimates of browse intake in relation to stocking rate may consequently be important additions to allow the refinement of a winter mass loss model. The summer mass gain model, based on the relationship between rainfall and stocking rate and summer mass gain, may provide a useful tool to assess the influence of various stocking strategies on production risk through the incorporation of stochastic rainfall effects. Integration of the beef production model outlined in this study into an economic model may provide an indication of the influence of various stocking strategies on the probability of obtaining given levels of income and hence the risk associated with each strategy (e.g. Hatch *et al.*, 1995).

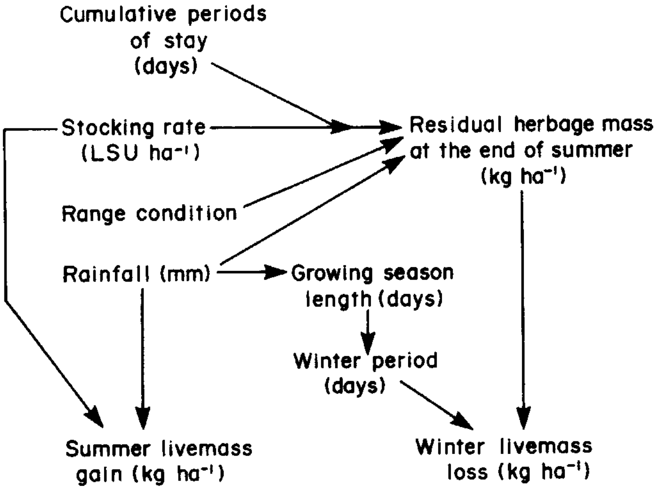

Figure 2 The relationship between the rainfall (mm), stocking rate ($LSU.ha^{-1}$), range condition (indexed as the sum of proportions of *Themeda triandra, Panicum maximum* and *P. coloratum*) and summer mass gain and winter mass loss ($kg.ha^{-1}$) in the semi-arid savanna of KwaZulu-Natal. LSU denotes large stock unit as defined by Meissner, *et al.* (1983).

Acknowledgements

Research funding provided by the Department of Agricultural Development, and the Range and Forage Institute; and the generous hospitality and assistance of Jannie and Rita Bender at Llanwarne Estates, Magudu is gratefully appreciated. Prof. J. van Ryssen, Department of Animal Science, University of Natal translated the abstract into Afrikaans.

References

ALDERMANN, G. & BARBER, W.P., 1973. A variable net energy system for beef animals. *Proc. VI Symp. on Energy Metabolism.* Stuggart.

BRANSBY, D.I. & TAINTON, N.M., 1977. The disc pasture meter: possible applications in grazing management. *Proc. Grassld Soc. sth. Afr.* 1, 25–28.

CONWAY, A.G., 1974. A production function for grazing cattle. 3. An estimated relationship between rate of liveweight gain and stocking rate for grazing steers. *Irish J. Agr. Econ. Rur. Soc.* 5, 43–55.

COWLISHAW, S.J., 1969. The carrying capacity of pastures. *J. Brit. Grassl. Soc.* 24, 207–214.

EDWARDS, P.J., 1981. Grazing management. In: Veld and pasture management in South Africa. (Ed.) Tainton, N.M. Shuter & Shooter, Pietermaritzburg.

ELLIS, J.E. & SWIFT, D.M., 1988. Stability of African pastoral systems: alternative paradigms and implications for development. *J. Range. Manage.* 41, 450–459.

FORAN, B.D., TAINTON, N.M. & BOOYSEN, P. de V., 1978. The development of a method for assessing veld condition in three grassveld types in Natal. *Proc. Grassld. Soc. Sth. Afr.* 13, 27–33.

GIBBS RUSSELL, G.E., WATSON, L., KOEKEMOER, M., SMOOK, L., BARKER, N.P., ANDERSON, H.M. & DALLWITZ, M.J, 1990. Grasses of southern Africa. Nat. Bot. Inst., Pretoria.

HATCH, G.P., 1994. The bioeconomic implications of various stocking strategies in the semi-arid savanna of Natal. Ph.D. thesis, University of Natal, Pietermaritzburg.

HATCH, G.P. & TAINTON, N.M.,1995. The influence of stocking rate, range condition and rainfall on residual herbage mass in the semi-arid savanna of KwaZulu-Natal. *Afr. J. Range For. Sci.* 12, 76–80.

HATCH, G.P., TAINTON, N.M. & ORTMANN, G.F., 1995. Assessing the risk of various stocking strategies in the semi-arid savanna of KwaZulu-Natal, South Africa. *Aust. Range. J.* 18(1), 136–143.

HEITSCHMIDT, R.K. & TAYLOR, C.A., 1991. Livestock production. In: Grazing management: an ecological perspective. (eds.) Heitschmidt, R.K. & Stuth, J.W. Timber Press, Portland.

JONES, R.J. & SANDLAND, R.L., 1974. The relation between animal gain and stocking rate. Derivation of the relation from the results of grazing trials. *J. Agric. Sci.* 83, 335–342.

MCDONALD, I.A.W. 1982. The influence of short-term climatic fluctuations on the distribution of savanna organisms in southern Africa. M.Sc. thesis, University of Natal.

MEISSNER, H.H., HOFMEYER, H.S., VAN RENSBURG, W.J.J. & PIENAAR, J.P., 1983. Classification of livestock for realistic prediction of substitution values in terms of a biologically defined Large Stock Unit. Technical Communication No. 175, Dept. of Agric., Pretoria.

MOTT, G.O., 1960. Grazing pressure and the measurement of pasture production. *Proc. 5th Int. Grassld Congr.* 606–611.

O'CONNOR, T.G., 1985. A synthesis of field experiments concerning the grass layer in the savanna regions of southern Africa. *S.A. Nat. Sci. Prog. Rep.* no: 14.

RIEWE, M.E., 1961. Use of the relationship of stocking rate to gain of cattle in an experimental design for grazing trials. *Agron. J.* 53, 309–313.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification: a binomial system for South Africa. Dept. Agric. Tech. Serv., Pretoria.

STEEL, R.G.D. & TORRIE, J.H., 1981. Principles and procedures of statistics: a biometrical approach. McGraw-Hill, Singapore.

TURNER, J.R.,1990. The development of stocking rate models for three veld types in Natal. Ph.D. thesis, Univ. of Natal, Pietermaritzburg.