Justification for grazing intensity experiments: Analysing and interpreting grazing data

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Abstract

Grazing trials in which treatments are compared at only 1 grazing intensity greatly outnumber those in which treatments are compared at several grazing intensities. This suggests that, compared to other treatments and the need for replication in grazing trials, researchers consider grazing intensity lower in priority. In this study, a regression modeling approach for analyzing and interpreting data was developed to enhance the value of grazing intensity trials. As an example, results from 5 irrigated bermudagrasses (*Cynodon dactylon* (L.) Pers) (Callie, Coastal, Brazos and experimental hybrids S-54 and S-16) which were continuously grazed without field replication by Santa Gertrudis steers at 4 grazing intensities were considered. The relationships between average daily gain (ADG) and stocking rate, ADG and herbage present (Mg/ha), and between stocking rate (animals/ha) and herbage present were well described by linear functions for all cultivars, with correlation coefficients (*r*) mostly above 0.9. Coefficients of determination (R^2) for linear regression models derived for ADG vs stocking rate, ADG vs herbage present, and stocking rate vs herbage present were 0.90, 0.89**, and 0.87**, respectively. Significant cultivar × grazing intensity (as measured by stocking rate or herbage present) interactions ($P \leq 0.01$) were observed. Furthermore, estimated stocking rates which provided maximum gain/ha ranged from 6.6 to 9.4 animals/ha, and the range in herbage present which provided maximum gain/ha was 0.35 to 1.95 Mg/ha. Callie provided an estimated maximum gain/ha of 881 kg/ha/season, while maximum gain/ha for the other cultivars ranged from 613 to 687 kg/ha/season. Comparison between these 5 cultivars at only 1 grazing intensity would have had very narrow application. The procedure described allowed statistical comparison of cultivars without replication, and inferences about the separate effects of forage quality and quantity on animal performance could be made. Herbage present and cultivar were descriptors of the pasture. Since there was a substantial range of values for herbage present and stocking rate, all important assumptions underlying linear regression were met and designs utilized in analysis of variance were not needed.**

Key Words: average daily gain, gain/ha, stocking rate, herbage present, *Cynodon dactylon*

An increase in stocking rate on continuously grazed pastures (for clarity, only continuous grazing is considered in this discussion) leads to increased frequency of plant defoliation, decreased stubble height, and reduced mass of herbage present/ha (herbage present). Collectively, these responses represent an increase in "grazing intensity," a term which incorporates both stocking rate and its effects on the pasture, as well as concepts such as grazing pressure. Since grazing intensity can be manipulated by adjusting animal numbers, it is a fundamental variable under the control of the grazier. Additionally, it has a pronounced effect on animal production and profit. Grazing intensity is therefore of very great importance to both producers and researchers.

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Brown and Waller (1986) have emphasized the undisputed value of replication in grazing studies. However, due to logistical and cost limitations, replication in grazing trials usually excludes grazing intensity or treatments other than grazing intensity. For example, most comparisons between replicated grazing treatments have included only one grazing intensity per treatment. Alternatively, grazing intensity trials have usually excluded other treatment comparisons. In other words, grazing intensity trials have usually been concerned mainly with the effects of grazing intensity per se, rather than the interaction of grazing intensity with other treatments: seldom has a number of treatments been compared at several grazing intensities. Consequently it appears that, with the exception of only a few researchers, inclusion of grazing intensity in grazing trials is considered lower in priority than additional treatments and the need for replication. Burns et al. (1970) emphasized some advantages of a multiple grazing intensity strategy, while Hart (1972) suggested that in certain cases it might be preferable to forfeit replication in favor of grazing each treatment at several grazing intensities. On the other hand, Walker and Richardson (1986) contend that despite the difficulties experienced with replication in grazing experiments, "the nonreplicated experiment should be considered the design of last resort." Disagreement therefore exists concerning the experimental design and approach which will optimize the value of data from grazing studies.

Riewe (1961) proposed a nonreplicated stocking rate design for grazing trials, but considered only 2 treatments each grazed at 3 stocking rates. However, his proposal received little subsequent support. The objectives of this paper are to justify wider use of grazing intensity experiments by (a) extending the approach of Riewe (1961) to include more than 2 treatments, and (b) developing an interpretive procedure that will enhance the value of grazing intensity trials which may or may not be replicated. As an example, previously published data (Conrad et al. 1981, Guerrero et al. 1984) from a nonreplicated grazing trial on 5 bermudagrasses (*Cynodon dactylon* (L.) Pers) each grazed at 4 grazing intensities are considered.

Procedure

Data Collection

Details of data collection have been abbreviated here because they have been published fully elsewhere (Conrad et al. 1981, Guerrero et al. 1984) and because the emphasis here is on analysis, interpretation, and modeling, rather than on the results of a particular field trial. The data presented, therefore, serve only as an example in pursuit of the objectives stated above.

The experimental site was 25 km west of College Station, Texas. "Callie", "Coastal," and "Brazos" bermudagrass and experimental hybrids S-16 and S-54 (hereinafter referred to as cultivars) which vary widely in growth habit (Burton et al. 1967) were grazed continuously in 0.25- to 1.21-ha pastures by Santa Gertrudis steers with a mean initial mass of 219 kg. Grazing started in May and ended in October during 1977, 1978, and 1979, lasting on average for 151 days. The put-and-take method, using 3 tester animals, was used to ensure a good spread of 4 grazing intensities on each cultivar. In February, pastures were mowed to remove residue from the previous year, and nitrogen was applied in equal amounts during March and July at a rate of 224 kg/ha annually.

Table 1. Regression constants and correlation coefficients (r) for 3 relationships (equations 1, 2 and 3) determined separately for data from 5 bermudagrasses.

	Regressions								
	ADG vs stocking rate			ADG vs herbage present			Stocking rate vs herbage present		
	General equations								
	$ADG = b_0 + b_1S$ (1)			$ADG = b_0' + b_1'H$ (2)			$S = b_0'' + b_1''H$ (3)		
Cultivar	b_0	b_1	r^{**}	b_0'	b_1'	r^{**}	b_0''	b_1''	r^{**}
Coastal	0.93	−0.050	−0.95	0.27	0.14	0.95	13.28	−2.73	−0.99
Callie	1.32	−0.075	−0.99	0.37	0.15	0.99	12.65	−2.02	−0.99
S-54	1.23	−0.093	−0.96	0.35	0.15	0.99	9.20	−1.49	−0.94
Brazos	1.13	−0.070	−0.93	0.35	0.17	0.88	10.93	−2.35	−0.91
S-16	1.24	−0.086	−0.99	0.56	0.10	0.92	7.81	−1.14	−0.89

**All r values significant ($P \leq 0.01$, 10 df).

Supplementary irrigation was provided to maintain active growth. Herbage present was estimated at 28-day intervals, and a mean of these for the whole season was used in the analysis. In 1977 and 1979 it was visually rated and in 1978 it was estimated by harvesting 5 randomly located 0.9 × 3-m strips from each pasture using a flail-type harvester. A 0.18-m^2 sample was harvested by hand to ground level in each mower strip and stubble mass was included in the estimate of herbage present. Clipped samples of herbage present were analyzed for in vitro digestible dry matter.

Analysis

Regression Relationships

Supplementary irrigation ensured low year-to-year variation in results. Analysis was therefore conducted on the 3-year mean stocking rate (S), average daily gain (ADG), and herbage present (H) for each grazing intensity on the 5 cultivars. The average stocking rate for each grazing intensity was calculated by dividing total animal grazing days/ha by the number of days in the grazing season. Previous grazing intensity studies have concentrated mostly on relating production/animal and/ha to stocking rate (Riewe 1961, Riewe et al. 1963, Jones and Sandland 1974, Bransby 1984). However, this essentially means that animal performance is related to animal numbers, thus providing little information on the pasture.

Although ADG has been related to grazing pressure (kg forage/animal/day) or forage allowance (kg forage/animal) (Peterson et al. 1965, Hart 1972, Adjei et al. 1980, Guerrero et al. 1984), this has more relevance for rotational grazing. The responses of gain/-animal and /ha to average herbage present over the season would appear to have more relevance for continuous grazing, but these have seldom been examined. Neither has the relation between stocking rate and herbage present been carefully considered. Without this information it is difficult to determine whether pasture quality or quantity causes differences between treatments, and the level of herbage present that yields maximum gain/ha cannot be determined. Consequently, separate linear regressions were used initially to relate ADG to stocking rate, ADG to herbage present and stocking rate to herbage present for each cultivar. Although it is recognized that in reality these relationships may not be linear over the full range in grazing intensity, it has commonly been found that linear functions provide good approximations over a limited range in grazing intensity (Riewe 1961, Riewe et al. 1963, Cowlishaw 1969, Hart 1972, Jones and Sandland 1974, Hart 1978, Bransby 1984). Hence, based on this assumption,

$$ADG = b_o + b_1S \quad [1]$$
$$ADG = b'_o + b'_1H \quad [2]$$
$$\text{and} \quad S = b''_o + b''_1H \quad [3]$$

Considering equation 1, the regression lines for the 5 cultivars were compared by using dummy variables (Draper and Smith 1966). A model was set up as follows:

$$ADG = \beta_0 + \sum_{j=1}^{4} \alpha_j \beta_{0j} + \beta_1 S + \sum_{j=1}^{4} \alpha_j \beta_{1j} S$$

The parameters β_0 and β_1 measure the intercept and slope, respectively, of the line for the "control" cultivar (arbitrarily chosen), and β_{0j} and β_{1j} the differences in intercept and slope between cultivar j and the control cultivar. The dummy coefficients j take on values 0 for the control and 1 for the jth subsequent cultivar.

In terms of this model, a test of the null hypothesis $\beta_{1j} = 0$ is equivalent to testing whether the lines for cultivar j and the control are parallel. If any such test is not significant, that term β_{1j} may be set to zero, which reduces the model by 1 term and recognizes that the control and jth lines are parallel. If, after accepting the null hypothesis $\beta_{1j} = 0$, a test is made for $\beta_{0j} = 0$ and this is also accepted, the control and jth line are in effect reduced to one co-incident line. In each case, the error term used was the pooled residual or error sum of squared deviations from regression. A procedure of this nature was followed, testing for parallelism and co-incidence until the model was reduced to its simplest form. Similarly, the relations between ADG and herbage present (equation 2) and between stocking rate and herbage present (equation 3) were also considered.

Derived Relationships

The relationship between seasonal gain/ha (G) and stocking rate can be derived from equation (1):

$$G = S \times ADG \times 151 = S(b_0 + b_1S) \times 151 = (b_0S + b_1S^2) \times 151 \quad [4]$$

where 151 is the number of days in the grazing season.

Two methods can be used to derive a relationship between gain/ha and herbage present. Method 1 involves substituting equation 3 into equation 4:

$$G = b_0 (b''_0 + b''_1H) + b_1 (b''_0 + b''_1H)^2 \times 151 \quad [5]$$

In method 2, the product of equations 2 and 3 is multiplied by 151:

$$G = (b'_0 + b'_1H) (b''_0 + b_1H) \times 151 \quad [6]$$

These mathematical links between grazing variables are illustrated diagramatically in Figure 1.

Estimating Maximum Gain/ha

The stocking rate at which maximum gain/ha occurred (S max) was estimated by equating the first derivative of equation 4 to 0 and solving for S. The level of herbage present which resulted in maximum gain/ha (H max) was estimated by substituting any of these 3 values back into the original equations.

Results and Discussion

Regression Relationships

Linear regressions provided good approximations for these grazing intensity data, thus corroborating the findings of others at least in respect of the ADG vs stocking rate relationship (Riewe 1961, Riewe et al. 1963, Cowlishaw 1969, Hart 1972, Jones and Sandland 1974, Hart 1973, Bransby 1984). Correlation coefficients (r) for linear regression relationships determined separately for

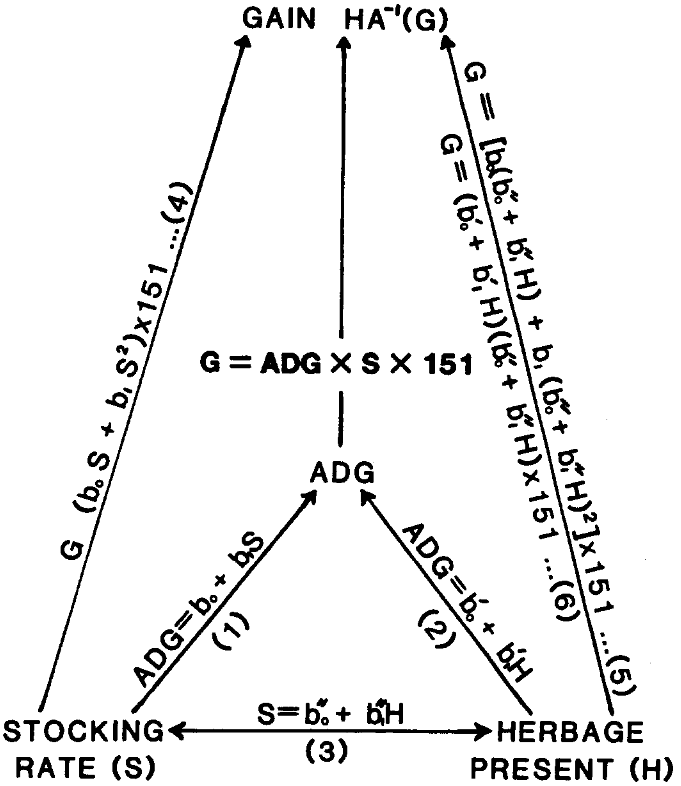

Fig. 1. *Mathematical links between grazing variables.*

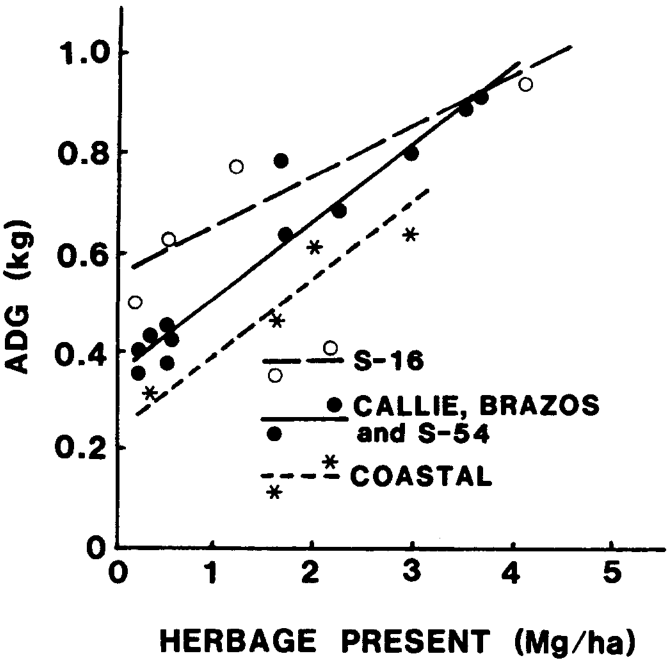

Fig. 3. *A linear regression model relating ADG to herbage present for 5 bermudagrasses. (Equations: S-16, y = 0.56 + 0.101x; Callie, Brazos and S-54, y = 0.37 + 0.154x; Coastal, y = 0.24 + 0.154x).*

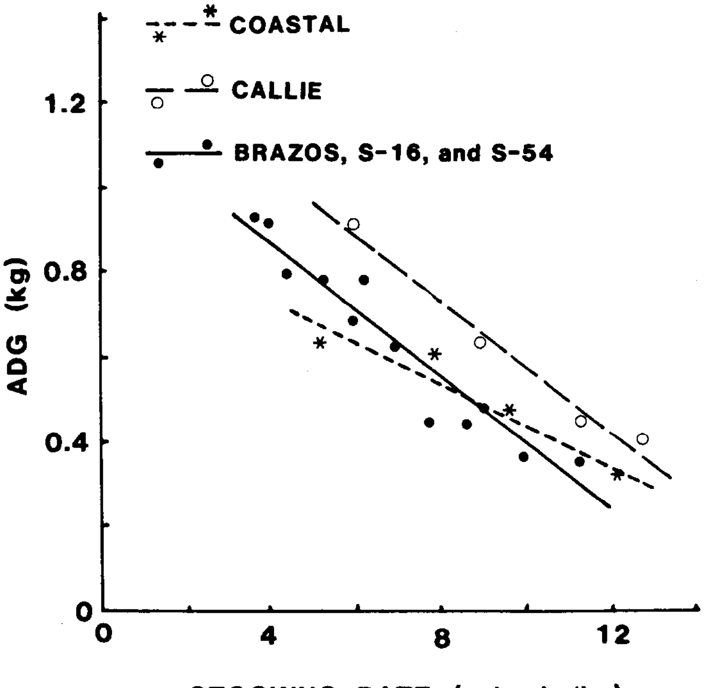

Fig. 2. *A linear regression model relating ADG to stocking rate for 5 bermudagrasses. (Equations: Coastal, y = 0.93 – 0.050x; Callie, y = 1.36 – 0.079x; Brazos, S-16 and S-54, y = 1.18 – 0.079x)*

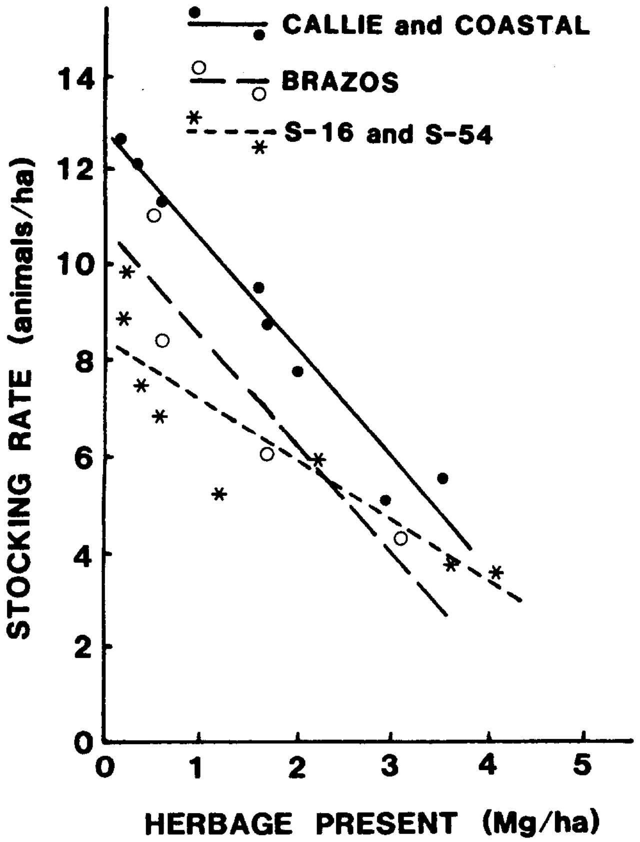

Fig. 4. *A linear regression model indicating average stocking rates resulting from different levels of average herbage present for 5 bermudagrasses. (Equations: Callie and Coastal, y = 12.81 – 2.30x; Brazos, y = 10.86 – 2.30x; S-16 and S-54, y = 8.45 – 1.28x)*

each cultivar were mostly above 0.90 (Table 1). Coefficients of determination (R^2) for the regression models established were 0.90 for ADG vs stocking rate (Fig. 2), 0.89 for ADG vs herbage present (Fig. 3) and 0.87 for stocking rate vs herbage present (Fig. 4). All these values were significant ($P \leq 0.01$). Here it should be emphasized that R^2 indicated the percent variation in all the data (5 cultivars by 4 intensities) accounted for by the models, and each of the 3 models consisted of 3 regression lines, 2 of which were parallel. Consequently, each R^2 value was based on 14 residual degrees of freedom. Furthermore, equations describing the linear functions presented in the models, and which appear with the appropriate figures, differ slightly from those in Table 1 as a result of eliminating all differences between individual regression coefficients which were not statistically significant.

Steers grazing Callie gained at a higher rate ($P\leq0.01$) than those grazing Brazos, S-54 and S-16 at equivalent stocking rates (Fig. 2). However, due to the general decline in ADG as stocking rate increased, the relative advantage of Callie was greater at high stocking rates; e.g., at 6 steers/ha ADG on Callie was 25% higher than on Brazos, S-54 and S-16, while at 10 steers/ha the difference was 58%. Furthermore, as stocking rate increased, animals grazing Coastal showed a lower rate of change in ADG than the other cultivars ($P\leq0.01$), indicating a stocking rate × cultivar interaction. Stocking rate affected ADG through its effect on quantity and quality of herbage. The ADG vs stocking rate response consequently represents the combined effect of these 2 variables on animal performance. Hence, for more detailed interpretation of results it is necessary to study separately the response of ADG and stocking rate to herbage present.

Assuming that herbage intake and ADG are influenced by herbage quality and herbage present only, then any difference among cultivars in ADG at a given level of herbage present will be due to quality differences. Higher ADG ($P\leq0.01$) was observed on Callie, S-54 and Brazos than on Coastal at equivalent levels of herbage present (Fig. 3). As herbage present increased, S-16 showed a lower rate of change in ADG than the other cultivars, indicating a herbage present × cultivar interaction. However, the model suggests that below 2 Mg/ha of herbage present the ADG on S-16 was higher than on the other cultivars. To a certain extent, these results were supported by digestibility data; average in vitro digestible dry matter of herbage present was 52.3% for Coastal, 60.6%, 56.1%, and 57.1% for Callie, S-54, and Brazos respectively, and 58.5% for S-16. At 1.5 Mg/ha of herbage present, estimated ADG from the common regression for Callie, S-54, and Brazos and from the single regression for S-16 was 28% and 51% higher, respectively, than for Coastal. This response became relatively more pronounced as herbage present decreased, and is interpreted as a combination of the direct effect of quality on ADG and its indirect effect via its influence on intake. Extrapolation of the ADG vs herbage present regressions (Fig. 3) suggests that appreciable gain is possible at 0 herbage present. Firstly, such extrapolation is not valid since 0 herbage present is beyond the limits of the data. Secondly, the remarkably high ADG's observed at very low levels of herbage present may be explained by the high resistence of bermudagrass to heavy grazing: the sod-forming nature of these cultivars allowed dry matter to be produced under heavy utilization and this was removed on a daily basis by animals, resulting in little accumulated herbage present at any one time. Finally, the quality of forage consumed under heavy stocking is likely to be high due to low contamination with mature, accumulated herbage present compared to lightly stocked pastures.

The relationships between herbage present and stocking rate reflect the changes in carrying capacity of cultivars with grazing intensity. Callie and Coastal carried more animals ($P\leq0.01$) than Brazos at equal levels of herbage present. In addition, as herbage present increased, stocking rate decreased at a higher rate ($P\leq0.05$) for these 3 cultivars than for S-54 and S-16, again indicating an interaction between herbage present and cultivars (Fig. 4). The implication here is that Callie and Coastal can carry more animals than the other cultivars at a given level of herbage present. This is extremely pronounced at levels of herbage present below 2.5 Mg/ha. At 1.5 Mg/ha of herbage present, the estimated stocking rate for Callie and Coastal was 26% higher than for Brazos, and 43% higher than that on S-54 and S-16. The latter cultivars can therefore be considered to have a low carrying capacity. An alternative interpretation is that, at medium to high stocking rates in particular, their capacity to maintain herbage present is low relative to Callie and Coastal.

Simultaneous examination of figures 2, 3 and 4 facilitates further interpretation. The inferred low quality of Coastal (Fig. 3) suggests that herbage intake by each animal was lower on this cultivar than on the others. Coastal should therefore be able to carry more animals, and this is confirmed by the higher stocking rates shown for Coastal in Fig. 4. The net result is that, on average, animals on Coastal perform no better than those grazing the other cultivars. However, due to its inferred low quality and consequent high carry capacity, relative to the other cultivars it had an increased ability to produce ADG's as stocking rate increased (Fig. 2).

Conversely, due to the inferred high quality (as indicated by ADG) of S-16 (Fig. 3), herbage intake on this cultivar is likely to be high. This resulted in a relatively low carrying capacity (Fig. 4) and, over a wide range in stocking rates, similar gains to all other cultivars except Callie (Fig. 2). However, the inferred medium quality of Callie (Fig. 3) and its high carrying capacity (Fig 4) resulted in the highest gains within the limits of the stocking rate data (Fig 2). These results are in agreement with those of Riewe et al. (1963) who showed that more animals could be carried on tall fescue, which had low quality (or perhaps an anti-quality factor) compared to annual ryegrass, which had high quality. However, gains on tall fescue were lower than those on ryegrass.

While it is recognized that averaging over years resulted in a loss in information, the possibility of examining between-year variation within treatments in a similar comparison to that between treatments described above should not be overlooked. Furthermore, in several cases data presented in figures would have been described better by nonlinear functions. However, the aim was not to maximize the R^2 value (this would probably be achieved by fitting separate functions to the data from each cultivar), but rather to eliminate all insignificant differences from the model while retaining an adequate description of the data. In this sense comparisons among the "average slopes" and "vertical separation" of linear regression lines for different cultivars appeared to successfully serve the purpose.

In the broadest sense, research is aimed at explaining variation in experimental data. Statistical differences are indicated when variance which can be explained is relatively large compared to variance which cannot be explained (experimental error). The non-replicated, multiple grazing intensity approach described above made use of this general principle, but was unable to isolate inherent variation among pastures. However, neither is analysis of variance capable of isolating this variance, since it assumes additivity and no treatment × replication interaction. Snedecor and Cochran (1967) indicate that there is no assurance that this assumption applies. In addition, inherent variation among pasture-herd units has plant and animal sources of variation confounded. Since plant variation is likely to be expressed mainly as differences in forage yield, the regression of ADG on herbage present in this study represents an attempt to separate these sources of variance in a strategy similar to analysis of covariance (with herbage present as a covariate) in a replicated experiment.

Derived Relationships

Relationships describing changes in gain/ha with stocking rate and herbage present were derived for each cultivar from the initial linear regression equations (Table 1). In all cases the range in stocking rates applied included Smax, thus meeting an important specification prescribed by Connolly (1976) for this procedure (Fig. 5). Although cultivars differed considerably in Smax, there was a wide range in stocking rate within which gain/ha changes by a relatively small amount. For example, between 6.1 and 11.6 animals/ha, gain/ha was within 90% of maximum for Callie. This relative insensitivity of gain/ha to grazing intensity is even more

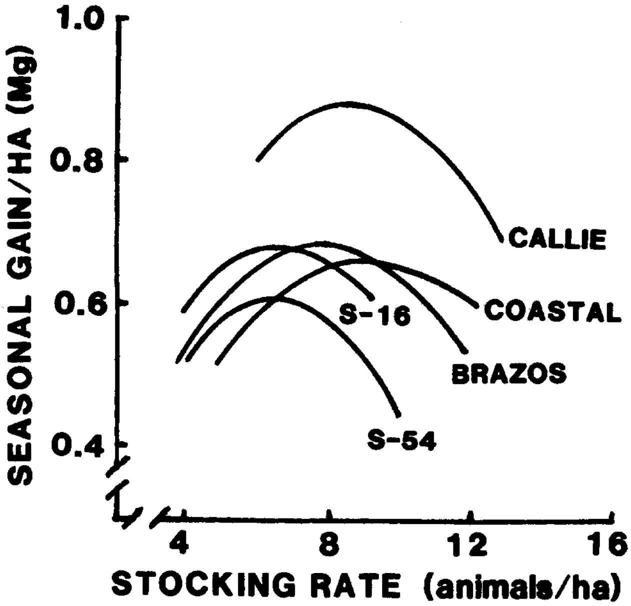

Fig. 5. *Derived relationships (equation 4) between gain/ha and stocking rate for 5 bermudagrasses. (Equations: Coastal, $y = 0.93x - 0.050x^2$; Callie, $y = 1.32x - 0.75x^2$; Brazos, $y = 1.13x - 0.070x^2$; S-54, $y = 1.23x - 0.093x^2$; S-16, $y = 1.24x - 0.086x^2$).*

evident when examined in relation to herbage present (Fig. 6). In terms of gain/ha, therefore, grazing systems on bermudagrass appear to be well buffered against changes in grazing intensity in the region of Smax and Hmax. Additionally, these results emphasize the dependence of relative differences among cultivars in gain/ha on level of herbage present.

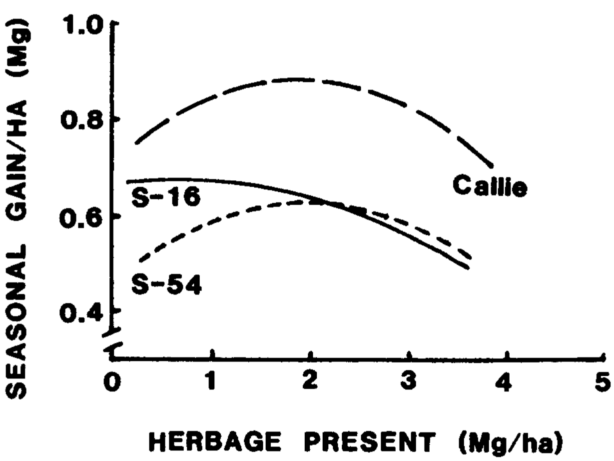

Fig. 6. *Derived relationships (equation 5) between gain/ha and herbage present for Callie, S-16 and S-54. (Equations: Callie, $y = 4.68 + 1.15x - 0.30x^2$; S-54, $y = 3.22 + 0.86x - 0.22x^2$; S-16, $y = 4.37 + 0.14x - 0.11x^2$).*

The estimated Hmax differed relatively more among cultivars than Smax (Table 2) and differed slightly, depending on which equations were used in their derivation. However, this had little effect on the ranking of cultivars. The relatively high Smax and Hmax for Callie suggests a high carrying capacity, as does the high Smax for Coastal. The low Smax and Hmax values for S-16 are indicative of a low carrying capacity.

Estimation of Gmax by means of 3 different equations showed little variation in estimates and did not alter ranking of cultivars (Table 2). The high and low Gmax for Callie and Coastal, respectively, resulted mainly from the difference between these cultivars in ADG (Fig. 3). Despite low carrying capacity, Gmax for S-16 was marginally higher than that for Coastal as a result of its apparent high quality.

Table 2. The stocking rate (Smax) and level of herbage present (Hmax) which result in maximum beef gain/ha and maximum gain/ha (Gmax) estimated from 3 different equations for 5 bermudagrasses. (Equations: (4) $G = (b_0 S + b_1 S^2) \times 151$; (5) $G = b_0 (b_0'' + b_1 H) + b_1 (b_0'' + b_1''H)^2 \times 151$ and (6) $G = (b_0' + b_1'H)(b_0'' + b_1''H) \times 151$.

Cultivar	Smax Estimated from equation (4)	Hmax Equations used for estimate: (5)	(6)	Gmax Equations used for estimate: (4)	(5)	(6)
	animals ha^{-1}	——Mg ha^{-1}——		————kg ha^{-1}————		
Coastal	9.41	1.41	1.45	663	655	662
Callie	8.85	1.89	1.91	880	881	882
S-54	6.60	1.75	1.95	613	613	619
Brazos	8.05	1.22	1.30	687	686	687
S-16	7.22	0.35	0.64	676	673	672

Conclusions

Logistical and financial constraints usually force a compromise between treatments and replication in grazing studies. If the trial described in this study had been replicated twice, it would have required 40 fenced paddocks, 120 tester animals, and about 60 filler or grazer animals. A possible compromise would have been to graze the 5 cultivars at 3 intensities with 2 replications, but even this would have increased the scale of the experiment by one half. Testing for differences among different grazing intensities on the same cultivar and for linearity requires replication. However, compared to testing differences between grazing intensity regressions for different cultivars, such issues may be considered less important.

The regression modeling approach and interpretive procedure described in this study had the following advantages: (a) statistical comparisons of several treatments could be made without field replication provided each treatment is applied at several grazing intensities; (b) inferences could be made about the separate effects of forage quality and quantity on animal performance; (c) cultivars could be compared at any given grazing intensity or alternatively, in terms of their maximum gain/ha, even though this occurred at different grazing intensities, and (d) the production functions developed facilitate a functional approach to economic analysis. It is clear that a comparison of cultivars considered in this study but using only 1 grazing intensity would have had narrow application. There could be no estimate of Smax, for example. Furthermore, since it is quite possible that many treatment × grazing intensity interactions may exist in grazing systems, results from other grazing trials which employed only 1 grazing intensity may apply only to that grazing intensity used. Many questions, however, remain unanswered: e.g., would partial replication have been a useful compromise, how successful would the nonreplicated approach be if the experimental site had been less uniform and if the trial had been conducted under rain fed conditions, and does the procedure have application for both continuous and rotational grazing?

The benefits of the nonreplicated grazing intensity approach are obvious, yet the current preference for replication in grazing trials as evidenced by the published literature suggest that such issues deserve further careful research attention. In particular, there is a need to re-examine data sets which permit comparisons of regression and analysis of variance to determine the relative importance of different sources of variance. We feel that if the choice is between replication or applying each treatment at several grazing intensities, evidence provided in this study may tip the balance in favor of grazing intensities.

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