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Cattle Liveweight Sampled on a Continuous versus Intermittent Basis*

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ABSTRACT

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The liveweight of a free-ranging cow is constantly changing. If she is weighed automatically upon entering a corral before drinking water, a liveweight profile results which can be used to manage her individual performance. Using a manual procedure and weighing the same cow every 28 days also results in a liveweight profile. To determine how the amount of information contained in the 2 weighing procedures differed, the same cows of an experimental herd were weighed using both procedures. The resulting data referred to 1281 manual and some 40 000 automatic weighings, which were then classified into the phenological stage of the grazed plants and the physiological stage of the cow. By assuming that a cow is biologically the same within a 7-day period, and with as little as 1 weeks' data, an 11% change in a cow's liveweight can be detected 90% of the time with only one additional automatic weighing. Real changes in liveweight as little as 5% can be detected at the same rate if more than a single weighing is observed. Therefore, automatic weighing not only can be used to estimate the effects of past management practices, but also can be useful in making sound day-to-day livestock management decisions on individual animals.

INTRODUCTION

Studies to determine the number of consecutive weights required to estimate the liveweight of an animal accurately have been conducted (Lush and Black, 1927; Lush et al., 1928; Baker et al., 1946; Patterson, 1947; Mott, 1959; Brink et al., 1981). With conventional manual weighing, consecutive weights taken more than once a day, or over several consecutive days to improve accuracy, cannot be justified because of the additional labor and stress to the animals.

Diurnal changes in gastrointestinal fill (Suzuki and Sawamura, 1981; Heitschmidt, 1982) and body fluids (Harris et al., 1959) are largely responsible

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for the highly variable day-to-day fluctuations in liveweight of grazing animals. Standardizing fill and fluids within free-ranging animals is difficult. Grazing patterns (Matches, 1969), watering patterns (Whiteman et al., 1954; Low et al., 1981; Squires and Siebert, 1983), changes in diet (Ward, 1975; Morgan et al., 1976) and changes in weather patterns (Lush et al., 1928; Rotschke and Lampeter, 1977; McCown, 1981) all interact to prevent fixed weighing procedures, most often designed for man's convenience, from minimizing the effect of gastrointestinal fill and body fluids on the grazing animal's liveweight (Anderson and Tietjen, 1982; Wythes and Shorthose, 1984).

Electronic scales, which use load cells, are replacing mechanical scales. The first use of electronics to automate livestock weighing was described by Martin et al. (1967). Concurrently, electronic animal identification was being developed (Sigrims and Scott, 1984). During the late 1970s, electronic identification and automatic weighing of individual animals were interfaced for the first time to obtain body weights of free-ranging beef cows (Anderson et al., 1981). Today, Adams et al. (1987) are successfully using an automated data-acquisition system to evaluate animal performance from plant–individual animal–weather data without disrupting individual free-ranging livestock activities. The objectives of this study were to obtain a liveweight profile of cattle based on data taken each time a cow entered a corral to drink (automatic) and also to compare the information in this estimate of a cow's liveweight profile to that obtained by weighing the same cows every 28 days (manual).

METHODS

Between 24 July 1980 and 28 February 1983 (950 days) two adjoining paddocks (32°40′N, 106°50′W) averaging 3477 ha in size with an average elevation of 1336 m above sea level were stocked with cattle under rotational put-and-take management (Gibbens et al., 1986). The bulk of the grazing animal's diet on a year-round basis was provided by mesa dropseed (*Sporobulus flexuosus*, [Thurb.] Rydb.). When soil moisture was adequate, perennial and annual forbs, e.g. desert baileya (*Baileya multiradiata* Harv. & A. Gray) and Wislizenus spectaclepod (*Dithyrea wislizenii* Engelm.), contributed significantly to diet quality.

Vernal annual growth (1 March through 30 June), perennial growth (1 July through 31 October) and dormance (1 November through the end of February) were characterized based on long-term precipitation (1915–1979) record averages of 34, 150 and 46 mm, respectively. Daily precipitation was monitored from 10 rain gauges located around the perimeter of each paddock.

Long-term average mid-range ambient air temperatures (1941–1979) for vernal annual growth, perennial growth and dormancy were 16.7, 22.0 and 5.7°C, respectively. Mid-range ambient air temperatures were recorded at headquarters throughout the period of this study.

The experimental single herd consisted of 26–41 Hereford and Hereford×Santa Gertrudis cows born between 1976 and 1978. Seasonal breeding with 2 Brangus bulls for 132, 142, 194 and 145 days, respectively beginning 6 May 1980; 10 April 1981; 18 March 1982 and 28 March 1983 was practiced. Calving dates were estimated unless calving was observed. Calves were weaned on 3 November 1980, 14 October 1981, 9 November 1982 and 18 October 1983.

A total of 1282 individual manual liveweights were taken approximately 28 days apart beginning 23 July 1980. Jornada Experimental Range cattle are normally gathered while at pasture using horses and brought to a corral where they are weighed immediately without being held off feed or water for a known period of time. However, in this study, cows were trapped using bayonet gates (Anderson and Smith, 1980) as they came to drink from the only available source of well water. Water was withheld for at most 19 h before weighing. Feed may have been withheld for upwards of 24 h before the weighing. Calves were provided ad libitum water in a creep area without having to negotiate the maze.

Between the 28-day manual weighings, all adult cattle previously trained to negotiate the maze (Fig. 1) were weighed before drinking. Approximately 40 000 liveweights were obtained automatically as follows: bayonet gates directed a unidirectional flow of cattle through the maze while an animal-powered cow spacer (Anderson and Mertz, 1983) insured only one animal at a time could enter the scale platform during the system's automatic operation. As an animal stepped on the scale platform an infrared light beam was broken. This signaled closure of a front gate for 11 s, during which time 4–6 liveweights, date, time of day and the animal's unique identification number (block of data) were automatically recorded on both paper and cassette tape.

A preliminary comparison of the median of the sequential liveweights and the maximum of the liveweights produced a difference of 1.17 kg based on 50 samples (G. Tietjen, personal communication, 1981). Therefore, the maximum identified liveweight, the identification number and the minimum time (sometimes a block of weights included a 2-min interval) were selected for analysis. Only data from the first weighing was used if an animal entered the system more than once in 24 h. If liveweights were not identified as coming from a specific cow the data were deleted. Except when parturition had occurred between consecutive weighings, consecutive liveweight differences equal to or greater than 75 kg were judged not to be biologically probable and were deleted. The number of liveweights judged suitable for analysis was 7293.

The raw liveweights obtained by manual and automatic weighing were classified into those that were collected during vernal annual growth, perennial growth, dormancy and by various physiological stages of the cow as follows: "Pregnancy" was defined to last 283 days and to encompass the period from conception until parturition. Pregnancy was further divided into 2 periods: the first 180 days and the last 103 days. "Lactation" was defined as the period from parturition until weaning and was also divided into 2 periods: the first 30 days

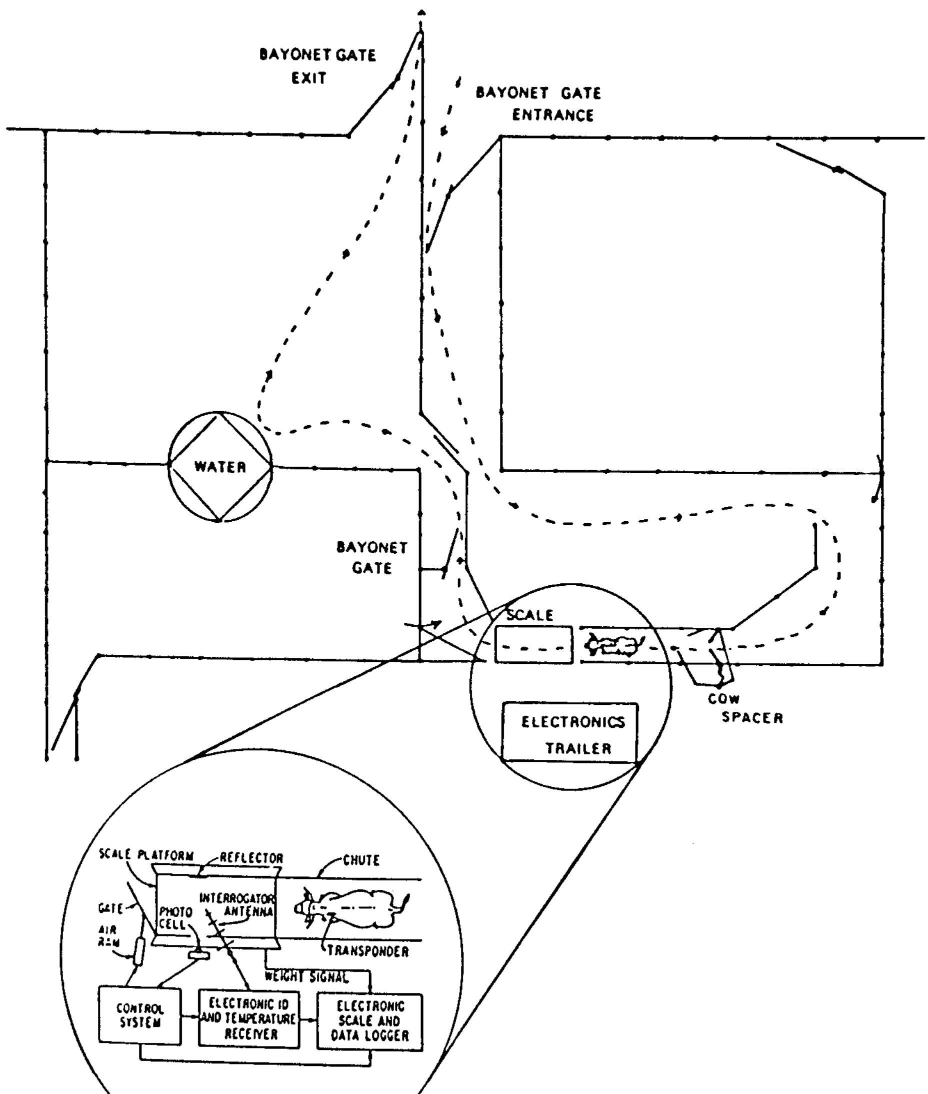

Fig. 1. Block diagram of the one-way maze built with bayonets to control movement of cattle through the corral in which the cow spacer, electronic scale and drinking water were located.

and from Day 31 until weaning. The not-pregnant interval was also divided into 2 periods: the first 30 days postweaning and the interval from Day 31 postweaning until conception. The variability of a cow's liveweight within a 7-day interval, was found to be constant across phenological periods. The arith-

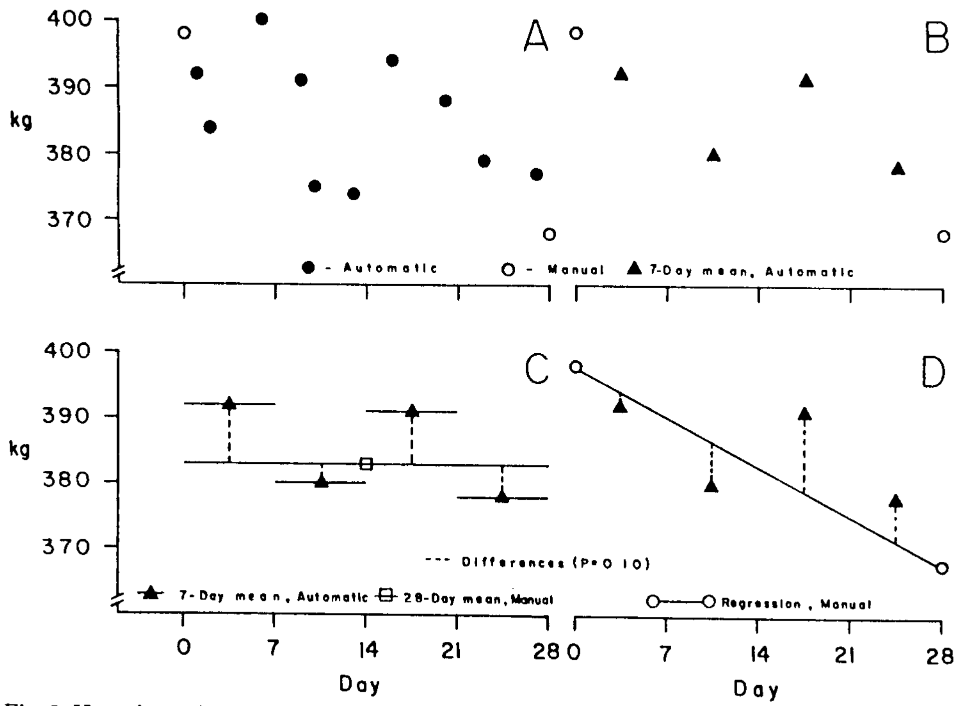

Fig. 2. Hypothetical liveweight profile for a free-ranging cow. Animal weighed frequently (automatic) and infrequently (manual, every 28 days), (A) with 7-day mean liveweights of frequently obtained data, (B) liveweight differences between means obtained every 7 days and every 28 days, (C) liveweight differences between means obtained every 7 days and a linear regression line of liveweights obtained every 28 days.

metic mean of automatically obtained liveweights taken during 7 consecutive days beginning on Thursday of each week was calculated for each cow (Fig. 2A and B). Each cow's manual liveweight profile estimated over 28 days was evaluated on a daily basis as: (1) a series of mean liveweights calculated from 2 consecutive manual weighings (Fig. 2C); or (2) a series of estimates each taken from a regression line fit to 2 consecutive manual weighings (Fig. 2D). Manual and automatic weighing methods were compared in 2 different ways as follows: (1) the 2 manual weighings taken 28 days apart were averaged. Liveweights obtained automatically during the 28-day interval were averaged by week. These 4-weekly averages were each subtracted from the average of the 2 manual weighings. The 4 absolute values of the differences that were computed were tested for statistical significance using the estimated standard deviation of weights of cows who were biologically the same as a basis. (2) A regression line was fit to the 2 manual weighings taken 28 days apart. On each week during this 28-day period that at least one weight was automatically obtained, the difference in this average weight and the predicted weight using the regression line was computed and tested for statistical significance.

The assumption that the cow is biologically the same during a given week permits one to assume that observations taken within a week are uncorrelated and that variability estimated from the data within a week is the appropriate basis for judging the statistical significance of differences taken by the two weighing procedures on the same cow. A simple *t* test on each difference was computed using the 2 procedures. While correlation is introduced in the differences in consecutive 28-day periods by virtue of having a common 28-day weighing, the average squared correlation of differences using either method was 6% or less. The effects of this size correlation were judged not to affect the validity of conclusions based on subsequent analyses seriously. Manual and automatic weighing procedures were compared as follows: (1) the absolute value of differences (Fig. 2C) was obtained by subtracting mean 7-day liveweights obtained automatically, and mean 28-day liveweights obtained manually were analyzed (Table 1), (2) the absolute difference values (Fig. 2D) obtained by subtracting mean 7-day liveweights obtained automatically, and the corresponding regression estimate calculated from the manually obtained liveweights were analyzed (Table 2). In addition, a liveweight profile for each animal, based on the automatic weighing procedure was developed (Fig. 2B). Liveweight differences obtained by subtracting the mean liveweight calculated over 7 consecutive days from the following 7-day mean, were analyzed (Table 3). A hypothetical example with calculations is given in the Appendix.

Data analyses were performed using the Statistical Analysis System (SAS, 1982) at the Computer Center, New Mexico State University. Data were very unbalanced within and between categories. When comparing differences in manual and automatic weighing, a significance of $P=0.10$ was selected since in these circumstances, it means that 10% of the time a difference in the 2 liveweight profile estimates will be declared statistically significant when in fact no change has taken place. Increasing this error rate to 10% from say 5% benefits the testing procedure by increasing the chances of detecting real changes in the information contained in the manual and automatic weighing procedures. Common sense would indicate that the two procedures do not usually contain the same information, thereby lending credibility to this choice of error rate. When there are real differences, the statistical procedure will say so more often when taking a higher risk of saying that there is a difference when actually there is not. Comments about the pattern of significant differences will be given in the results and discussion section.

Sources of variation

Four components of variability in the liveweights that were recorded automatically were estimated. Each component is additive to the total variability

TABLE 1

Patterns ($P=0.05$) of nonrandomness when comparing differences ($P=0.10$) between weekly mean automatic and consecutive mean manual individual cow liveweights by animal, plant and time-interval categories

Plant phenology stages	Animal status					
	Pregnancy		Lactation		Not pregnant interval	
	First 180 days	Last 103 days	First 30 days	Day 31 until weaning	First 30 days post-weaning	Day 31 until conception
1980-1981						
Perennial (July-Oct.)	NS[a]	ND[b]	NS	$\frac{16}{81}=0.20$[c] $0.13<P$[d]	ND	NS
Dormant (Nov.-Feb.)	NS	$\frac{27}{170}=0.16$ $0.11<P$	NS	NS	NS	NS
1981-1982						
Vernal annual (March-June)	NS	$\frac{21}{50}=0.42$ $0.31<P$	$\frac{18}{62}=0.29$ $0.20<P$	$\frac{61}{295}=0.21$ $0.17<P$	ND	NS
Perennial (July-Oct.)	$\frac{29}{81}=0.36$ $0.27<P$	NS	NS	$\frac{109}{453}=0.24$ $0.21<P$	$\frac{18}{52}=0.35$ $0.24<P$	$\frac{11}{48}=0.23$ $0.13<P$
Dormant (Nov.-Feb.)	$\frac{30}{162}=0.19$ $0.14<P$	$\frac{24}{110}=0.22$ $0.15<P$	NS	ND	NS	NS
1982-1983						
Vernal annual (March-June)	$\frac{9}{30}=0.30$ $0.16<P$	$\frac{22}{72}=0.31$ $0.22<P$	$\frac{9}{18}=0.50$ $0.31<P$	$\frac{4}{13}=0.31$ $0.10<P$	ND	$\frac{15}{86}=0.17$ $0.11<P$
Perennial (July-Oct.)	$\frac{25}{126}=0.20$ $0.14<P$	$\frac{10}{36}=0.28$ $0.16<P$	ND	$\frac{37}{187}=0.20$ $0.15<P$	ND	$\frac{12}{55}=0.22$ $0.13<P$
Dormant (Nov.-Feb.)	NS	$\frac{35}{140}=0.25$ $0.19<P$	$\frac{25}{57}=0.44$ $0.33<P$	$\frac{13}{46}=0.28$ $0.17<P$	NS	NS

[a]Not significant ($P>0.05$).
[b]No data.
[c]Fraction of comparisons between weighing methods that differed significantly ($P=0.10$).
[d]The interval is a lower one-sided confidence (95%) interval on the true proportion of significances.

associated with weighing free-ranging cows and reduces the resolution possible in determining actual changes in animal liveweight.

The standard deviation (variability) contributed by only the weighing

TABLE 2

Patterns ($P=0.05$) of nonrandomness when comparing differences ($P=0.10$) between weekly mean automatic and consecutive predicted manual individual cow liveweights by animal, plant and time-interval categories

Plant phenology stage	Animal status					
	Pregnancy		Lactation		Not pregnant interval	
	First 180 days	Last 103 days	First 30 days	Day 31 until weaning	First 30 days post-weaning	Day 31 until conception
1980-1981						
Perennial (July-Oct.)	NS[a]	ND[b]	NS	$\frac{16}{81}=0.20$[c] $0.13<P$[c]	ND	NS
Dormant (Nov.-Feb.)	NS	NS	NS	NS	NS	NS
1981-1982						
Vernal annual (March-June)	NS	$\frac{19}{50}=0.38$ $0.27<P$	$\frac{14}{62}=0.23$ $0.14<P$	$\frac{60}{295}=0.20$ $0.17<P$	ND	NS
Perennial (July-Oct.)	$\frac{27}{81}=0.33$ $0.25<P$	NS	NS	$\frac{103}{453}=0.23$ $0.20<P$	$\frac{22}{52}=0.42$ $0.31<P$	NS
Dormant (Nov.-Feb.)	$\frac{28}{162}=0.17$ $0.12<P$	$\frac{22}{110}=0.20$ $0.14<P$	NS	ND	NS	NS
1982-1983						
Vernal annual (March-June)	$\frac{11}{30}=0.37$ $0.22<P$	NS	NS	NS	ND	NS
Perennial (July-Oct.)	$\frac{20}{126}=0.16$ $0.11<P$	$\frac{8}{36}=0.22$ $0.11<P$	ND	NS	ND	NS
Dormant (Nov.-Feb.)	NS	$\frac{23}{140}=0.16$ $0.11<P$	$\frac{17}{57}=0.30$ $0.20<P$	NS	NS	NS

[a]Not significant ($P>0.05$).
[b]No data.
[c]Fraction of comparisons between weighing methods that differed significantly ($P=0.10$).
[d]The interval is a lower one-sided confidence (95%) interval on the true proportion of significances.

equipment on the same day was estimated to be 2 kg. To estimate this variability, data were collected on 33 cows, each weighed three times between 0900 and 1025 h on 9 December 1981. These animals were observed not to have urinated or defecated during the 85-min weighing trial. The 33 cows were weighed in a random order for each of 3 replications. An analysis of variance for data in a 2-way cross classification (replication and cow) was computed. The square root of the replication by cow interaction mean square was 2. This measures the average failure of the difference of 2 cows to be the same in replicate weighings made consecutively and immediately.

An analysis of 191 empty scale platform weights recorded before taring between August 1980 and October 1981 had a random scatter of deviations around zero. An estimate of the standard deviation of the weighing system operating automatically, under ambient conditions was 7 kg. The 7 kg includes the weighing and the taring components of variability.

There were 3 components of the total variability involving the variation of animals weighed within the same time interval, the same phenological stage of the standing crop and the same physiological stage of the animal. An extensive study revealed that the magnitude of the variation associated with these sources was independent of the plant, animal, or time-interval category under consideration.

An estimate of the standard deviation of the liveweight of an individual cow within a given phenological and physiological stage, including that attributable to the weighing equipment, and the infrequent taring under ambient conditions, was found to be 15 kg. The standard deviation of liveweight of a randomly selected cow of the same breed and age during the same week during any weather condition was estimated to be 50 kg. In terms of this total variance, the 4 estimated variance components were 4, 45, 176 and 2275 for weighing, taring individual cows and among cows, respectively.

RESULTS AND DISCUSSION

Precipitation was below normal (10–71%) during the major periods of growth, except between March and June 1981. Above-normal precipitation preceded the study and also characterized the dormant period (102%) at the close of the study. Mid-range ambient air temperatures were slightly below but not atypical from the long-term averages in six of the eight 4-month study periods.

Mean liveweight and standard deviation for the herd determined using manual weighing was 388 ± 62 kg with a liveweight range of between 222 and 656 kg. Based on automatically obtained data, liveweights ranged between 220 and 686 kg with a mean and standard deviation of 385 ± 60 kg. On average, each cow was weighed 31 times manually and 178 times automatically. The similarity in standard deviations associated with mean liveweights obtained either manually or automatically indicates the dry matter to fluid ratio of the alimentary tract was similar regardless of whether or not weighing was done directly off the paddock (automatic weighing) or if a drylot shrink preceded weighing (manual weighing). Free water was the one common factor withheld

TABLE 3

Patterns ($P=0.05$) of nonrandomness when comparing differences ($P=0.10$) between consecutive weekly mean automatic individual cow liveweights by animal, plant and time-interval categories

Plant phenology stages	Animal status					
	Pregnancy		Lactation		Not pregnant interval	
	First 180 days	Last 103 days	First 30 days	Day 31 until weaning	First 30 days post-weaning	Day 31 until conception
1980-1981						
Perennial (July-Oct.)	$\frac{9}{26}=0.35$[a] $0.19<P$[d]	ND[b]	ND	$\frac{14}{44}=0.32$ $0.20<P$	ND	NS[c]
Dormant (Nov.-Feb.)	NS	$\frac{38}{118}=0.32$ $0.25<P$	ND	NS	NS	$\frac{5}{18}=0.28$ $0.10<P$
1981-1982						
Vernal annual (March-June)	NS	$\frac{17}{41}=0.41$ $0.29<P$	$\frac{18}{51}=0.35$ $0.24<P$	$\frac{68}{265}=0.26$ $0.21<P$	ND	NS
Perennial (July-Oct.)	NS	NS	NS	NS	$\frac{13}{52}=0.25$ $0.15<P$	NS
Dormant (Nov.-Feb.)	$\frac{28}{150}=0.19$ $0.13<P$	NS	NS	ND	NS	$\frac{42}{267}=0.16$ $0.12<P$
1982-1983						
Vernal annual (March-June)	NS	NS	$\frac{7}{11}=0.64$ $0.40<P$	NS	ND	NS
Perennial (July-Oct.)	$\frac{21}{93}=0.23$ $0.15<P$	$\frac{13}{26}=0.50$ $0.34<P$	ND	$\frac{43}{140}=0.31$ $0.24<P$	ND	$\frac{9}{45}=0.20$ $0.10<P$
Dormant (Nov.-Feb.)	$\frac{16}{67}=0.24$ $0.15<P$	$\frac{27}{104}=0.26$ $0.19<P$	$\frac{16}{47}=0.34$ $0.23<P$	NS	NS	NS

[a]Fraction of comparisons between weighing methods that differed significantly ($P=0.10$).
[b]No data.
[c]Not significant ($P>0.05$).
[d]The interval is a lower one-sided confidence (95%) interval on the true proportion of significances.

prior to weighing in both procedures. Apparently water is a more important source of variation in gut fill than forage. Whiteman et al. (1954) made a similar conclusion concerning liveweight data obtained from steers grazing

Oklahoma range.

The total number of liveweight differences was less than the total number of days in the period of study because, during 384 days, automatically obtained data were not obtained for the following reasons: (1) for 32 days manual weighing took place; (2) for 8 days a shrink study took place (Anderson and Tietjen, 1982); (3) for 92 days equipment was being repaired; (4) for 252 days there was no assignable cause for the absence of data. Voltage fluctuations from 12-V DC batteries caused by loose or dirty terminal connections resulted in some lost data. Approximately 40% of the data loss occurred on Saturdays and Sundays, because equipment was checked less frequently on those days.

During the last 103 days of pregnancy, from March 1981 through June 1981, there were 50 differences observed in the two weighing procedures (Table 1). Five differences were expected to be declared significant (10% of 50). The number of differences actually declared significant, i.e. the number of those differences that were above the inherent variability of the animal, was 21 or 42%. It would be unusual (less than 1 chance in 20) to have this many differences declared significant if the amount of information in the two procedures was the same. It can thereby be concluded that there is more information in the automatic weights than the manual. Twenty-three of the 41 cells containing data in Table 1 had a percentage of statistically significant differences significantly ($P<0.05$) greater than 10%. However, there appears to be no pattern of significant differences in the plant, animal and time-interval categories of the 23 cells which contain data.

Fourteen of the 41 cells containing data in Table 2, had differences greater ($P<0.05$) than the expected number. Except for the complete absence of significant differences from Day 31 postweaning until conception there appears to be no pattern of significance that can be associated with the plant–animal stages and time-interval categories. However, for the category involving the liveweight profile of cows not pregnant for greater than 31 days postweaning, a pattern of non-significance ($P>0.05$) was observed, regardless of plant stage and time interval.

Changes between consecutive pairs of automatically obtained individual 7-day mean liveweights differed significantly ($P<0.10$) within all plant, animal and time interval categories (Table 3). Between March and June 1981, precipitation exceeded the long-term average by 147%. During this time, 3 of the 5 cells contained data indicating that the cow's liveweight was changing between consecutive 7-day intervals ($P<0.10$). In 1982, below-average precipitation was received during vernal annual growth and a less variable liveweight profile was observed, as evidenced when only 1 out of the 5 cells differed ($P<0.05$). It appears that in some plant, animal and time-interval categories, more information is contained in the automatically obtained data than that obtained manually. This may especially be true in periods of above-average precipitation. However, the pattern when the automatically obtained data contains more

TABLE 4

The absolute change in the mean liveweight of a cow that must be equalled or exceeded in order to indicate a significant ($P = 0.10$) change in liveweight when comparing means of 7-day intervals in which 1-7 weights were taken

Number of liveweights recorded during a 7-day interval[a]		Liveweight change[b] (kg)
Interval 1 (n)	Interval 2 (m)	
1	1	34.9
1	2	30.2
1	3	28.5
1	4	27.6
1	5	27.0
1	6	26.7
1	7	26.4
2	2	24.7
2	3	22.5
2	4	21.4
2	5	20.6
2	6	20.1
2	7	19.8
3	3	20.1
3	4	18.8
3	5	18.0
3	6	17.4
3	7	17.0
4	4	17.4
4	5	16.6
4	6	15.9
4	7	15.5
5	5	15.6
5	6	14.9
5	7	14.4
6	6	14.2
6	7	13.7
7	7	13.2

[a]A cow is considered biologically the same during 7 consecutive days.

[b]Significant liveweight change $= (t\infty;\, 0.10)\,(s_{pooled})\left(\sqrt{\frac{1}{n}+\frac{1}{m}}\right)$

$$= (1.645)\,(15)\left(\sqrt{\frac{1}{n}+\frac{1}{m}}\right)$$

information than the manually obtained data appears to be random and similar to those in Tables 1 and 2.

If a cow is weighed at least once during 7 consecutive days, and she is again weighed on Day 8, an absolute difference in liveweight of $\geq$ 35.0 kg would indicate her liveweight profile had changed ($P=0.10$). However, if she is weighed daily for 7 consecutive days, followed by a second 7-day interval of weighing, which need not immediately follow the first 7-day interval, an absolute difference between means of the first and second 7-day intervals must only be ≥ 13.2 kg to declare a significant change ($P<0.10$) in her liveweight profile. Based on the number of liveweights obtained (1–7) during a 7-day period, Table 4 lists the minimum change in liveweight that will be equaled one time out of 10 if an animal is biologically the same in different weeks.

CONCLUSIONS

Significant changes over time within the liveweight profile of a single cow did not appear to be associated with any particular plant or animal category, regardless of year or weighing procedure. For long-term trends, infrequent and frequent weighing provide essentially identical information. In this study, differences in liveweight between animals accounted for approximately 90% of the variability associated with obtaining mean liveweights within a week. The scale itself was quite precise and contributed <1% to liveweight variability. Automatic operation of the weighing system increased total variability in an animal's liveweight slightly (to 2%) as a result of manual rather than automatic taring. Variability associated with liveweight of a randomly selected cow of any age and breed on any week when she was biologically the same, contributed 9% ($100\times225/2500$) to the total variability. Future research involving automatic monitoring of liveweight could improve precision by selecting a herd that is homogeneous with regard to genotype, age and phenotype. In addition, a slight improvement in precision could be gained by automating the tare procedure. If batteries are used to operate an automatic weighing identification system, it is essential that constant voltage be maintained to prevent data loss.

There were 9 categories in which more significant differences occurred between the 2 weighing procedures if mean liveweights, rather than predicted liveweights, were used to describe the cow's liveweight profile. Therefore, if only manually obtained liveweights can be taken, a series of predicted liveweights using regression techniques more accurately estimates the liveweight of the grazing cow's profile within a 28-day interval than does the arithmetic mean. Except for non-pregnant cows in which regression estimates were used, the pattern of significant and non-significant differences obtained from comparing manual and automatic weighing procedures, produced no detectable patterns in response to plant, animal and time interval categories into which data were classified. However, there were periods during which manual weighing differed ($P<0.05$) from automatic weighing.

If we consider a cow to be biologically the same over 7 consecutive days, the best estimate of the cow's liveweight within this time interval is the arithmetic mean of all the liveweights obtained. Between July 1980 and February 1983, most cows in the herd weighed themselves automatically 2–3 times every week. For a cow's liveweight to be considered as having changed significantly ($P=0.10$) between weeks, the absolute value of the difference in weekly mean liveweights for $n=2$ and $m=3$ (Table 4) must be ≥ 22.5 kg (an average change of 3.2 kg day^{-1}). For example a 445-kg cow whose liveweight changed between 2 consecutive weeks by an average of $\geq 0.7\%$ day^{-1} would be declared to have changed liveweight significantly. Liveweight is dynamic; therefore, automatic weighing has the potential to associate cause and effect relationships more closely than infrequent manual weighing, thereby allowing optimal individual and herd management practices.

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REFERENCES

Adams, D.C., Currie, P.O., Knapp, B.W., Mauney, T. and Richardson, D., 1987. An automated range-animal data acquisition system. J. Range Manage., 40: 256-258.

Anderson, D.M. and Mertz, D.L., 1983. A mechanical animal-powered cow spacer. J. Range Manage., 36: 542-543.

Anderson, D.M. and Smith, J.N., 1980. A single bayonet gate for trapping range cattle. J. Range Manage., 33: 316-317.

Anderson, D.M. and Tietjen, G., 1982. Drylot shrink of cattle grazing semidesert rangeland. Proc. West. Sec. Am. Soc. Anim. Sci., 33: 242-245.

Anderson, D.M., Landt, J.A. and Salazar, P.H., 1981. Electronic weighing, identification and subdermal body temperature sensing of range livestock. In: J.L. Wheeler and R.D. Mochrie (Editors), Forage Evaluation: Concepts and Techniques. Commonwealth Scientific and Industrial Research Organization and Am. Forage and Grassl. Council, Melbourne, Australia, pp. 313-328.

Baker, A.L., Phillips, R.W. and Black, W.H., 1946. The relative accuracy of one-day and three-day weighing of calves. J. Anim. Sci., 6: 56-59.

Brink, D., Merrill, J., Klopfenstein, T., Olson, R. and Brown, B., 1981. Multiple weighing is more accurate. Beef Cattle Rep. Nebraska Coop. Ext. Serv. EC 81-218, pp. 56.

Gibbens, R.P., Herbel, C.H., Morton, H.L., Lindemann, W.C., Ryder-White, J.A., Richman, D.B., Huddleston, E.W., Conley, W.H., Davis, C.A., Reitzel, J.A., Anderson, D.M. and Guiao, A., 1986. Impacts of 2, 4, 5-T on a mesquite duneland ecosystem in southern New Mexico: A synthesis. J. Range Manage., 39: 320-326.

Harris, L.E., Cook, C.W. and Butcher, J.E., 1959. Symposium on forage evaluation: V. Intake and digestibility techniques and supplemental feeding in range forage evaluation. Agron. J., 51: 226-234.

Heitschmidt, R.K., 1982. Diurnal variation in weight and rates of shrink of range cows and calves. J. Range Manage., 35: 717-720.
Low, W.A., Tweedie, R.L., Edwards, C.B.H., Hodder, R.M., Malafant, K.W.J. and Cunningham, R.B., 1981. The influence of environment on daily maintenance behavior of free-ranging shorthorn cows in central Australia. 1. General introduction and descriptive analysis of day-long activities. Appl. Anim. Ethol., 7: 11-26.
Lush, J.L. and Black, W.H., 1927. How much accuracy is gained by weighing cattle three days instead of one at the beginning and end of feeding experiment. Am. Soc. Anim. Prod. Proc. 1925, 26: 206-210.
Lush, J.L., Christensen, F.W., Wilson, C.V. and Black, W.H., 1928. The accuracy of cattle weights. J. Agric. Res., (Camb.), 36: 551-580.
Martin, S.C., Barnes, K.K. and Bashford, L., 1967. A step toward automatic weighing of range cattle. J. Range Manage., 20: 91-94.
Matches, A.G., 1969. Pasture research methods. Proc. Natl. Conf. Forage Quality Evaluation Utilization, University of Nebraska Sect. 1, pp. 1-32.
McCown, R.L., 1981. The climatic potential for beef cattle production in tropical Australia: Part 1. Simulating the annual cycle of liveweight change. Agric. Syst., 6: 303-317.
Morgan, P.J., Pienaar, J.P. and Clark, R.A., 1976. Animal-based methods of determining herbage intake and quality under grazing conditions. Proc. Grassl. Soc. South Africa, 11: 73-78.
Mott, G.O., 1959. Symposium on forage evaluation: IV. Animal variation and measurement of forage quality. Agron. J., 51: 223-226.
Patterson, R.E., 1947. The comparative efficiency of single versus three-day weights of steers. J. Anim. Sci., 6: 237-246.
Rotschke, W. and Lampeter, W., 1977. Studies regarding the influence of weather conditions on the performance of grazing cattle. Proceedings of the XIII International Grassland Congress, Vol. II, pp. 879-883.
SAS, 1982. SAS User's Guide. Statistical Analysis System Institute, Cary, NC, 494 pp.
Sigrims, N.A. and Scott, N.R., 1984. A passive electronic identification system for livestock. In: Agricultural Electronics - 1983 and Beyond; Vol. II. Controlled environments livestock production systems materials handing and processing. Proc. Natl. Conf. Agric. Elec. Appl. ASAE Publ. 9-84. Am. Soc. Agric. Eng., St. Joseph, MI, pp. 543-555.
Squires, V.R. and Siebert, B.D., 1983. Botanical and chemical components of the diet and liveweight change in cattle on semi-desert rangeland in Central Australia. Aust. Rangeland J., 5: 28-34.
Suzuki, S. and Sawamura, H., 1981. On the diurnal pattern of weight change of heifers as a characteristic of the grazing behavior under rotational grazing. J. Jpn. Grassl. Sci., 27: 324-331.
Ward, D.E., 1975. Seasonal weight changes of cattle on semidesert grass-shrub ranges. J. Range Manage., 28: 97-99.
Whiteman, J.V., Loggins, P.F., Chambers, C., Pope, L.S. and Stephens, D.F., 1954. Some sources of error in weighing steers off grass. J. Anim. Sci., 13: 832-842.
Wythes, J.R. and Shorthose, W.R., 1984. Marketing cattle: Its effects on liveweight, carcasses and meat quality. Aust. Meat Res. Commun. Rev., No. 46.

APPENDIX

A hypothetical set of cow liveweight data is given in Appendix Table 1 to illustrate the procedures used on the actual liveweight data. First, the mean of all automatically obtained liveweights in a given week were calculated. Second, an estimate of the within cow-week (intra-week) variance was found. Third,

APPENDIX TABLE 1

Hypothetical example of a cow's liveweight (kg) obtained manually and automatically over 56 days, and the statistical procedures used to determine if a change in liveweight was statistically ($P=0.10$) significant

Weighing method[a]	Period of 28 days	Week	Number of automatic weighings per week	Mid-week day[b] [D]	Liveweight: Automatic and (manual)	Automatic, weekly means and intra-week variance[c]: $[\bar{X}_A]$	$[S^2]$	df	Manual, consecutive means $[\bar{X}_M]$	Manual predicted[d] $[\hat{Y}_M]$
M	-[k]	-			(459)				(473)	
A	1	1			452					
A	1	1	2	3.5	463	458	60.50	1		(463)
A	1	2	1	10.5	484	484	-	-		(470)
A	1	3			463					
A	1	3			472					
A	1	3			488					
A	1	3	4	17.5	480	476	114.92	3		(477)
A	1	4			475					
A	1	4	2	24.5	480	478	12.50	1		(484)
M	-	-			(487)				(494)	
A	2	5			475					
A	2	5	2	31.5	470	473	12.50	1		(489)
A	2	6			465					
A	2	6			462					
A	2	6	3	38.5	455	461	26.33	2		(492)
A	2	7			467					
A	2	7	2	45.5	470	469	4.50	1		(496)
A	2	8			475					
A	2	8			480					
A	2	8	3	52.5	490	482	58.33	2		(499)
M	-	-			(501)					

[a]M = manual; A = automatic.

[b]Days at mid-week used to predict liveweight from regression equation fit to manual weighings.

[c]$s^2 \text{ pooled} = \frac{\epsilon(n_i - 1)(s_i^2)}{\epsilon(n_i - 1)}$

$= \frac{1 \times 60.5 + 3 \times 114.9 + 1 \times 12.5 + ...}{11}$

$= 54.9$, 11 degrees of freedom (df)

[d]Predicted liveweights were calculated from regression lines fit to manually obtained liveweights at the weekly mid-points.

$\hat{Y}_{01} = 459 + 1.0 \times \text{day} = 473 + 1.0\ (\text{day} - 14)$

$\hat{Y}_{12} = 473 + 0.5 \times \text{day} = 494 + 0.5\ (\text{day} - 42)$

Absolute differences ± standard deviations						t values which must be equalled or exceeded $P=0.10$		
$[\bar{X}_A-\bar{X}_M]$	$[S]^e$	$[\bar{X}_A-\hat{Y}_M]$	$[S]^f$	$[\bar{X}_{A_1}-\bar{X}_{A_2}]$	$[S]^g$	$[\bar{X}_A,\bar{X}_M]^h$	$[\bar{X}_A,\hat{Y}_M]^i$	$\bar{X}_{A_1},\bar{X}_{A_2}]^j$
15	7.40	5	8.79			2.10	0.60	
11	9.10	14	8.79	26	9.07	1.20	1.58	2.87
3	6.40	1	4.72	8	8.28	0.40	0.11	0.97
5	7.40	6	6.00	2	6.42	0.60	0.72	0.31
21	7.40	16	8.79	5	7.41	2.90	1.94	0.67
33	6.80	31	6.37	12	6.76	4.90	4.58	1.78
25	7.40	27	6.00	8	6.76	3.40	3.61	1.18
12	6.80	17	5.18	13	6.76	1.80	2.24	1.92

[e] $s=\sqrt{s^2_{pooled}(1/2+1/n_i)}$

[f] $s=\sqrt{s^2_{pooled}\left[1/2+2\left(\frac{day-14}{28}\right)^2+1/n_i\right]}$

[g] $s=\sqrt{s^2_{pooled}[1/n_i+1/(n_i+1)]}$

[h] Absolute values of t used to assess evidence against the assumption of "no difference" in the mean of the automatically obtained liveweights and the mean of the manually obtained liveweights.

[i] Absolute values of t used to assess evidence against the assumption of "no difference" in the mean of the automatically obtained liveweights and the predicted liveweight based on manual weighings.

[j] Absolute values of t used to assess evidence against the assumption of "no difference" between the means of automatically obtained liveweights taken in separate weeks.

[k] No data.

a regression equation was developed for Periods 1 and 2 (see Appendix Table 1) based on manual weighings taken on Days 0, 28 and 56. Fourth, the appropriate regression equations were used to calculate predicted values at mid-week days (3.5, 10.5, etc.). Fifth, the absolute values of differences between weekly means (automatic and manual), weekly means and predicted values (automatic and manual) and weekly means of only the automatically obtained data were computed along with their estimated standard deviations. Sixth, *t* tests were run on all absolute differences and judged for significance at the 10% level. The proportion of these tests judged significant were then tabulated (Tables 1, 2 and 3) as a function of the range and cow states. In evaluating the correlations between differences within a cow-range state, the size of correlation depends on: (1) whether the 2 differences were within the same week, consecutive weeks or 2 weeks removed; (2) sample sizes for the automatically obtained data in the 2 weeks whose correlations were being evaluated.

RESUME

Anderson, D.M. et Weeks, D.L., 1989. Estimation du poids vif des bovins de façon continue ou par intermittence. *Livest. Prod. Sci.*, 23: 117—135 (en anglais).

Le poids vif de la vache pâturant en liberté change constamment. Si on la pèse automatiquement quand elle entre boire dans le corral, on obtient un profil de poids vif qu'on peut utiliser pour conduire ses performances. On peut aussi la peser manuellement à intervalle de 28 jours. On a appliqué ces deux méthodes aux mêmes vaches d'un troupeau expérimental afin de comparer les informations qu'elles fournissent. On a classé les données, se référant à 1281 pesées manuelles et 40 000 pesées automatiques, selon le stade phénologique des plantes pâturées et selon le stade physiologiques des vaches. En supposant que la vache reste biologiquement la même au cours d'une période d'une semaine, on peut déceler une variation de 11% de son poids dans 90%du temps avec seulement une pesée automatique additionelle. Des modifications réelles de seulement 5% du poids peuvent être décelées de la même façon si on enregistre plus d'une seule pesée. On peut donc utiliser la pesée automatique non seulement pour estimer les effects de la conduite antérieure, mais aussi pour décider au jour le jour de la conduite de certains animaux.

KURZFASSUNG

Anderson, D.M. und Weeks, D.L., 1989. Zur Erhebung von Rindergewichten auf einer kontinuierlichen bzw. diskontinuierlichen Basis. *Livest. Prod. Sci.*, 23: 117-135 (auf englisch).

Das Lebengewicht einer Kuh auf der Weide verändert sich fortlaufend. Wenn das Gewicht automatisch beim Eintritt in das Gehege zur Wasseraufnahme festgestellt wird, entsteht ein Gewichtsprofil, welches zur Überwachung ihrer Gewichtsentwicklung herangezogen werden kann. Die Abstand führt ebenfalls zu einem Lebendgewichtsprofil. Es wurden die gleichen Kühe einer Versuchsherde mit beiden Verfahren gewogen, um den unterschiedlichen Informationsgehalt beider Verfahren zu bestimmen. Die gefundenen Daten bezogen sich auf 1281 manuelle und etwa 40 000 automatische Wiegungen und wurden daraufhin entsprechend des Wachstumsstandes der ver-

zehrten Pflanzen und dem physiologischen Status der Kuh ausgewertet. Unter der Annahme, da eine Kuh biologisch im Zeitraum von 7 Tagen gleich bleibt, kann mit einer zusätzlichen automatischen Wiegung eine Veränderung des Lebendgewichtes von 11 Prozent in 90 Prozent der Fälle festgestellt werden. Reale Gewichtsveränderungen von rd. 5 Prozent können bei gleicher Fehlerrate festgestellt werden, wenn mehrere Wiegungen vorgenommen werden. Deshalb können automatische Gewichytsfeststellungen nicht nur dazu dienen, die Auswirkungen von Management-Praktiken der Vergangenheit zu überprüfen, sondern sie sind auch nützlich, um tägliche Entscheidungen über Einzeltiere in der Herde zu unterstützen.