Applied Animal Behaviour Science, 16 (1986) 11—23
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

USING DIGITAL PEDOMETERS TO MONITOR TRAVEL OF COWS GRAZING ARID RANGELAND[1]

D.M. ANDERSON

Jornada Experimental Range, Agricultural Research Service, U.S. Department of Agriculture, Box 3JER, NMSU, Las Cruces, NM 88003 (U.S.A.)

N.S. URQUHART

New Mexico State University, Las Cruces, NM 88003 (U.S.A.)

Cooperative investigations of Agricultural Research Service, U.S. Department of Agriculture and the New Mexico Agricultural Experiment Station. Journal Article 1139, Agricultural Experiment Station, New Mexico State University, Las Cruces

(Accepted for publication 22 October 1985)

ABSTRACT

Anderson, D.M. and Urquhart, N.S., 1986. Using digital pedometers to monitor travel of cows grazing arid rangeland. *Appl. Anim. Behav. Sci.*, 16: 11—23.

Cows grazing large (3000+ ha) arid rangeland paddocks were fitted with digital pedometers. Raw pedometer readings should be corrected for instrument and cow biases by calibrating the pedometers to individual cows, because both cows and pedometers exhibited substantial variability. If routine procedures are followed for recording pedometer readings and adjusting them with the calibration information, digital pedometers appear to be a promising tool to monitor travel of grazing cows. In the context of this study, age of cow and pregnancy status had no apparent effect on the distance these mature cows traveled. However, genotype, external parasites and movement of the herd to a new paddock did have an influence. Because mean daily travel of grazing cows appears to be influenced by management decisions, the impact of various management alternatives deserves further research. Bipedometered cows can contribute to such research, but this work shows that accurate comparisons of distances traveled require a substantial number of bipedometered cows.

INTRODUCTION

Grazing probably accounts for the greatest amount of travel (Wagnon, 1963) and is the primary mechanism by which the free-ranging animal lo-

---

[1] Mention of a trademark does not constitute a guarantee or a warranty of the product by the United States Department of Agriculture, Agricultural Research Service or New Mexico State University, and does not imply its approval to the exclusion of other products that may be suitable.

cates food. When livestock are moved into a new paddock, travel often increases as animals explore the new area (Arnold and Dudzinski, 1978; Gluesing and Balph, 1980). External factors such as horn flies, *Haematobia irritans*, have been shown to increase cattle travel (Harvey and Lauchbaugh, 1982). In addition to external stimuli, cattle containing *Bos indicus* genes tend to travel further on a daily basis compared to *Bos taurus* cattle (Hafez and Bouissou, 1975). However, breeds within the *Bos taurus* species may not travel differently if managed together (Oldenbroek and Jansen, 1979).

Early studies estimated animal travel by following an animal on foot (Cory, 1927) or with a vehicle (Dwyer, 1961). The need for intensive field labor to obtain travel data has been reduced by appropriate instrumentation (Cresswell and Harris, 1959; Anderson and Kothmann, 1977) and mathematics (Kubo, 1978). Pedometers proved inadequate for monitoring sheep travel (Powell, 1968; Furnival et al., 1982), but were successful with free-ranging cattle (Anderson and Kothmann, 1977; Walker et al., 1985).

There were five objectives in this study: (1) to quantify the influence of subjective judgements in obtaining odometer readings from digital pedometers; (2) to determine the utility in using an adjustment factor to reduce the bias contained in raw odometer readings; (3) to document the instrument-to-instrument variation within and among cows; (4) to quantify cattle travel as influenced by age, reproductive status, genetic background and management; (5) to determine the number of bipedometered cows needed to conduct an experiment to a specific predetermined level of precision.

MATERIALS AND METHODS

The study was conducted between 13 April and 8 June 1983 on the Jornada Experimental Range (32°37'N, 106°45'W) in Dona Ana County, New Mexico. Two paddocks, ranging in elevation between 1310 and 1341 m above sea level, were used for the study. A 3634-ha, rectangular-shaped paddock (2S) was used first. An adjoining 3058-ha, triangular-shaped paddock (4) was used second. Both paddocks were located on sandy soils characterized as mesquite dune rangeland. Vegetation within the study area consisted predominantly of the grass mesa dropseed (*Sporobolus flexuosus*) and the shrub honey mesquite (*Prosopis juliflora* var. *glandulcsa*). Perennial and annual forbs were also numerous. Meteorological data were recorded at ranch headquarters, located at the southeastern corner of the triangular-shaped paddock, and have been summarized in Table I.

This study was conducted with bipedometered cows which were managed as one herd and allowed to graze 2 adjoining paddocks in sequence. The cows differed in several characteristics. some were pregnant, others were not; some were pure-bred Hereford while the rest were Hereford × Santa Gertrudis cross-breds; their ages were 5, 6 and 7 years old (Table II). Each animal was assigned 2 digital pedometers, one for the metacarpus of each foreleg, to be worn throughout the study. The average of the 2 odometer

TABLE I

Mean 7-day maximum and minimum ambient air temperatures and precipitation recorded at the Jornada Experimental Range headquarters, and mean hours between sunrise and sunset per 7-days for latitude 32°18'N, longitude 106°46'W between 13 April and 8 June 1983

Week	Period analyzed[1]	Temperature (°C)		Total precipitation (mm)	Daylight (h)
		Max.	Min.		
1	1	19	–1	0	12.97
2[2]		24	4	0	13.18
3	2	24	6	0	13.36
4		27	5	0	13.56
5	3	26	2	0	13.73
6		27	6	1.5	13.88
7	4	32	11	2.1	14.01
8		31	8	0.5	14.11

[1] A period refers to 14 days and represents the shortest interval over which travel can be calculated if odometers are read on a weekly basis.

[2] A time-change took place at 02.00 h on 23 April 1983 from mountain standard time to mountain daylight time.

TABLE II

Breed, age, number and mean liveweight[1] of cows monitored for distance traveled with digital pedometers between 13 April and 8 June 1983 on the Jornada Experimental Range

Breed[2]	Age (years)	No.	Mean weight (kg)
Hereford	7	5	392
	6	7	397
Crossbred	7	3	426
	6	4	429
	5	9	427
Total		28	
Mean			415

[1] Liveweights were taken at the initiation of the study after the majority of the herd had had an overnight of drylot shrink.

[2] The cross-bred cows were of Hereford × Santa Gertrudis and the reciprocal cross.

readings from each cow in the herd formed the data base used to describe the travel profile of the herd, but individual pedometers provided data for evaluating instrument comparability. Each instrument was switched to the opposite leg on the same cow on 25 May. Adjustment factors obtained on 11 May were used to adjust all raw travel data obtained between then and

25 May; thereafter, adjustment factors obtained on 8 June were used. This procedure assured a correspondence between the adjustment factors and leg—instrument combinations.

This study was conducted over 8 weeks, broken into 4 periods, each 2 weeks in length (Fig. 1). The first period ended when the cows were moved to the smaller pasture. The second period ended when a polyvinylchloride ear-tag impregnated with 10% Permetrin was put in each animal's right ear to reduce horn-fly infestations. The last period began when the pedometers were switched to opposite legs.

Odometer readings were taken from the pedometers, following trapping of the cows in a corral by bayonet gates as they came to drink water (Anderson and Smith, 1980). Trapping began on Tuesday of each week. Most odometer readings were taken on Wednesday morning, after which cows were released back into the paddock. In addition to the weekly odometer readings, date, time of day, pedometer identification, animal identification and leg identification were recorded in the field. Analyzable data were obtained from 28

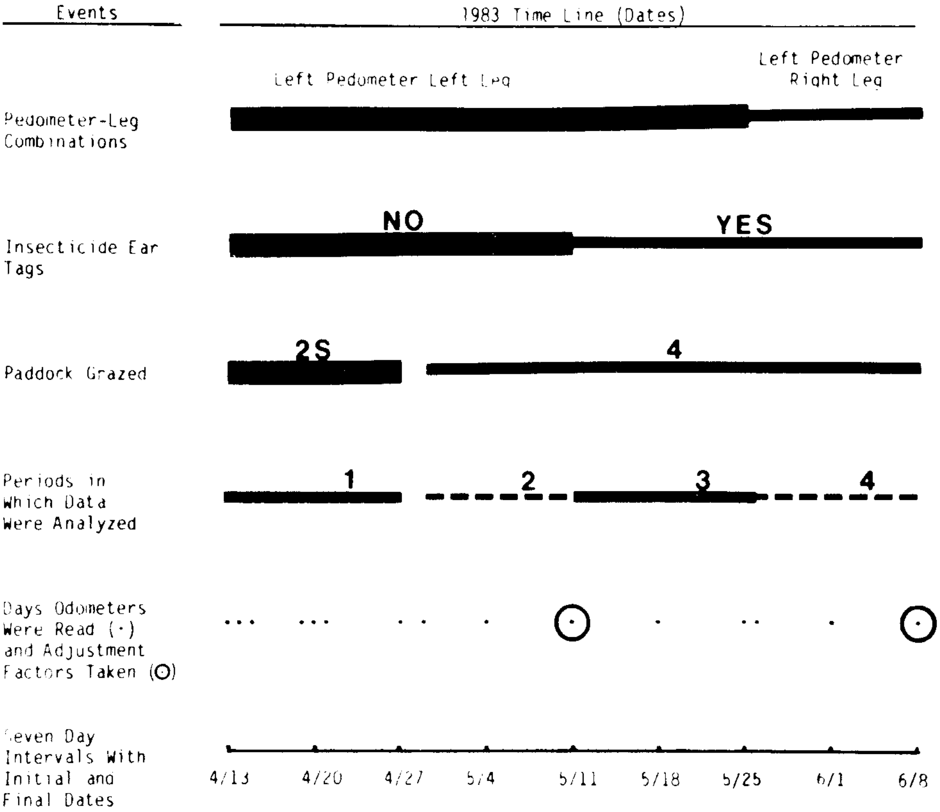

Fig. 1. Time-line indicating pedometer—leg combination, insecticide treatment, grazing location, periods data were analyzed, and days odometer readings and adjustment factors were taken between 13 April and 8 June 1983.

of the 34 cows wearing Edge-Mark Digital pedometers. The 6 cows without analyzable data either had pedometers that failed or the animals escaped evalution in one of the weeks. The liveweight of the 28 cows ranged from 392 to 429 kg. A minimum pace-length setting, as described by Anderson and Kothmann (1977), was used with the pedometers.

Sometimes the odometers provided unique readings, but more often (60% of the readings) they required judgement to obtain a specific reading. The odometer portion of the pedometer consisted of 3 separately activated wheels, each having consecutively numbered positions from 0 to 9. When read from left to right, the 3 wheels represented tens, ones and tenths of miles. Wheel positions were displayed under a plastic window on top of the pedometer. If the numbers on the wheels did not align directly under the window, parts of 2 consecutive numbers appeared on the same wheel and a split number was seen. When this condition was observed, both numbers were recorded in the field from any or all of the 3 odometer wheels. Back in the laboratory, a judgment was made about which number to use, based on the following criteria. By convention, the even numbers were always chosen when split numbers occurred in the tenths position. If split numbers were observed in the ones position, the larger of the 2 consecutive numbers was recorded when the value in the tenths position was 0 or 1; otherwise, the smaller of the split numbers was recorded for the ones position. This convention was based on the presumption that if the number in the tenths position was a 0 or 1, then the ones-position wheel was sluggish in responding or carrying forward; therefore, the larger of the split numbers would be correct. Otherwise, the presumption was that the ones-position wheel had begun to carry forward too soon; therefore, the smaller number would be correct. If the number in the tens position was split, the majority of the time, the smaller number was chosen. However, this judgment involved checking the split number within the context of the animal's previous travel record and the travel record of the other cows during the same time-interval.

To reduce bias within each animal/leg/instrument combination, a unique adjustment factor (A_F) was evaluated for each animal/leg combination. However, no studies have been published on how frequently this adjustment factor needs to be determined. The adjustment factor was obtained by walking the animals along a fence over a distance of 2 miles and taking 3 odometer readings. By subtracting the initial odometer reading from the third and final reading, the change in instrument readings was obtained. The second odometer reading, taken at the end of the first mile, provided a check on equipment function and was used only if the total distance was not covered by the animal walking; e.g. the animal breaking into a run. If the instrument was recording exact distance traveled, this difference would be exactly 2 miles, but this was seldom the case. Instrument distance was divided by the measured distance to get the adjustment factor for that pedometer—leg combination. Both raw travel (in instrument units) and adjusted travel (in miles) were analyzed. However, only adjusted travel expressed in km/day is presented in the results and discussion section. The adjusted mean distance traveled each week was evaluated from each pedometer as follows:

$$T = \left[\frac{(F - I)(A_{\mathrm{F}})}{(E)}\right] \left[K\right] \qquad (1)$$

where

T = Distance traveled (km/day)
F = Final odometer reading (instrument units [iu])
I = Initial odometer reading (iu)
A_{F} = Adjustment factor (miles/iu)
E = Elapsed time between when I and F were taken (h)
K = Constant of 38.616 to convert miles/h to km/day (h-km/day/miles)

Data were analyzed using the General Linear Models (GLM) procedure in the Statistical Analysis System (SAS, 1979) computer system. Statistical models used for these analyses included factors for time-interval (period), cows and an appropriate cow-leg, cow-age, cow-breed and pedometer identification. All models used recognized that multiple determinations were made on the same cows. Least square means with significance levels are presented.

RESULTS AND DISCUSSION

Variability and pedometers

The subjective judgments that had to be made when odometers contained split numbers caused concern regarding the accuracy of the pedometers to monitor the travel of cows. However, comparison of the adjusted travel data with that predicted by the model, i.e. residual analysis, revealed no pattern that could be associated with split numbers occurring in any of the odometer positions. When subtracting consecutive odometer readings, 38.5% of the combinations were whole, not split, numbers. Split numbers in the tens position of both initial and final readings accounted for only 15.5% of the data (Table III). A thorough analysis of the data leading to Table III indicated that some pedometers were more prone to split numbers than others.

The utility of using a factor to adjust raw odometer readings from grazing cows has only recently been investigated (Walker et al., 1985). In our study, adjustment factors ranged between 0.59 and 2.00, with a mean and standard deviation of 1.15 ± 0.31 miles/instrument unit. Because adjustment factors for a specific pedometer/animal/leg combination differed ($P<0.001$), a unique adjustment factor for each instrument–leg combination appeared to increase the precision in comparisons of mean daily travel between cows and between treatments involving herd differences. The differences seen between the adjustment factor obtained for the pedometer worn on the left leg compared to the one worn on the right leg indicated the magnitude of instrument-to-instrument variation. The variability demonstrated in both the animal's stride and the pedometer's recording mechanism interact simultaneously to produce the unique adjustment factors that arise for each instrument—leg combination. If the pedometers were without bias, the 2 adjustment factors for any given cow would be equal (accurate). However, the deviation between the 2 adjustment factors within a cow indicated individual pedometer bias.

TABLE III

Percentage of occurrences in which split (x) and whole (0) numbers were encountered in 400 pairs of odometer readings when initial pedometer readings were subtracted from final pedometer readings

Initial readings	Final readings								Total
	xx.x	xx.0	x0.x	x0.0	0x.x	0x.0	00.x	00.0	
xx.x	1.25	1.75	0.25	0.00	0.00	1.00	0.25	0.50	5.00
xx.0	2.00	4.25	0.00	0.00	0.50	0.50	0.00	0.75	8.00
x0.x	0.50	0.00	0.25	1.25	0.00	0.25	0.00	0.00	2.25
x0.0	0.00	0.00	0.75	3.25	0.00	0.00	0.25	0.50	4.75
0x.x	0.50	0.00	0.00	0.00	0.25	1.25	0.50	1.75	4.25
0x.0	0.75	1.00	0.25	0.25	1.50	4.00	0.25	0.75	8.75
00.x	0.25	0.50	0.00	0.00	0.50	0.00	2.75	10.00	14.00
00.0	0.75	0.75	0.50	0.50	2.00	0.75	9.25	38.50	53.00
Total	6.00	8.25	2.00	5.25	4.75	7.75	13.25	52.75	100

It is logical to expect the cow's left leg to travel the same distance as her right leg. If this is true, adjusted odometer readings taken from the left leg should equal those obtained from the right leg, which they did not. With the raw odometer readings, about 30% of the predictable variation in mean daily travel of the cows could be attributed to pedometers (sum of squares between legs divided by the sum of squares of the model; 219/706). Once the difference in consecutive raw odometer readings had been multiplied by the adjustment factor (eqn. 1), variation in the mean daily travel of the cows attributable to the pedometers fell to 18% (88/482). This 12% decrease indicated a substantial reduction in the bias attributable to pedometers. Concomitantly, variation between cows increased from 27 (188/706) to 34% (163/482), showing that some of the cow-to-cow variation was being masked by biases within the pedometers.

Even after adjustment of the odometer readings to remove instrument biases, variation remained. Variance among repeated readings in different weeks in the same period on the same cow was 1.81 $(\text{km/day})^2$. To evaluate variance among cows in different groups, such as breeds, the period × cow interaction gave an appropriate estimate of variance of 3.62 $(\text{km/day})^2$. The fact that the latter variance is twice the former is a coincidence of this experiment, but indicates that instruments and cows are somewhat comparable contributors to variance.

Treatment differences

Walking, grazing or standing while twitching the skin all can result in vertical displacement (counts). The measured distance traveled by a cow depends on the ratio of horizontal displacement to number of vertical displacements counted by the pedometer.

The mean daily travel among the 28 mature cows was quite variable ($P<0.0001$), ranging from 5.6 to 10.6 km/day (3.5 and 6.6 miles/day), with an average of 7.1 km/day (4.4 miles/day). Mean daily travel obtained from the left and right forelegs did not differ ($P>0.25$) over all cows. However, on the same cow, the 2 pedometers did not always indicate that the same distance had been traveled [F (27, 87.11) = 4.57, $P<0.0001$)], indicating that calibration had not removed all of the instrument—cow effects.

The age of the cows (5, 6 or 7 years) showed no effect on daily travel ($P>0.10$), possibly because all the cows were mature. Hereford cows traveled less than the cross-breds; 6.9 versus 7.3 km/day (4.3 and 4.6 miles/day). This 0.4 km/day (0.3 miles/day) increase ($P<0.04$) in travel shown by the crossbred cows agrees with the hypothesis that *Bos indicus* cattle travel further on a daily basis than do *Bos taurus* cattle (Hafez and Bouissou, 1975). The mean daily travel of these same cows apparently was not influenced by physiological condition. Cows in their last trimester of pregnancy did not travel differently ($P>0.75$) from non-pregnant cows.

Ambient weather conditions were considered to be similar throughout the study (Table I), although a small amount of precipitation was recorded during the last 3 weeks of the study. Therefore, it is doubtful if the minor changes in weather recorded during the study were responsible for the significant ($P<0.05$) differences noted between Periods 1 and 2 and Periods 2 and 3. This hypothesis appears to be valid because no trend ($P>0.10$) was seen between Periods 3 and 4 once insecticide and paddock-treatment effects were removed.

The largest difference in mean daily travel of the cows was apparently caused by the paddock change on 29 April. At that time, mean daily travel increased from 5.6 km/day (3.7 miles/day) to 7.7 km/day (4.8 miles/day) ($P<0.0001$). This increase documents what cattlemen report; cattle appear to explore a new paddock. Arnold and Dudzinski (1978) labeled this phenomenon exploratory behavior. The mean daily travel in the new paddock remained above 7.2 km/day (4.5 miles/day) for the remainder of the study (40 days).

Control of horn flies may reduce mean daily travel. Horn-fly control was initiated at the beginning of the third period; mean daily travel decreased slightly from 7.7 km/day (4.8 miles/day) to 7.4 km/day (4.6 miles/day)

(P=0.05). Permetrin ear tags accomplished the desired horn-fly control. Fly populations decreased from approximately 100 flies per cow before ear tags were applied to less than 10 flies per cow thereafter.

Determining precision when using pedometers

Sample-size is often determined by availability of resources; such an experiment may lack precision. On the other hand, a researcher can specify the sample size and desired precision in an objective manner if a prior estimate of variance is available. For example, if Tukey's procedure (Steel and Torrie, 1980) is used for multiple comparisons among the means, then

$$r = \frac{s_1^2 q_\alpha^2(t,f_2) F_\beta(f_2,f_1)}{d^2} \qquad (2)$$

where

s_1^2 = prior estimate of variance based on f_1 degrees of freedom
$q_\alpha^2(t,f_2)$ = tabled value for the Studentized range at a significance level of α for t treatments of f_2 degrees of freedom in the experiment being designed
$1 - \beta$ = Prob. ($w \leqslant d$) where w is the Tukey significant difference (Steel and Torrie, 1980; section 8.6).
$F_\beta(f_2,f_1)$ = upper β point in the F distribution with degrees of freedom f_2 and f_1

see Steel and Torrie, 1980; section 9.15, for example). This formula assumes that its user has a prior estimate of variance (s_1^2), which applies to the planned experimental context, based on f_1 degrees of freedom. Also, its user must decide how big a difference (d) will be uninteresting at a significance level of α.

After the planned experiment is run, its significance will be evaluated using s_2^2 (with degrees of freedom = f_2). The multiplicative factor $F_\beta(f_2,f_1)$ provides a mathematically defensible crib factor that compensates for the lack of precise information about what s_2^2 will be; s_1^2 only estimates what is the common variance. Because f_2 depends on r, and vice verse, eqn. (2) must be solved recursively, but it ordinarily converges in 2 steps.

In the present situation, eqn. (2) must be adapted slightly because the period × cow interaction provides the appropriate estimate of variance. Furthermore, the treatments (t) will be compared by the average across cows in the same treatment. Suppose t = 2, as in comparing the 2 breeds here, and r cows of each breed were evaluated for 4 periods; there would be $4r$ observations in each breed mean. Earlier we reported s_1^2 = 3.62 based on f_1 = 81 degrees of freedom. If a researcher was interested in establishing significance between treatments that led to difference in average distance walked per day of $d \geqslant 2$ km/day, then we might guess that r = 6 cows would be needed in each treatment, or 12 in both treatments, so $f_2 = (4-1)(12-1) = 33$; $q_\alpha(t,f_2) = q_{0.05}(2,33) = 2.86$. Using $1 - \beta = 0.9$, $F_\beta(f_2,f_1) = F_{0.10}(33,81) = 1.40$ so the right-hand side of eqn. (2) becomes

$$\frac{(3.62)(2.86^2)(1.40)}{2^2} = 10.4. \tag{3}$$

This should equal the number of cow-periods in each treatment mean, namely $4r$, which implies that r can be no less than 3. Repeating this process with 3 cows per treatment, we get $f_2 = (4-1)(6-1) = 15$, so

$$\frac{(3.62)(3.01^2)(1.57)}{2^2} = 12.9 \tag{4}$$

which is satisfied by $r = 3$ cows per treatment in 4 periods. This entry appears in the upper part of Table IV in the column for 4 periods and the row for $d = 2.0$.

The number of animals required to sample the daily travel to a specified

TABLE IV

Number of cows per treatment needed to provide the specified assurances $(1 - \beta)$ of achieving the specified precision (d) for various numbers of periods and circumstances

Precision d(km)	Number of 2-week periods					
	2	3	4	5	10	15
Assurance $(1 - \beta) = 0.9$; fixed sample size						
0.25[1]	290	195	145	115	60	45
0.5	72	48	36	29	15	10
1.0	21	14	11	9	5	3
2.0	6	4	3	3	2	1
Assurance $(1 - \beta) = 0.95$; fixed sample size						
0.25[1]	310	210	155	125	65	45
0.5	78	52	39	31	16	11
1.0	23	15	12	9	5	3
2.0	7	5	4	3	2	1
"Survival"	0.96^{2}	0.96^{3}	0.96^{4}	0.96^{5}	0.96^{10}	0.96^{15}
Probabilities	0.922	0.885	0.849	0.815	0.665	0.542
Overall assurance $(1 - \beta) = 0.9$; allowing for instrument failure						
0.25[1]	350	245	195	165	110	95
0.5	90	65	52	44	32	30
1.0	28	20	18	15	12	11
2.0	10	8	7	6	6	5

---

[1] The number of cows in these rows were rounded up to the nearest 5 due to slight limitations in the standard statistical tables.

degree of precision decreases as the precision required decreases and the duration of the study increases (Table IV). However, for great precision (d = 0.25), the number of cows (instruments) required becomes impractical to manage.

The top part of Table IV applies for $1 - \beta = 0.9$ while the middle part relates to $1 - \beta = 0.95$. In a planned experiment in which the amount of data collected remains constant from beginning to end, the number of observations required increases as the assurance of the desired precision increases. However, in studies involving instruments, the probability that an animal—instrument combination remains functional throughout the study is not one. We found that the pedometer failure rate was about 0.04 per period; therefore, the survival rate will be 0.96 per period. To remain functional throughout the study, a unit must survive each period, an event which occurs with 0.96^p where p = number of periods. If the study runs for only 5 periods (10 weeks), the probability that a unit survives the whole study is only 4 out of 5 ($0.96^5 = 0.815$).

To conduct an experiment with the desired precision in the face of unit failure, enough units must be started to give the required number of surviving units at the end of the study. This matter is considered more fully in a forthcoming publication (Urquhart, 1986). With weekly odometer readings, the loss of pedometer data in this study amounted to 0.04 per period (14 days). However, whether a unit survives is also an uncertain event. Thus, the assurance probability must be increased in the usual formula and a chance of failure introduced into the sample sizes. This can be achieved by requiring assurance $(1 - \beta)^{\frac{1}{2}t}$ that the number of units surviving will be large enough to meet the usual sample-size criteria with $1 - \beta$ increased to $(1 - \beta)^{\frac{1}{2}}$.

For example, with $1 - \beta = 0.90$, $(1 - \beta)^{\frac{1}{2}} = (0.90)^{\frac{1}{2}} = 0.9487$ which can be approximated by 0.95. (Approximations are used so that a person can follow the calculations with standard statistical tables.) Likewise, $(0.90)^{\frac{1}{4}} = 0.9740$, similarly approximated by 0.975. Further, consider 4 time-periods so that the survival probability of $0.96^4 = 0.849$, which can be approximated by 0.85. With d = 2 and assurance = 0.95, the middle part of Table IV shows that four animal—instrument units would be needed. If this number of units were started, the binomial probability distribution [$B(4,0.85)$] shows that the probabilities of having 0, 1, 2, 3 or 4 functioning units at the end of the study are 0.0005, 0.0115, 0.0975, 0.3685 or 0.5220, respectively. In other words, there are only about even odds that either treatment will have enough units, or about only 0.25 that both treatments will have 4 functioning units throughout. To get a joint probability of 0.95, or individually of 0.975, more units will have to be started. Would 5 be enough to start? The probabilities of 0, 1, 2, 3, 4 and 5 from $B(5,0.85)$ are 0.0001, 0.0022, 0.0244, 0.1382, 0.3915 and 0.4437, respectively; the probability of getting 4 or more surviving is 0.3915 + 0.4437 = 0.8352, which is substantially less than the required probability of 0.975. Similarly, if we started 6 units, the probability of 4 or more surviving is 0.9527; still not enough. However, if 7 are started, the probability of 4 or more survivors is 0.9879, a bit larger than the required 0.975. In other words, 7 units must be started to have the required assurance that at least 4 will survive in each treatment and, consequently, that the overall experiment will have the desired precision. This value (7) appears as the appropriate entry in the bottom part of Table IV.

CONCLUSIONS

Digital pedometers are a useful tool to monitor travel of grazing cows, provided adjustment factors are used to reduce instrument bias. By reducing instrument bias, the components of variance can be accurately apportioned to the sources; animal, instrument and animal × instrument. Split numbers from the odometer readings do not reduce the pedometer's usefulness if the criteria used in this study are followed when making the subjective judgements required. Because digital pedometers cost relatively little when considered within a study designed to evaluate mean daily travel of cows, the authors would recommend the use of 2 pedometers per cow to reduce the potential amount of data that can be lost as a result of broken or lost instruments. Based on the expected instrument failure rate, it is possible to calculate the number of instrument—animal combinations required to conduct a study of mean daily travel to any specified degree of precision. Frequent odometer readings are recommended. With weekly odometer readings, possible cause and effect relationships that may influence mean daily travel will be associated within a management time-frame, and loss of data from broken pedometers will be detected after only a minimum of time has elapsed.

The major thrust of this study was to evaluate how to effectively use digital pedometers as a tool to monitor travel of grazing cows. Conclusions involving treatments must be viewed as tentative, because all treatment results are confounded with time. Pedometers should only be used to evaluate treatment differences when the assumption is that treatments will not influence the number of counts recorded, because pedometers count relative, and not absolute, distances.

From this study, mean daily travel of mature cows grazing arid rangeland between April and June 1983 was not influenced by age or physiological condition of the cow related to pregnancy. However, when horn flies were controlled, a corresponding reduction in mean daily travel of 4% was recorded. A 30% increase in the mean daily travel of the grazing herd was recorded when the herd was moved to a fresh paddock. This study also supports previously documented studies that indicate that cows with *Bos indicus* genes will travel farther on a daily basis compared to *Bos taurus* cattle.

From these tentative results, it appears that the mean daily travel of cows can be manipulated by management decisions. Knowledge of animal travel may prove useful in designing grazing strategies (Anderson and Kothmann, 1980). However, if cause and effect relationships are not clear, care must be used when translating behavior data into management guidelines (Tribe, 1950). A further understanding of factors that influence travel will allow breakthroughs in optimizing the grazing cow's endergonic requirements for maintenance and production.

REFERENCES

Anderson, D.M. and Kothmann, M.M., 1977. Monitoring animal travel with digital pedometers. J. Range Manage., 30: 316—317.

Anderson, D.M. and Kothmann, M.M., 1980. Relationship of distance traveled with diet and weather for Hereford heifers. J. Range Manage., 33: 217—220.

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

Arnold, G.W. and Dudzinski, M.L., 1978. Ethology of Free-Ranging Domestic Animals. Elsevier, New York, 198 pp.

Cory, V.L., 1927. Activities of livestock on the range. Tex. Agric. Exp. Stn. Bull. 367, 47 pp.

Cresswell, E. and Harris, L.E., 1959. An improved rangemeter for sheep. J. Anim. Sci., 18: 1447—1451.

Dwyer, D.L., 1961. Activities and grazing preferences of cows with calves in Northern Osage County, Oklahoma. Okla. Agric. Exp. Stn. Bull. 588, 61 pp.

Furnival, E.P., Philip, S.A. and Corbett, J.L., 1982. Measurements with a pedometer of distances walked by sheep. Proc. Aust. Soc. Anim. Prod., 14: 654.

Gluesing, E.A. and Balph, D.F., 1980. An aspect of feeding behavior and its importance to grazing systems. J. Range Manage., 33: 426—427.

Hafez, E.S.E. and Bouissou, M.F., 1975. The behaviour of cattle. In: E.S.E. Hafez (Editor), The Behaviour of Domestic Animals. Ballière, Tindall and Cassell, London, pp. 203—245.

Harvey, T.L. and Launchbaugh, J.L., 1982. Effect of horn flies on behavior of cattle. J. Econ. Entomol., 75: 25—27.

Kubo, S., 1978. A simple method of measuring travel distance of livestock in pasturing. JARQ, 12: 141—144.

Oldenbroek, J.K. and Jansen, A.A.M., 1979. The effect of the grazing behaviour of a breed on the performance of another breed when they are grazing together. Z. Tierz. Zuechtungsbiol., 95: 132—139.

Powell, T.L., 1968. Pedometer measurements of the distance walked by grazing sheep in relation to weather., J. Br. Grassl. Soc., 23: 98—102.

Statistical Analysis System Institute, 1979. SAS User's Guide. SAS Institute, Raleigh, NC, 494 pp.

Steel, R.G.D. and Torrie, J.H., 1980. Principles and Procedures of Statistics. 2nd edn. McGraw-Hill, New York, 633 pp.

Tribe, D.E., 1950. The behaviour of the grazing animal: A critical review of present knowledge. J. Br. Grassl. Soc., 5: 209—224.

Urquhart, N.S., 1986. Sample size determinations when experimental units can "die". Technical Report No. 41, University Statistics Center, New Mexico State University, Las Cruces, NM.

Wagnon, K.A., 1963. Social dominance in range cows and its effect on supplemental feeding. Calif. Agric. Exp. Stn. Bull. 819, 31 pp.

Walker, J.W., Heitschmidt, R.K. and Dowhower, S.L., 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. J. Range Manage., 38: 90—93.