Sampling Requirements of the Water-Intake Method of Estimating Forage Intake by Grazing Cattle[1]

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Highlight

The water-intake method of estimating forage intake by grazing cattle can permit a valuable extension of research on semiarid grasslands, but eventually we shall require a wider applicability and greater assurance of accuracy than can be attained at present. This method requires the measurement of water drunk, mean air temperature, and moisture content of forage. Sampling requirements of each measurement were evaluated in 1966 and limits of application were defined in terms of mean air temperatures and moisture contents of forage.

The water-intake rates of "European" breeds of cattle published by Winchester and Morris (1956) were used to develop a water-intake method of estimating forage intake by grazing cattle (Hyder et al., 1966). The method requires the measurement of drinking water, air temperature, and moisture content of forage. Each of these measurements presents sampling problems that must be reconciled with respect to sampling precision and limits of application.

Drinking water can be measured accurately. However, since mean water-intake rates are not applicable to individual animals, problems in sample size and sampling precision arise from the variability among animals, and among days by animals, in the amounts of water drunk. Individual animal-day observations are needed to develop a sample structure in terms of the number of animals included in the sample and the number of days during which drinking water is measured.

The measurement of air temperature in an instrument shelter located on a pasture can be accomplished with sufficient accuracy. However, the procedure of averaging maximum and minimum temperatures to estimate the mean should be compared with more detailed procedures. In addition, the wide variability of water-intake rates at high temperatures imposes a practical limit of applicability of the water-intake method.

The moisture content of forage is estimated from hand-plucked samples of herbage taken to approximate that eaten by grazing animals. The objective in sampling is to determine the average moisture

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Table 1. Forage intake by yearling Hereford steers in 1966.

Grazing period & date	Mean air temp. (°F)	Water source H_f (%)	Water source H_d (gal/day)	G (lb/day)	W (lb)	F (lb/day)	F_{adj} (lb/day)
1. 5/31–6/14	58	48	5.5 ± 0.9	1.7 ± 0.4	463 ± 26	16.5	16.7 ± 1.7
2. 6/14–6/28	65	71	5.4 ± 1.0	2.1 ± 0.2	490 ± 26	26.4	25.4 ± 2.9
3. 6/28–7/12	74	58	7.9 ± 1.1	2.2 ± 0.4	520 ± 26	19.4	17.8 ± 1.6
4. 7/12–7/26	73	49	9.0 ± 1.1	2.3 ± 0.3	550 ± 30	20.0	17.5 ± 1.4
5. 7/26–8/9	70	51	8.3 ± 0.8	2.4 ± 0.2	583 ± 31	20.3	17.2 ± 1.1
6. 8/9–8/23	64	69	6.4 ± 0.8	2.2 ± 0.2	614 ± 31	28.9	23.5 ± 2.1
7. 8/23–9/6	66	70	7.0 ± 0.9	2.6 ± 0.1	652 ± 24	31.1	24.1 ± 3.3
8. 9/6–9/20	59	68	6.6 ± 1.0	3.0 ± 0.4	690 ± 22	33.5	24.8 ± 3.5
9. 9/20–10/4	57	56	6.5 ± 0.6	2.6 ± 0.6	730 ± 21	22.6	16.1 ± 1.4

H_f, The mean moisture content of fresh hand-plucked herbage.
H_d, Mean daily amount of water drunk and standard deviation (s.d.) among steers. The numbers of steers observed were 12, 12, 12, 12, 11, 10, 6, 6, and 6 in chronological order by grazing periods.
G, Mean daily gain and s.d. among steers.
W, Mean liveweight "in" each grazing period and s.d. among steers.
F, Estimated forage intake in pounds of dry matter per day.
F_{adj}, Forage intake as adjusted to a constant metabolic size ($W^{.75}$) of 100, and confidence limits at the 5% probability level.

content of forage in a 2-week period. This requirement imposes a considerable problem because the moisture content of forage not only changes more or less gradually through the season, but also may fluctuate diurnally and change sporadically with precipitation or the whims of animal preference. The difficulty one encounters in approximating the animal diet can vary from slight to extreme. In addition, the need for accuracy in estimating the mean moisture content of forage becomes more and more critical as the moisture content increases. Absolute limits of application of the water-intake method are imposed by high moisture contents of forage that supply the total amount of water needed by cattle. These absolute limits were given in a previous paper (Hyder et al., 1966). Practical limits of application must occur at lower moisture contents than those which define the absolute limits. Thus, sampling requirements of the hand-plucking procedure and practical limits of application should be determined.

This paper presents the results of a grazing trial undertaken in 1966 to determine sampling requirements for the measurement of drinking water, air temperature, and moisture content of forage.

Methods

Twelve average-sized yearling Hereford steers were selected out of a single-owner lot of about 90 steers delivered to the Central Plains Experimental Range for "summer" grazing. These 12 steers were assigned a half section of blue-grama range, which then was grazed continuously from May 17 to October 5, 1966. Six of the 12 steers were removed from pasture for use in other research during part of the season. The first 2 weeks, May 17–30, were reserved for preconditioning and training of steers. Measurements and observations were initiated on May 31.

Metered drinking water was provided in pens to which individual steers were admitted daily from about 11 AM to 4 PM. Water meters were read daily Monday through Friday to obtain individual animal-day observations of water drunk. On Saturday and Sunday, when water meters were read to determine evaporation losses from individual waterers, drinking water was provided in a common tank. Records of water drunk were omitted for days when rain water was ponded on the pasture.

Air temperatures were recorded continuously by thermograph placed in an instrument shelter located near the pens.

Hand-plucked samples of herbage were collected by an observer as he moved with the grazing animals during each morning and evening grazing period on Tuesday, Wednesday, and Thursday each week. Samples of freshly-dropped feces also were collected at these times. All samples were collected in plastic bags, then dried in a forced-air electric oven at 70 C for 12 to 24 hr to determine moisture contents.

The steers were weighed directly from pasture on their way to water on 3 consecutive days every 2 weeks. Estimated forage intake was adjusted to a constant metabolic size ($W^{.75}$) of 100 to remove the seasonal effect of increasing animal size.

Results

Estimated Forage Intake.—As estimated by the water-intake method, mean forage intake in consecutive 2-week grazing periods varied from 16.5 lb/day of oven dry matter to a high of 33.5 lb/day (Table 1). Seasonal increases in forage intake associated with increases in liveweights are removed by adjusting the estimates to a constant metabolic size. Adjusted forage intake (F_{adj}), which varied from a minimum of 16.1 lb/day in late September to a maximum of 25.4 lb/day in late June, was highly correlated ($r = 0.93$, $n - 2 = 7$) with the moisture content of hand-plucked herbage (H_f). The confidence limits of the adjusted-forage-intake estimates, based upon the variability among steers, vary from 6 to 14% of the mean. Large confidence

Table 2. Analysis of variance among individual animal-day amounts of water drunk, and components of variance.

Analysis of variance (pooled)[a]

	Source	d.f.	Ssqs.	Msq.
(S)	Steers	16	462.0	28.9**
(W)	Weeks	16	1531.3	95.7**
(e)	S × W	122	203.1	1.7
(D)	Days in weeks	72	752.9	10.5**
(E)	Discrepancy	552	465.5	0.8
	Total	778	3414.8	

** Significant at 1%.

Components of variance (pooled)[a]

S: $\sigma_E^2 + 5\sigma_e^2 + 45\sigma_S^2 = 28.9, \sigma_S^2 = 0.6$

W: $\sigma_E^2 + 5\sigma_e^2 + 45\sigma_W^2 = 95.7, \sigma_W^2 = 2.1$

e: $\sigma_E^2 + 5\sigma_e^2 = 1.7, \sigma_e^2 = 0.2$

D: $\sigma_E^2 + 9\sigma_D^2 = 10.5, \sigma_D^2 = 1.1$

E: $\sigma_E^2 = 0.8, \sigma_E^2 = 0.8$

[a] The amounts of water drunk by 12 steers in the first 8 weeks and by 6 steers in the last 10 weeks were analyzed separately and pooled.

limits are associated with high moisture contents of forage, suggesting that lush forage presents difficult sampling problems. High moisture contents of forage were encountered in grazing periods 2, 6, 7, and 8, when the steers selected Russian thistle (*Salsola kali*) in preference to blue grama (*Bouteloua gracilis*). Since the forage-intake estimate in each of these 4 grazing periods is unusually large, it is also necessary to consider the possibility of positive bias.

Amounts of Water Drunk.—In the analysis of water drunk, the first 8 weeks with 12 steers and the last 10 weeks with 6 steers were pooled to obtain average components of variance (Table 2). All main-effect sources of variation are significant. Seasonal changes in the amounts of water drunk, as defined by differences among weeks, provide the largest component of variation (Table 3). The small mean square for steers by weeks (S × W) shows that differences among steers tend to continue through the season.

Differences among consecutive days in weeks show the importance of maintaining continuous measurements of water drunk. This measurement of drinking water is, therefore, treated as a parameter measurement. The sampling problem has to do with the number of animals and number of days to be included in an observation.

As estimated from the separate component of variance for consecutive days (1.1) and an acceptable confidence limit of ± 0.5 gallon per day, an observation period would include ($n = t^2 \times 1.1/0.5^2$) 18 days. The separate component of variance among steers was found to be 0.60. As estimated from this variance and an acceptable confidence

Table 3. Amounts of water drunk (gallons per day) by each of 12 steers in the first 8 weeks (May 31–July 25, 1966).

Steer No.	Weeks 1	2	3	4	5	6	7	8	Mean[a]
4	2.8	5.2	2.7	2.9	4.8	6.8	8.0	8.7	5.2[a]
10	4.3	4.2	4.1	4.2	5.5	6.9	6.6	7.3	5.4[a]
8	5.3	5.2	5.8	5.7	6.4	7.0	6.3	7.6	6.2[b]
6	4.2	4.8	4.9	4.8	6.4	8.5	8.7	8.8	6.4[bc]
3	5.0	5.4	4.6	5.5	7.5	9.3	8.5	8.3	6.8[bcd]
11	5.1	6.4	5.4	5.6	7.2	9.1	8.8	8.8	7.0[cde]
1	5.3	5.0	4.9	6.6	7.8	9.3	9.1	10.3	7.3[def]
9	6.3	5.6	5.4	6.1	7.8	9.2	8.7	9.1	7.3[def]
12	6.4	5.5	5.5	5.9	7.8	9.0	8.5	9.5	7.3[def]
5	6.0	6.4	5.3	5.5	7.2	9.6	9.8	9.9	7.5[efg]
2	6.5	6.2	6.4	6.2	8.4	9.7	9.6	10.3	7.9[fg]
7	5.5	7.0	6.2	6.6	8.8	9.5	10.6	10.5	8.1[g]
Mean[a]	5.2[a]	5.6[ab]	5.1[a]	5.5[a]	7.1[b]	8.6[c]	8.6[c]	9.1[c]	6.9

[a] Means with the same letter superscript are not significant at 5%.

limit of ± 0.5 gallon, a sample would include ($n = t^2 \times 0.6/0.5^2$) 9 animals. However, with animals less uniform in size than the steers selected for this experiment, a larger number would be appropriate. Substitutions between the numbers of animals and days in the ratio of two days per animal (as defined by respective variance components) gives the following sample sizes:

No. of Animals	*No. of Days*
9	18
11	14
15	7
16	4

In 1966, the steers drank, by overall average, 7.0 gal/day. Drinking water amounts changed from week to week as air temperature and forage conditions changed (Table 4). The simple correlation between weekly mean water drunk and air temperature was r = 0.705, which is significant at 1%, and that between water drunk and moisture content of hand-plucked herbage was r = –0.333, which is not significant at 5%. Liveweight, daily gain, moisture content of feces, and day length accounted for very little, if any, of the variation in water drunk.

In consecutive days when air temperatures changed considerably, the amounts of water drunk increased or decreased in proportion to temperature increases or decreases. However, the adjustment in water drunk was not immediate. The correlation between water drunk and mean air temperature of the same day was r = 0.641, and that between water drunk and mean temperature of the previous day was r = 0.590, each being significant at 1%. It will be understood, of course, that the animal response must appear after the environmental effect. For this reason, drink-

Table 4. Relations between water drunk, air temperature, and moisture content of hand-plucked herbage.

Week[a]	Water drunk (gal/day)	Mean air temperature (°F)	Moisture content of herbage (%)
3	5.1	62	69
1	5.2	62	36
4	5.5	67	73
2	5.6	54	59
11	5.6	64	72
18	6.0	52	50
16	6.4	54	69
17	6.4	63	62
15	6.9	65	67
13	7.0	66	71
5	7.1	72	59
14	7.1	64	68
12	7.2	64	66
6	8.6	75	56
7	8.6	74	52
9	8.7	72	41
10	8.8	68	61
8	9.1	72	46

Correlation coefficients:
Water drunk on temperature, r = 0.705**
Water drunk on moisture, r = –0.333

[a] Weeks are rearranged to coincide with increasing amounts of water drunk.
** Significant at 1%.

ing water should be measured for a minimum of 4 days regardless of the number of animals included in the observation.

Air Temperatures.—Mean air temperatures derived from daily minimum and maximum temperatures were compared with means derived from temperatures recorded at 3 hr intervals. Weekly means expressed to the nearest degree F were nearly always identical by the two procedures, and never differed by more than one degree. Therefore, the simple procedure of averaging maximum and minimum daily temperatures is retained.

The wide variability of water-intake rates at high temperatures imposes a practical limit of applicability of the water-intake method. The standard deviations of mean water-intake rates given by Winchester and Morris (1956) were carried through the calculation of forage-intake rates and expressed in percentage thereof (Table 5). The variability imposed on the forage-intake rates increases with an increase in mean air temperature and moisture content of forage. Practical limits of usefulness are somewhere between 90 to 100 F mean air temperature and 60 to 70% moisture in the forage.

Moisture Contents of Forage.—Weeks and time of day were sources of highly significant differences in the moisture contents of hand-plucked herbage, and their interaction was significant. Differences among weeks resulted from changes in animal selectivity as well as from changes in plant growth and maturation. Moisture contents averaged 5% higher in the morning than in the evening, but afternoon thundershowers sometimes reversed the diurnal trend.

This estimation of mean forage-moisture content over a 2-week period is an unusual kind of sampling problem because the population parameters are not fixed. The residual mean square, however, provides an evaluation of sampling precision that may be used to estimate the number of hand-plucked samples needed in a 2-week grazing period. Under the conditions encountered in 1966, an average of 31 samples were needed to estimate the mean moisture content with a confidence limit of ± 2% at a probability level of 5%. The difficulty one encounters in hand-plucking to estimate the mean moisture content of forage can vary from slight to extreme, but the kinds of variability encountered require a systematic daily observation and collection of herbage.

The confidence limit of ± 2% was chosen as reasonable and desirable, but we must investigate the consequences of error in estimating the mean

Table 5. Forage-intake rates in pounds of forage dry matter per gallon of water drunk.[a]

Moisture content of forage (%)	Mean air temperature (°F)						
	40	50	60	70	80	90	100
10	2.79 ± 3%[b]	2.58 ± 3%	2.25 ± 4%	1.91 ± 7%	1.64 ± 8%	1.16 ± 9%	0.54 ± 14%
20	2.93 ± 3%	2.70 ± 3%	2.34 ± 4%	1.98 ± 7%	1.68 ± 9%	1.19 ± 9%	0.54 ± 14%
30	3.12 ± 4%	2.86 ± 3%	2.46 ± 5%	2.06 ± 8%	1.74 ± 9%	1.22 ± 9%	0.55 ± 14%
40	3.44 ± 4%	3.12 ± 4%	2.65 ± 5%	2.19 ± 8%	1.84 ± 10%	1.26 ± 10%	0.56 ± 14%
50	3.98 ± 5%	3.57 ± 4%	2.97 ± 5%	2.40 ± 9%	1.98 ± 11%	1.33 ± 10%	0.57 ± 14%
60	5.24 ± 6%	4.54 ± 5%	3.61 ± 7%	2.81 ± 10%	2.25 ± 13%	1.45 ± 11%	0.59 ± 15%
70	10.99 ± 13%	8.33 ± 10%	5.65 ± 10%	3.91 ± 14%	2.91 ± 16%	1.69 ± 13%	0.62 ± 16%
75	83.33 ± > 99%	24.39 ± 30%	10.20 ± 20%	5.65 ± 20%	3.77 ± 20%	1.95 ± 15%	0.66 ± 17%

[a] The equation for forage-intake rates is given by Hyder, et al., 1966.
[b] The standard deviations of water-intake rates given by Winchester and Morris (1956) are carried through the calculations and expressed in percent of forage-intake rates.

Table 6. Percentage error in forage intake estimates resulting from an error of + 2% in the estimate of mean moisture content of forage.

Moisture content of forage	Mean air temperature (°F)				
	40	50	60	70	80
20	1.4	1.1	0.8	0.5	0.6
30	1.9	1.7	1.2	1.0	1.1
40	2.3	2.2	1.9	1.8	1.1
50	4.3	3.6	3.0	2.5	2.0
55	6.3	5.3	4.3	3.5	2.9
60	9.0	7.9	6.1	4.6	4.0
65	16.4	13.3	9.6	7.2	5.2
70	44.4	30.5	18.8	12.3	8.6

moisture content of forage. To do so, we calculate the errors in forage intake resulting from an error of + 2% in the mean moisture content of forage (Table 6). This error in forage intake increases with an increase in moisture content of forage and decreases with an increase in mean air temperature. Where the moisture content of forage exceeds 65%, the probability of error becomes so great that the estimates of forage intake cannot be considered trustworthy. The moisture contents of hand-plucked herbage exceeded 65% in grazing periods 2, 6, 7, and 8, but moisture contents were undersampled with only 12 observations in two weeks.

Discussion

Sampling Requirements.—The measurement of drinking water and air temperature presents no great problem. An observation should include an appropriate number of animals and days as defined by the respective variance components. Two water meters may be attached in series and read daily for protection against malfunction.

The estimation of the moisture content of forage presents the only major sampling problem. The estimation by hand-plucked herbage is subjective, and, furthermore, the population parameters are not fixed. Systematic and continuous observation and collection of herbage is required for approximation of the animal diet. Each interval of grazing should be represented. This characteristic, with sampling restricted to 3 days/week, was undersampled in 1966.

Limitations.—A limitation is inherent in the basic relations defined by Winchester and Morris (1956). High temperatures increase the requirement for water in the control of body temperature and reduce the relative importance of the dry-matter function. Thus, variability in the amount of water required per pound of dry matter consumed increases with increasing temperature. This variability becomes excessive at temperatures greater than 90 F, but since our highest 14-day mean temperature in 1966 was only 74 F, this limitation did not apply.

A limitation on moisture content of forage did apply in grazing periods 2, 6, 7, and 8. The high probability of error in estimating the intake of forage containing more than 65% moisture is a weakness that must limit application of the water-intake method. On the other hand, opportunities to improve the efficiency of grazing practices on semiarid grasslands are most likely to result from conditions in which the forage contains considerably less than 65% moisture (Hyder, 1967). The water-intake method can permit a valuable extension of research on semiarid grasslands, but eventually we shall require wider applicability and greater assurance of accuracy than can be attained at the present time.

Accuracy.—There appears to be a possibility of positive bias in the estimate of forage intake for grazing periods 2, 6, 7, and 8. In final analysis the accuracy of the forage-intake estimates depends on the applicability of the water : dry-matter intake ratios defined by Winchester and Morris (1956). They obtained a substantial base of data that appears to apply very well to our conditions, but were unable to equate all the conditions that affect the water requirement of cattle. They reviewed literature showing that the effect of humidity was negligible at temperatures below 75 F. Other environmental factors also are most likely to become important only at high temperatures where the vapor component of water excreted is large. Since high temperatures were not encountered in our work, and mean temperatures exceeded 70 F only in grazing periods 3 and 4, it seems unlikely that environmental factors could have caused a bias in forage intake.

An increase in crude protein intake can increase water excretion rates and water requirements (literature reviewed by Winchester and Morris, 1956). The crude-protein contents of forage (hand-plucked samples) in 1966 were 11.6, 15.6, 12.9, 11.8, 12.3, 14.8, 12.0, 11.4, and 11.0%, respectively, by grazing periods. Some increase in water requirement in grazing periods 2 and 6, and a corresponding positive bias in the estimate of forage intake, might have resulted from the greater concentrations of N in the forage. The highest preferences for Russian thistle were expressed in grazing periods 7 and 8 when the moisture contents of feces increased to 84%. Average moisture contents of feces were 82, 80, 82, 81, 82, 82, 84, 84, and 82%, respectively, by grazing periods. Thus, a laxative effect of Russian thistle (Cave et al., 1936; Christensen et al., 1948) probably increased the water requirement about 1 gal/day and resulted in a corresponding positive bias of 3 to 5 lb/day in the estimate of forage intake in grazing periods

7 and 8. Procedures for evaluating and removing sources of bias must, therefore, be taken into consideration in future work.

Conclusions

Drinking water can be measured accurately. Nevertheless, problems in sample size arise out of the variability among animals, and among days by animals, in the amounts of water drunk. Appropriate sample sizes are as follows: 9 animals for 18 days, 11 animals for 14 days, 15 animals for 7 days, or 16 animals for 4 days.

Mean air temperatures derived from daily minimum and maximum temperatures were compared with means derived from temperatures recorded at 3-hr intervals. Weekly means expressed to the nearest degree F were nearly always identical by the two procedures, and never differed by more than one degree. Therefore, the simple procedure of averaging maximum and minimum daily temperatures is retained.

The moisture content of forage was estimated by hand-plucked samples collected by an observer as he moved with the yearling Hereford steers. Fluctuations in the moisture content of forage require a systematic daily observation and collection of herbage. All grazing intervals should be represented. Even so, where the moisture content of forage exceeds 65% the probability of error in the estimate of forage intake becomes so great that the results can not be considered trustworthy.

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