Comparison of weight estimate and rising-plate meter methods to measure herbage mass of a mountain meadow

EMILIO A. LACA, MONTAGUE W. DEMMENT, JOY WINCKEL, AND JOHN G. KIE

Abstract

A rising plate meter (RPM) and ocular estimation of herbage fresh weight (OCES) were compared as double sampling methods to measure herbage dry weight (DWT) in a mountain meadow grazed by cattle (0, 2.5, 3.2, and 6.9 AUM/ha) and deer. On 8 dates, 5 to 10 plots were clipped and 50 to 100 plots were estimated in 2 or 4 pastures, each of which had 6 vegetation types, resulting in 120 groups of observations. Whereas 11 different calibration lines were necessary to calibrate the OCES (r^2 = 0.74 to 0.91), 17 lines were needed for the RPM (r^2 = 0.04 to 0.82). Average residual standard deviations (Sy.x) were 653 for OCES vs. 846 kg ha^{-1} for RPM. The different calibrations for OCES were caused by differences in the %DM of the herbage (dates and meadow type), whereas RPM calibrations were affected by grazing treatment, date, meadow type, and observer. When the same number of clipped and estimated plots were used for both methods, OCES was 24% more precise than RPM. To obtain a precision of ±200 kg ha^{-1} (P = 0.05) OCES required 697 fewer clipped plots for the whole experiment than RPM, but OCES field costs were 3% higher. If calibrated on net readings (before-after clipping) RPM overestimated herbage mass, relative to clipped plots and OCES. The lower cost per RPM reading was counterbalanced by greater precision and generality of OCES calibrations.

Key Words: double-sampling, biomass estimation

Accurate and precise measurement of herbage biomass is essential for both range research and management. Difficulties in estimation arise because of the great variability in herbage biomass in range situations. As a result, obtaining an adequate number of samples for characterization of the vegetation can be costly, time consuming, and if destructive, may consume significant portions of the vegetation within a treatment. Double sampling methods were developed to cope with these problems (Pechanec and Pickford 1937) by calibrating an indirect but inexpensive method with another that is precise but costly (e.g., clipping). A good double sampling method results in calibrations that remain unchanged over a wide range of factors, so data can be pooled to increase precision and reduce total sampling cost.

Observers can estimate fresh or dry weight per unit area. Estimation of dry weight has the advantage of incorporating the often substantial variability in dry matter percentage (DM%) that occurs under range conditions (Tadmore et al. 1975). Conversely, estimation of fresh weight allows continuous training in the field. The drawback of fresh weight estimates is that an estimate of %DM is needed to calculate DWT. If variance in %DM is large the value of estimated fresh weight in predicting dry weight is reduced.

The rising plate meter (RPM, described in Earle and McGowan 1979) has been successfully applied to estimate herbage mass, particularly in intensively managed pastures of uniform botanical composition (Michell and Large 1983, Scrivner et al. 1986).

In this paper we compare precision and accuracy of ocular estimates and a rising plate meter. The practical implications of the tradeoff between cost and precision are discussed.

Methods

Factors

Measurements were conducted at middle Bell Meadow in Stanislaus National Forest, California. The meadow was divided into 4 pastures grazed by cattle at 0 (NG), 2.47 (LG), 3.19 (MG), and 6.92 (HG) AUM/ha. Each pasture was stratified into 6 vegetation types. Date were collected on 8 dates during the summer of 1985: (1) 4–7 July (all pastures); (2) 18–19 July (NG, HG); (3) 25–28 July (LG, MG); (4) 3–4 August (all); (5) 15 August (NG, HG); (6) 19 August (LG, MG); (7) 31 August (NG, MG); (8) 2 September (LG, HG). One of 5 observers performed both OCES and RPM on each site through the sampling season.

Sampling Procedure

Neither method required any training previous to the actual sampling other than a practical explanation of the basis of each method. Training to ocularly estimate herbage biomass was performed as samples necessary for calibration were clipped and weighed in the field. Ocular estimations of total fresh weight and initial RPM readings were recorded within the same 0.1 m^2 quadrat (=plot). One of every 10 quadrats on which OCES and RPM were performed was clipped close to ground level, bagged and weighed, and a second RPM reading was taken on the stubble. Samples were dried (in the sun and later 48 h at 60° C) and weighed. Fifty to 100 estimations and RPM readings and 5–10 clipped plots were collected from each meadow type within each pasture on each sampling date, which resulted in 120 groups of data points. In the mesic meadow types with high (MHCL) and low (MLCL) density of corn lily (*Veratrum californicum* Durand), stems of corn lily were removed before estimating the remaining herbage.

Statistical Analysis

Separate linear regressions were developed for dry weight (DWT) of herbage per unit area as a function of net plate meter reading (before vs. after clipping) and as a function of ocular estimates of fresh weight. Usually a linear relationship is adequate for these relations (Campbell and Arnold 1973). An F-test (Steel and Torrie 1980:420–423) was used to determine when more than one calibration line was necessary to predict herbage weight.

First, regressions were calculated for all possible lines (each meadow type in each pasture on each sampling date), and a single line with all data pooled. Second, an F value was calculated to test whether a single line could be used instead of all possible lines. The third step depended on the result of the second. If the F-value was significant, then plots of regression coefficients (b) against intercepts (a) were examined to identify clusters of lines that were similar and to identify the combination of factors associated with the clusters. Scatterplots of raw data were also examined. The data

Authors are research assistant, assistant professor, and graduate student, Agronomy and Range Science Department, University of California-Davis, Davis, Calif. 95616; research wildlife biologist, Range Management Research, US Forest Service, Pacific Southwest Forest and Range Experiment Station, Fresno, Calif. 93710.

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Table 1. Pooled regressions relating herbage mass and ocular estimation of fresh weight. $S_{y.x}$: residual standard deviation. OCES and DWT are the means for each line. n: sample size. Slopes have units of kg dry weight•kg fresh weight^{-1}.

Meadow Type	Date	Slope	Intercept kg ha^{-1}	r^2	$S_{y.x}$ kg ha^{-1}	n	OCES kg ha^{-1}	DWT kg ha^{-1}
DRY MNCL WCR-WCN	1	0.308	222	0.80	817	94	7520	2538
MHCL MLCL	1	0.244	144	0.74	602	52	10930	2813
ALL	2	0.327	470	0.82	790	103	8270	3176
ALL	3	0.337	406	0.80	708	73	6350	2541
ALL	4	0.388	370	0.83	753	120	4860	2255
DRY MNCL	5	0.519	36	0.91	341	20	1590	859
MHCL MLCL WCN	5	0.302	298	0.85	581	37	4850	1763
WCR	5	0.394	1083	0.76	986	13	9450	4812
ALL	6	0.471	339	0.85	505	80	3010	1756
ALL	7	0.518	334	0.89	653	71	3520	2156
ALL	8	0.665	120	0.81	451	78	1300	984

were then grouped according to the factor that appeared to explain most of the clustering. Each one of the new groups was then subjected to the same process, which was repeated until no significant F-values were obtained.

Results and Discussion

Calibration of Ocular Estimates

It is important to note that our sampling procedure differed from that used by Tadmore et al. (1975). Their observers were trained (i.e., plots were estimated and clipped) only at the beginning of each day or when moving into a new vegetation type. Our observers estimated and clipped plots continuously through the sampling period. Our approach has the advantage in that it does not rely on longer term visual memory of observers, and calibration is based on a real subsample of the total estimations. This difference in ocular methods is important because evidence indicates that observers tire, resulting in a reduction of their precision. Regression lines developed in the morning when observers are fresh may overestimate precision obtained after hours of work (Johnson et al. 1986).

OCES data were pooled into 11 calibration lines produced by the effects of date and meadow types (Table 1). Since OCES was based on fresh weight, slopes of the regressions of DWT on OCES were related to the mean %DM of herbage. Sites that had different mean %DM required different calibration lines. Most of the variation in %DM was explained by different meadow types and dates. The rate of increase in dry matter concentration of herbage was 0.6% to 0.8% per day, and meadow type MNCL generally exhibited higher DM concentrations. Regression coefficients (b) ranged from 0.244 in the moister sites on 4–7 July to 0.664 in all meadow types on 2 September. In this experiment r^2 values of OCES ranged from 0.74 to 0.91. These values were bracketed by those (0.49 to 0.92) reported elsewhere for this method (Wilm et al. 1944, Campbell and Arnold 1973).

Calibration lines exhibited stability over vegetation types, sites, and observers. This method was capable of adjusting for site differences, and observers could readily correct the estimates when uneven ground or a different sward density or composition were encountered.

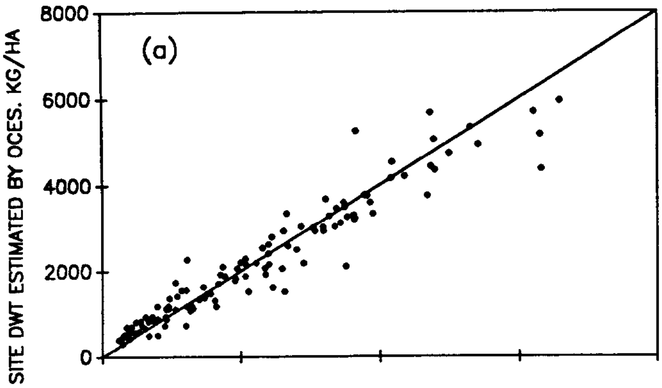
Calibration of Rising-Plate Meter

A minimum of 17 calibration lines (Table 2) was necessary for the RPM. Regressions differed due to effects of date, stocking rate, meadow type, and observer. The slopes of pooled regressions varied from 30.6 kg ha^{-1} unit reading^{-1} for meadow type WCR in the HG pasture during the first 3 dates, to 475.4 kg ha^{-1} unit reading^{-1} for observer A in meadow type MNCL. Coefficients of determination ranged from 0.04 (meadow type WCR in pasture NG on dates 1, 2 and 4) to 0.82 (for meadow type WCR HG dates 5

Table 2. Pooled regressions relating herbage mass and rising-plate meter net readings. $S_{y.x}$: residual standard deviation. RPM and DWT are the means for each line. n: sample size.

Line applies to: Meadow Type	Observer	Date	Pasture	Slope kg ha^{-1} unit^{-1}	Intercept kg ha^{-1}	r^2	$S_{y.x}$ kg ha^{-1}	n	RPM units	DWT kg ha^{-1}
DRY	——[a]	——	——	62	326	0.51	250	120	3.61	549
MHCL	——	——	——	170	587	0.56	747	113	5.20	1472
MNCL	A	5-6	NG LG	475	−126	0.59	870	12	3.17	1379
MNCL	BCDE	1-3	——	118	1426	0.42	981	49	11.76	2809
MNCL	BCDE	4-8	——	126	704	0.29	677	52	3.87	1190
MLCL	A	3-5	NG MG	199	1304	0.36	1039	18	6.11	2519
MLCL	CDE	1-4	——	98	1611	0.51	799	76	13.25	2905
MLCL	BD	5-8	——	118	543	0.40	541	41	5.12	1147
WCR	——	——	NG	56	4811	0.16	1364	30	26.00	6270
WCR	——	——	LG	89	2321	0.46	893	29	19.34	4036
WCR	——	——	MG	47	3524	0.11	1261	33	23.18	4608
WCR	——	1,2,4	HG	31	3613	0.04	1065	20	19.30	4203
WCR	——	5,8	HG	221	225	0.82	513	14	10.36	2514
WCN	A	5	NG	258	1380	0.77	839	6	8.83	3660
WCN	BCE	——	NG	103	2122	0.37	1182	23	14.83	3643
WCN	BD	——	MG	114	908	0.56	613	34	12.91	2377
WCN	BCDE	——	LG HG	186	464	0.70	747	71	9.51	2236

[a]——indicates subdivision according to this factor was not necessary.



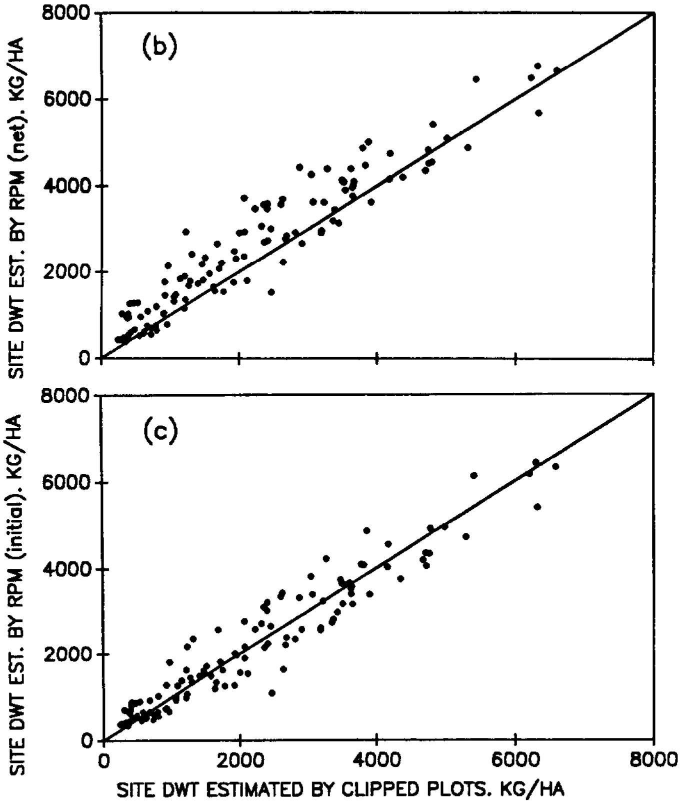


Fig. 1. *Relationship between herbage dry mass estimated by (a) ocular estimation of fresh weight method (OCES), (b) rising-plate meter calibrated on net readings (RPM net), (c) rising-plate meter calibrated on initial readings, and herbage dry weight estimated by clipped plots used in the calibrations. Diagonal 1:1 lines represent unbiased values, assuming that estimates based on clipped plots were unbiased.*

and 8). The regressions appeared to be sensitive to height, stiffness, and density of vegetation, and had r^2 values that were in general lower than r^2 values usually reported for RPM. Scrivner et al. (1986), using the identical plate meter, obtained coefficients of determination above 0.80 in all but 2 regressions on subclover or ryegrass pastures, whereas Michell (1982) obtained correlation coefficients consistently above 0.80 (r^2 = 0.64) on rotationally grazed perennial ryegrass-white clover pastures.

The lowest r^2 and slopes were obtained, together with the highest intercepts, on sites of highest herbage masses dominated by tall *Carex rostrata* Stokes (Table 2). Remarkably, the highest r^2 value was obtained in the same vegetation type but later in the season when canopy structure had changed because of grazing. Coefficients and precision of calibration lines appeared to be affected by height and total herbage mass of the WCR meadow type. Whereas dominant in terms of area, this meadow type was not preferred and remained practically ungrazed until late in the season, except in the HG pasture where the other meadow types were depleted earlier. A reduction in height and herbage mass from ca. 4,200 to 2,500 kg ha^{-1} due to grazing greatly improved the RPM calibration in WCR on the HG pasture (Table 2). These results were consistent with the poor performance of the meter on tall and senescent swards observed by Michell and Large (1983), and with the significantly higher slopes and lower intercepts obtained by Michell (1982) for heavily grazed ryegrass (*Lolium perenne* L.) as opposed to ungrazed and regrowth ryegrass or prairie grass (*Bromus catharticus* Vahl.), a more erect species.

The relationship between RPM reading and DWT also was affected by the way the meter was used by different observers; an effect described by Earle and McGowan (1979). One observer showed a consistent tendency to generate higher slopes due to lower RPM readings, likely caused by more gentle placement of the meter than the rest of the observers.

In many plots irregular ground surface caused the RPM reading after clipping to be equal to or greater than the initial reading. This resulted in a great number of 0 net readings paired with various positive DWT's, particularly when herbage biomass was low (negative net readings were corrected to 0).

Similar to ocular estimation, linear relationships between meter reading and herbage weight have usually been reported (Earle and McGowan 1979, Michell 1982, Michell and Large 1983, Scrivner et al. 1986). Differences in calibration lines have been attributed to differences in botanical composition, season or phenological state (Scrivner et al. 1986), observer (Earle and McGowan 1979), and management (Scrivner et al. 1986).

Comparison of Precision of Methods

In spite of observers not having previous experience with the method, OCES was more precise and required fewer calibration lines than RPM. The r^2 values obtained with OCES were considerably higher than with the RPM method. Average residual standard deviations (Sy.x) were 653 for OCES vs. 846 kg ha^{-1} for RPM.

Precision of estimates is a function of both precision of calibrations and sample size. In theory, any degree of precision could be achieved by taking enough samples. Thus, the objective comparison of RPM and OCES must be based on a constant level of sample size, cost, or precision. The best method is the one which yields tighter CI's for a given cost, or that requires less sampling effort to obtain a given precision. OCES and RPM were compared in 2 ways. First, we compared the precision obtained with the methods as actually used in the field: with equal sample size and a clipped:estimated ratio of 1:10. Second, we estimated the number of samples and field cost required to obtain a precision of $\pm$200 kg ha^{-1} with 95% confidence if methods were applied using the optimum clipped:estimated ratio.

Ocular estimation was 24% more precise than rising-plate meter when compared at the same number of clipped and estimated plots. Average 95% CI half widths for the 120 site-dates were 235 vs. 292 kg ha^{-1} for OCES and RPM, respectively.

Because the precision of methods might be affected by the ratio of clipped to estimated plots, and the ratio 1:10 used in the experiment might have favored one of them, methods were further compared at the optimum clipped:estimated ratio for each line. The optimum ratio of clipped to estimated plots was calculated using equation 2 (Table 3), which takes into account that each calibration line was used to obtain more than one estimate of herbage mass (e.g., OCES line for date 2 was used to estimate herbage mass in all pastures and meadow types). Based on our field experience,

Table 3. Equations and sources used in comparison of precision of methods.

Equation	Source
1) $S^2_y = S^2_{y.x}/n + b^2S^2x_e/m$	Michell (1982)
2) $k = [(S^2_{y.x}/b^2S^2x_e)(c_x/c_y)r]^{1/2}$	modified from Francis et al. (1979)
3) $n = t^2(S^2_{y.x}+b^2S^2x_e\,k)/(1/2\,CI)^2$	derived from Steel & Torrie (1980) and eq. 1 & 2

Symbols:

- S^2_y.............. approximate sample variance of the estimates obtained with the calibration equation.
- $S_{y.x}$.............. residual standard deviation of the calibration equation.
- S^2x_e.............. sample variance of the indirect measures (ocular estimations or RPM readings).
- n.............. number of points used to develop the calibration line.
- m.............. number of indirect measures taken to estimate the herbage mass in a given experimental unit or stratum (site).
- b.............. slope of the calibration line.
- k.............. optimum ratio of clipped to estimated plots that minimizes the variance for a given sampling cost.
- c_x/c_y.............. cost ratio of the indirect to the direct measure.
- r.............. number of sites encompassed by one calibration line.
- CI.............. desired width of the confidence interval.

20 RPM readings or 12 ocular estimates can be performed in the time necessary to clip one 0.1-m^2 plot (ca. 6 min). Number of clipped plots per regression line to obtain a precision of ±200 kg ha^{-1} was calculated for each line using equation 3 (Table 3).

OCES required 62% (1,123 vs. 1,820) fewer clipped plots than RPM, but RPM needed 24% fewer estimations (readings) than OCES to estimate mean DWT ±200 kg ha^{-1} (P=0.05) for the whole experiment. This result translated into a total field cost 2.7% (7 man hours) lower for RPM (Table 4). Thus, when methods were used at the optimum ratio clipped:estimated plots, the higher precision and generality of OCES calibration lines were counterbalanced by the lower field cost of RPM readings.

Table 4. Estimated sample sizes and field costs to obtain a precision of ±200 kg ha^{-1} (P=0.05).

	OCES		RPM	
	sample size	cost (man • h)	sample size	cost (man • h)
clipped	1123	112	1820	183
oces/readings	17942	150	14444	72
Total		262		255

Although our analysis of field costs would appear to indicate that the methods are practically not different, we feel most confident in the qualitative results of the comparison. First, the 12:20 cost ratio used for RPM:OCES was central to the quantitative comparison of costs, and this ratio is likely to vary depending upon the distance between plots and speed of the observer. In our study we walked only 2–4 steps between plots. As the distance increases, the ratio will favor the ocular method. Second, the laboratory costs associated with the extra 697 clipped samples required by RPM would more than counteract its slightly lower field cost. Third, if destruction of the vegetation is a limiting factor the advantage of OCES becomes greater. Finally, the ability to estimate herbage mass at a site visually can be combined with other aspects of field studies to provide additional perspectives relating sward to grazing. For example, we were able to record estimations of herbage available at feeding sites of cattle at the same time that we recorded biting and movement while grazing.

Accuracy of Methods

Herbage masses estimated using both methods were compared to the mean DWT obtained from the clipped plots in order to detect any possible bias (Fig. 1a, b). Estimations based on regressions of DWT on OCES were closer to clipped DWT, and showed no pattern of bias. On the other hand, estimations based on the regression of DWT on RPM consistently overestimated clipped DWT. Overestimation was observed both when using one regression per site and pooled regressions from Table 2. On average, estimates based on RPM were 13% higher than those based on clipped plots, while for the weight-estimate method the average deviation was 1%.

This overestimation was explained by 2 consequences of clipped DWT being regressed on net RPM reading (i.e., on the difference between readings before and after clipping). First, RPM estimated total herbage mass as opposed to clipped mass estimated by OCES. Second, numerous net readings were 0 or even <0, yet we clipped the plots close to ground level leaving barely any herbage. It is likely that most of the overestimation occurred because calibration lines were shifted to the left as a result of subtracting a second reading on irregular or soft soil (mulch). This indicated that the results of RPM would be improved by taking only preclipping readings and clipping to ground level in some consistent manner. Calibrations on initial RPM readings proved to be marginally more precise than regressions on net readings, and did not overestimate herbage mass relative to clipped plots (Fig. 1c).

Conclusions and Practical Implications

An examination of the efficiency of the methods indicated, for the specific conditions of this study, that the time to complete a given level of sampling precision was similar for the 2 methods. However, differences between the methods are apparent and important. OCES calibration lines were more precise and general than RPM ones. Compared at the same number of plots clipped and estimated for the whole experiemnt, OCES showed an average precision 24% better than RPM. Compared at the same level of precision of estimates, OCES required 697 fewer clipped plots for the whole experiment than RPM, and consequently, was less destructive.

RMP calibrations were affected by meadow type, observer, date, and grazing treatment, whereas OCES required new calibrations for different dates and meadow types. RPM was inadequate for sites dominated by tall *Carex rostrata* Stokes and, if calibrated on net readings, it overestimated the herbage mass relative to the OCES and clipping methods. In complex plant communities where species have different structural characteristics that produce species specific relationships between biomass and resistance to the plate, RPM will show higher variability and lower efficiency. The advantage of OCES over RPM should increase as experiments include more factors or vegetation heterogeneity that require proportionally more calibration lines for RPM. The ability of observers to compensate for structural differences at sampling sites would appear to be a major factor increasing the efficiency of this method for use in rangelands.

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