Sampling Herbaceous Native Vegetation with an Electronic Capacitance Instrument

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Highlight: *Dry matter yields of herbaceous native vegetation were effectively estimated with electronic herbage meters. Yields were estimated on vegetation types varying from a low-elevation annual type to a high-elevation alpine type. Phenology, dead organic matter, plant stature, composition, and meter placement within the vegetation affected efficiency of yield estimates. Double sampling techniques are necessary. Optimum sample size for either a fixed-cost or fixed-variance estimate should be determined for each vegetation type.*

Since 1949, when the concept was first tried, electronic capacitance instruments have evolved into practical tools for estimating the weight of standing herbage (Neal and Neal, 1973). The newer instruments are electronically reliable and rapid, but information has been lacking on how to use these instruments for sampling native vegetation. Thus, the objectives of this study were to evaluate the meters in reference to sampling precision, efficiency, and required sample sizes on various types of native herbaceous vegetation.

Tests were conducted at eight locations in the western United States. Two locations were in an annual grass type, four were in perennial grass, and two were in high-altitude mountain meadows and alpine vegetation. Of the four perennial grass locations, two were in pine-bunchgrass, one was in a high-elevation bunchgrass, and one was in a low-elevation oak-hickory-bluestem savannah. The latter two locations had substantial accumulations of standing litter. A Neal Electronics Company Model 15FFF, 18-612, or 18-1000 meter was used for each of these tests (Neal and Neal, 1973).[1] All meters, regardless of model, sampled a 12-inch by 24-inch (0.19 m^2) plot size.

Study Areas

Annual Grass Tests

The primary work in sampling annual vegetation was done at the San Joaquin Experimental Range (SJER) in the Sierra Nevada foothills near Fresno, Calif. The SJER is located at approximately 1,000 ft (300 m) elevation on well-drained granitic soils. The climate is Mediterranean, characterized by mild rainy winters and hot dry summers. Annual precipitation averages 20 inches (51 cm) with 70% received as rain between December and March.

Two similar areas were sampled on the SJER. On one area plants were green with little difference in phenology; on the other, some plants had started to dry and phenology was variable. Herbage was estimated on several 20-plot sets within each area, using the Model 15FFF meter. Plants were then clipped to a ½-1 inch stubble height and weighed. From a combined large sample made up of the 20-plot sets, three small samples were drawn at random to simulate double sampling. Plots to serve as small (clipped) and large (meter-read) samples were drawn in a ratio of 1:5. Double sampling statistics were computed on each of the three sets to estimate sample size requirements for a fixed variance within ± 10% of the mean at the 95% confidence level (± $0.1\bar{Y}$, $P_{.05}$).

The second location for evaluating meter performance on annual grass was on an introduced cheatgrass (*Bromus tectorum* L.) type near Boise, Idaho[2]. At this location, two areas were sampled with 20 plots each. The plots were estimated with the meter and clipped to a ½-1 inch stubble height. Comparisons again were made between an area with relatively uniform soil and plant moisture, and one where phenology was variable.

Perennial Bunchgrass Tests

Estimates of weight and perennial bunchgrass vegetation in the ponderosa pine (*Pinus ponderosa* Laws.) type were evaluated at locations in California and Colorado. Harvey Valley, Calif., is in the southern Cascade Mountains at an elevation of 5,600 ft (1,710 m). The climate is characterized by relatively dry summers and substantial winter snow with an annual precipitation of 18 inches (46 cm). In contrast, the Manitou Experimental Forest at 7,800 ft (2,380 m) elevation in the Rocky Mountains of Colorado has minimal winter snows with substantial summer rainfall (Currie et al., 1973).

Double sampling was used at both pine-bunchgrass locations. At Harvey Valley, six areas were sampled. At each area, 105 plots were estimated with the meter (large sample); 21 plots were read with the meter, then clipped to a ½-1 inch stubble and weighed (small sample). Vegetation on these areas ranged from scattered bunchgrasses to a low shrub-bunchgrass type to a rather dense sedge-rush-grass wet meadow complex.

Meters were evaluated at Manitou in connection with a study of herbicide and fertilizer treatments. Data were taken

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Manuscript received January 10, 1975.

[1] Trade and company names are used for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

[2] Tests on cheatgrass were supported in part by the Bureau of Land Management, U.S. Department of Interior.

on replicated blocks over a period of 3 years. Each year 240 clipped plots and 600 meter-estimated plots were evaluated. This sample was partitioned into 60 meter-read and clipped plots and 150 meter-read plots on each of four areas that had been sprayed with herbicides, fertilized with a complete fertilizer, sprayed and fertilized, or left untreated. All clipped plots were harvested to a ½ inch stubble height by a three-dimensional clipping method. With this method all plant material within the 12 X 24 X 18 inch area sensed by the meter is clipped regardless of where it is rooted. Aerial parts of plants rooted outside the plot area but extending into the sensed area are clipped (Currie et al., 1973). Principal plant species on the area included Arizona fescue (*Festuca arizonica* Vasey), mountain muhly (*Muhlenbergia montana* (Nutt.) Hitchc.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag.), fringed sagebrush (*Artemisia frigida* Willd.), and antennaria (*Antennaria* spp.). These last two genera were the primary targets of the spray treatment.

The high-elevation bunchgrass location used to evaluate the influence of litter was at the Black Mesa Experimental Forest in the central Rocky Mountains west of Gunnison, Colo. Elevation on the Mesa ranges from 9,500 ft (2,900 m) to 10,500 ft (3,200 m). About 70% of the 25 to 30 inches (64 to 76 cm) annual precipitation falls as snow, but rather frequent storms provide moisture for plant growth during summer. The rolling terrain provides good drainage and a variety of exposures. The dominant bunchgrass is Thurber fescue (*Festuca thurberi* Vasey), a rather coarse plant that tends to grow in large clumps.

Meter performance was evaluated on two areas at Black Mesa. On the area where Thurber fescue was the dominant plant, it and substantial amounts of standing litter from previous years were estimated on 26 individual blocks. Total standing crop harvested from plots within blocks was hand separated to evaluate the contribution of different components to the meter estimate. Stepwise regression was used to evaluate the data. Components for the regression were current growth dry matter and older standing litter. Litter was also estimated ocularly for each plot. On the second area Thurber fescue was mixed with forbs. Here the evaluation was restricted to determining sample size and efficiency for this type of vegetation.

The oak-hickory-bluestem savannah location was in the Ozark Mountains of south central Missouri, in rolling topography at approximately 1,250 ft (380 m) elevation with an annual precipitation of approximately 44 inches (112 cm). Bluestems (*Andropogon* spp.) dominated the grass stands. At this location, paired sample areas were compared. One area had been burned the previous winter to remove accumulated litter. The other area was left unburned. Twenty plots were estimated with the meter and clipped within each area. Regression and correlation analyses were used to evaluate meter estimates between the two areas.

Mountain Meadow and Alpine Tests

Meters were evaluated on mountain meadows on several areas between 9,000 ft (2,740 m) and 11,500 ft (3,500 m) elevation in the southern Sierra Nevadas of California. These mountain locations receive heavy winter snow as well as summer rains. Growing seasons are short, and plant heights seldom exceed 2 ft (61 cm). On these areas various meadow types were sampled by a double sampling technique. Two sample sizes were compared for efficiency.

At the alpine location, 12,000 ft (3,660 m) elevation of Pikes Peak, Colo., vegetation was composed primarily of mat and cushion plants. Two meters were compared, Models 18-612 and 18-1000. A meter reading was made with each model on each plot with the corner probes resting on the soil surface. This placed the ends of the sensing elements approximately 2 inches (5.1 cm) above the soil. A second reading was taken with each model with the corner probes pushed 1 inch (2.5 cm) into the soil. This placed the elements 1 inch above the soil surface. All plots were clipped to ground level and green and dry weights recorded. Regression analyses were used to evaluate each meter's effectiveness in estimating yield of short alpine vegetation, and to determine the influence of element-to-soil distance on the meter estimate.

Table 1. Effect of phenology differences on meter estimates of annual vegetation.

Location	Phenology	b	$s_{y \cdot x}$	r^2	Plant water (%) $\bar{X}$	Plant water (%) Range
SJER	Green	2.67	11.5	0.84	78	13
	Drying	2.48	11.8	0.48	66	60
Boise	Green	1.55	1.76	0.84	53	15
	Drying	1.34	4.27	0.52	36	28

Results

Annual Grass Tests

Coefficients of determination (r^2) between meter estimates and oven-dry weight differed greatly between moist and drying vegetation in the annual grass types (Table 1). The meter estimated herbage with more precision on wetter sites where plants were green than it did on drying sites where plants were in a variable state of phenology.

At the San Joaquin Experimental Range (SJER), dry weights of standing crops were similar for both areas. Variation in phenology of the drying vegetation created differences in capacitance, conductance, and dielectric loss per unit of dry weight, which resulted in a lower r^2 (Neal and Neal, 1973). The optimum double sampling ratio computed from combining plots showed that 24 clipped samples (SS) and 275 meter-estimated samples (LS) were required. This ratio of approximately 1:11 was an average for the three sets of randomly drawn simulated double sample estimates. All values were computed for a fixed variance to sample within 10% of the mean at the 95% confidence level ($\pm 0.1\ \bar{Y}, P_{.05}$) using the method described by Currie et al. (1973).

The Boise location results were very similar to those for SJER. The r^2 was higher where cheatgrass moisture content was higher and less variable (Table 1). The regression coefficients (b) were lower and standard errors were more variable than the SJER.

Perennial Bunchgrass Tests

On the ponderosa pine-bunchgrass location at Harvey Valley (tests 1-3, Table 2), sampling ratios averaged one clipped plot for each seven meter-estimated plots, 35% larger

Table 2. Sampling efficiencies and sample size requirements for perennial vegetation at Harvey Valley, Calif.

Test no.	Vegetation type	r^2	$s_{y \cdot x}$	Optimum sample size[1] Small sample (SS)	Optimum sample size[1] Large sample (LS)	Ratio
1	Open grassland	0.56	5.37	35	172	1:5
2	Open grassland	0.77	13.80	150	1,197	1:8
3	Open grassland	0.79	9.19	57	485	1:8
4	Open shrub grass	0.73	18.50	88	625	1:7
5	Sedge-rush-grass meadow	0.69	8.01	14	94	1:7
6	Sedge-rush-grass meadow	0.66	8.67	18	109	1:6

[1] Variance = ± 0.1 $\bar{Y}, P_{.05}$; actual sample—SS = 21, LS = 126, ratio = 1:6.

Table 3. Statistics for relations between oven-dry weight and meter estimates, by treatment at the Manitou Experimental Forest, Colo. Mean values of three blocks.

				Optimum sample size[1]		
Treatment	r^2	b	$s_{y.x}$	Small sample	Large sample	Ratio
Fertilized	0.72	1.46	10.10	33	235	1:7
Sprayed (2,4-D)	0.64	1.54	5.33	30	177	1:6
Fertilized and sprayed	0.59	1.31	10.10	32	171	1:5
Control	0.53	1.99	6.75	54	253	1:5

[1] Based on a fixed variance of ± 0.1 $\bar{Y}, P_{.05}$.

than required for the annual grass type. Fixed-variance sample sizes for perennial plants ranged from 14 small samples (SS) and 94 large samples (LS) to 150 SS and 1,197 LS. The meadow type, which is more homogeneous, required a much smaller sample than the drier and less uniform open bunchgrass types.

Tests 2 and 3 in the open bunchgrass types had similar r^2's, but test 2 had a considerably larger standard error of estimate ($s_{y.x}$). This accounts for the greatly different sample size requirements between the two tests. These results emphasize the folly of using r^2 as the only basis for evaluating the relation of herbage yields to meter estimates, as was pointed out earlier by Back (1968).

On the treated plots at Manitou Experimental Forest, estimates of b and r^2 were not significantly different between blocks, and were similar for all treatments except the control (Table 3). Dry matter yields from fertilized and fertilized-sprayed treatments averaged 1,970 lb/acre (2,210 kg/ha) and 1,920 lb/acre (2,150 kg/ha) respectively. Sprayed and control treatments averaged 1,060 lb/acre (1,190 kg/ha) and 960 lb/acre (1,080 kg/ha). Vegetation on the control plots was shorter, and much of it was below the ends of the sensing elements. However, this short vegetation was cut and contributed to the dry matter weights for each plot and to a higher b value for the control. Heights of grass species generally increased after the spray treatment, while broad-leaved plants were killed. The net effect was that dry matter yields were similar to that of the control. This difference in stature of grass accounted for the intermediate b value for the spray treatment. Further changes in the b values were small for the other treatments. Sample size requirements, particularly for clipped plots (SS), were similar for the three treatments but were about 40% larger on the control.

A comparison of sample size requirements among years for all treatments combined (Table 4) showed that combined sample requirements for the first 2 years were only slightly larger than those for individual treatments shown in Table 3. In 1971, small sample (SS) size was nearly twice as large as in 1970 and one-third larger than in 1969. Large sample (LS) size was about twice as large as in 1970 and similar to that in 1969. These yearly variations must be taken into account when sampling to detect treatment differences.

Table 4. Mean yield (g/plot) and sample efficiencies of meter estimates combined by treatments and blocks. Manitou Experimental Forest, Colo.

		Optimum sample size[1]		
Year	Yield	Small sample (SS)	Large sample (LS)	Ratio
1969	31.2 ± 1.63	42	323	1:8
1970	29.3 ± 1.24	32	168	1:5
1971	13.8 ± 0.78	61	347	1:6

[1] Based on a fixed variance of ± 0.1 $\bar{Y}, P_{05}$; actual sample size taken each year—SS = 240, LS = 600, ratio = 2:5.

Litter Influence

Stepwise regression showed that old growth litter accounted for 0–15% of the total weight variation of Thurber fescue vegetation on Black Mesa. On only four of the 26 blocks, however, did the increased variation exceed 5% and only one value exceeded 10%. The tests also showed that, unless an estimate of litter is needed, separation of litter from the sample to obtain its weight for regression is not worthwhile. The coefficient of determination between ocular estimate of litter and the actual weight of litter was 0.85. Since correcting the regression estimate by the actual litter did not generally improve the equation, the ocular estimates were not considered to be useful for refining meter estimates in these tests.

All 26 blocks at Black Mesa were quite variable in yields, both within and between blocks. The yields in g/plot varied from a low of 27 ± 2.5 to a high of 56 ± 6.6. In the relations between dry matter yields and meter readings, b values ranged from 0.55 to 1.28 and r^2 values from 0.44 to 0.86. The estimated SS sizes for a fixed variance (± 0.1 $\bar{Y}, P_{.05}$) ranged from 13 to 54 and the LS sizes from 67 to 370. Estimated SS to LS ratios varied from 1:4 to 1:11 and averaged 1:6.5 for all 26 blocks.

In comparison to the 26 blocks which were variable in yield, a second area of three contiguous blocks was selected for uniformity and for similarity in yield between blocks (Table 5). These three blocks, although having similar sample size requirements, differed enough to again point out that sample size, even on a uniform site, should be based on a treatment or sample unit comparison rather than for the total area.

Table 5. Dry matter yields (g/plot) and sample sizes for area 2 at Black Mesa, Colo.

		Optimum sample size[1]		
Blocks	Yield	Small sample	Large sample	Ratio
1	38.4 ± 5.18	22	114	1:5
2	40.4 ± 3.89	15	142	1:9
3	37.0 ± 4.64	19	119	1:6
Combined estimate	38.6 ± 2.51	19	124	1:7

[1] Based on a fixed variance of ± 0.1 $\bar{Y}, P_{.05}$; Actual sample ratio was 1:11 on all 3 blocks.

At the Ozark Mountain location, accumulated litter had been removed by burning on one area prior to the start of growth, while the other area was left unburned. Because of these differences in litter, the r^2 between clipping and meter estimates nearly doubled and the $s_{y.x}$ was reduced by about two-thirds for the burned site (Table 6). This illustrates the greater sensitivity of the meter to the higher dielectric constant of live vegetation. In contrast to Black Mesa, where separation and analytical removal of litter did not significantly

Table 6. Sampling statistics for Oak-Hickory-Bluestem Savannah rangeland in Ozark Mountains.

Treatment	r^2	b	$s_{y.x}$
Unburned	0.42	3.32	21.2
Burned	0.81	1.92	8.33

Table 7. Sampling statistics and sample size requirements for mountain meadows in the southern Sierra Nevadas of California.

				Sample size				
				Actual		Optimum[1]		
Area	r^2	b	$s_{y \cdot x}$	Small sample	Large sample	Small sample	Large sample	Ratio
1	0.82	1.25	9.24	20	120	29	264	1:9
2	0.52	1.12	10.4	20	120	51	231	1:5
3	0.71	.895	6.99	20	120	41	283	1:7
4	0.67	1.42	10.0	10	60	21	126	1:6
5	0.69	1.45	17.2	20	120	80	522	1:7
6	0.64	2.36	10.8	20	120	56	322	1:6

[1] Based on a fixed variance of ± 0.1 $\bar{Y}$, $P_{.05}$.

improve the estimate, physical removal by burning at the Ozark site substantially improved the meter estimate.

Mountain Meadow and Alpine Tests

In the southern Sierra Nevada meadow study, the meter was used to minimize sampling time and expense. The meadows were variable in composition and phenology. The first three sample areas illustrate how such variability must be considered when using the meter (Table 7). Area 1 was an open, stable meadow community with fairly uniform species composition and phenology. Area 2 was part of the same meadow, but had been invaded by trees which were subsequently cut. These changes produced an unstable vegetation complex in a state of rapid plant succession, where species composition and phenology were variable. The r^2 was reduced and $s_{y \cdot x}$ increased by this variability. Area 3 was a timbered fringe of the same meadow. Vegetation was quite stable and undisturbed, but very moist. This resulted in a higher r^2 and a lower $s_{y \cdot x}$ than the cut-over area.

Meadows 4 and 5 had comparable r^2 and b values, but meadow 5 had a much larger $s_{y \cdot x}$. Meadow 5 had a larger sample, but was very diverse in composition and the sample was not stratified as to type. As a result, meadow 5 required a fixed-variance sample ratio of 1:7, while meadow 4 could be sampled with a ratio of 1:6.

In meadow 6 the meter probes sank into the saturated substratum while the reading was being taken. The resulting extreme variability in meter estimate and high sample size requirement point out that ordinary physical factors also need to be recognized when using the meter.

Tests on alpine vegetation on Pikes Peak, Colo., further confirmed the influence of physical features in sampling. Both the Models 18-612 and 18-1000 estimated standing vegetation with approximately the same precision (Table 8). However, moving the sensing elements closer to the soil surface improved the estimates by both instruments. On each meter the $s_{y \cdot x}$ decreased about three-fourths, while r^2 improved about one-third. These differences occurred because the sensing elements were placed closer to the mat and cushion plants, which provided closer contact with the mass being sampled.

Table 8. Effect of meter placement in relation to soil surface for alpine vegetation, Pikes Peak, Colo.

	Sensing element distance above soil			
	2 inches		1 inch	
Meter	r^2	$s_{y \cdot x}$	r^2	$s_{y \cdot x}$
18–612	0.72	34.5	0.92	9.71
18–1000	0.75	32.4	0.95	9.99

Conclusions

The meter, regardless of model, was an efficient instrument for estimating dry matter yields on a number of uncultivated vegetation types. Phenology very strongly influenced the precision of meter estimates of dry weight. As plants dried, internal moisture decreased and electrolyte content also became less; thus, the dielectric constant sensed by the meter decreased. To obtain the best estimate with a meter, it is desirable to measure at a physiologically active period of plant growth. This does not imply that good estimates cannot be obtained at other than optimum phenology, but variation in meter estimates will be greater and a larger sample will be required.

The presence of standing litter creates a similar measurement problem. Meter estimates were much more precise when litter was removed by grazing or burning. While the meter is relatively insensitive to litter as such, this material can contribute substantially to variability of estimated dry matter yield.

Some form of double sampling is required when using the meter to estimate herbage weight. If meter precision is high, the number of clipped samples (SS) for a given confidence level is small. The number of meter-estimated samples (LS) required changes with the variability in the stand being sampled. Most of our results showed that a 1:5 ratio was a reliable starting point for perennial vegetation. On annual types, 1:10 was adequate. Both tended to be conservative for developing dependable estimates. The final number of samples which should be taken can be determined from the double sampling analysis for the cost or precision specified.

Variations in species composition presents a problem similar to phenology. Different species tend to have a different chemical makeup and, therefore, different dielectric constants. If these differences are large or if proportions of species change greatly from plot to plot, error will become large. When this happens, both the large and small sample size requirements increase.

Estimates of alpine vegetation showed that short plants can be estimated as efficiently as tall plants. However, estimates are much more precise when the probe elements are brought closer to the soil surface to sense these shorter plants.

Literature Cited

Back, H. L. 1968. An evaluation of an electronic instrument for pasture yield estimation. Part 1. General relationships. J. Br. Grassl. Soc. 23:216-222.

Currie, P. O., M. J. Morris, and D. L. Neal. 1973. Uses and capabilities for electronic capacitance instruments for estimating standing herbage. Part 2. Sown ranges. J. Br. Grassl. Soc. 28:155-160.

Neal, D. L., and J. L. Neal. 1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 1. History and development. J. Br. Grassl. Soc. 28:81-89.