Sampling Shrub Ranges with an Electronic Capacitance Instrument

MEREDITH J. MORRIS, KENDALL L. JOHNSON, AND DONALD L. NEAL

Highlight: *Electronic capacitance meters can provide a rapid, accurate, and nondestructive means of estimating the total aboveground and herbaceous dry matter yields in low-shrub lands of the western United States and other parts of the world. A double sampling technique is necessary to obtain reliable yield estimates, maximum cost reduction, and the most efficient use of the meters.*

Neal and Neal (1973) have recently discussed the history and development of electronic capacitance instruments for estimating herbage yields. Capacitance-meter estimates of herbage yields on mechanically seeded pastures were evaluated by Currie et al. (1973). The work reported here is an evaluation of meter estimates of plant yields from low-shrub lands, common over much of the western United States and other parts of the world. Sampling precision and sample size requirements for several shrub types are particularly emphasized. All estimates were made with Neal Electronics Model 18-612 or 18-1000 Herbage Meters.¹

Study Areas and Methods

The capacitance meter was used to estimate total plant yields (aboveground) from: (1) a big sagebrush (*Artemisia tridentata* Nutt.) community near Saratoga, Wyo.; (2) a common winterfat (*Eurotia lanata* (Pursh) Moq.) community near Milford, Utah; (3) big sagebrush stands near Kremmling, Colo.; and (4) a row-planted, fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) stand at Riverside, Calif. Data from the Colorado tests were provided by L. H. Carpenter, Colorado Division of Wildlife, and O. C. Wallmo, Rocky Mountain Forest and Range Experiment Station.

The authors are or were principal biometrician and research hydrologist, Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Fort Collins, Colorado, and range scientist, Pacific Southwest Forest and Range Experiment Station, Fresno, California. Johnson is now associate professor, University of Wyoming, Laramie.

Research reported here was supported in part by the Bureau of Land Management, U.S. Department of the Interior.

Manuscript received January 15, 1975.

¹Trade 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.

Wyoming

The big sagebrush site near Saratoga, Wyo., is located on rolling terrain at elevations of 7,700–8,100 ft (2,350–2,470 m). Precipitation averages about 15 inches (38 cm) annually, with about 65% received as snow and the balance as summer rainfall, mostly from convectional storms. The area is subject to strong winds, which redeposit much of the incident snow in stream channels and on lee slopes, creating growth sites ranging from xeric to fairly mesic. This uneven pattern of effective precipitation, together with desiccating summer winds and a variety of slopes and exposures, results in a wide range of sagebrush growth forms, from dwarf hummocks on dry exposed ridge tops to well-developed plants 2–3 ft (61–91 cm) tall in moist, sheltered swales. The associated grasses and forbs range similarly in growth, all making up a sagebrush-grass community in good condition.

Total vegetative yield on the area was sampled annually in July or August of 1968 through 1971. In 1968, 407 randomly located plots were sampled with the meter; 128 of these were clipped to establish weight relations. Clipping was done by a 3-dimensional technique described in Currie et al. (1973), which includes all plant material occurring within the cubic volume sensed by the instrument. A stubble height of ½–1 inch (1.3–2.5 cm) was left, including large sagebrush trunks.

After the clipped samples had been allowed to air dry for several weeks, each was separated into its herbaceous and woody components. Herbaceous plant material was defined as shrub leaves and succulent stems, grasses, and forbs. The air-dry leaves readily shattered from the woody stems of the shrubs; each shrub fragment was thoroughly stripped. The divided samples were oven dried at 105°C for 24 hours and weighed; the weights of herbaceous and woody fractions added together were regarded as total dry weight of plant material.

Part of the sampling objective in this program was to determine optimum double sample sizes to employ in obtaining estimates of herbaceous yields in the big sagebrush type. In 1969, the sample size was reduced to 320 with 64 clipped plots, and was reduced still further in 1970, due to instrument breakdown in the midst of field sampling, to 264 with only 44 clipped plots.

All data gathered in the three sample years were analyzed to derive the optimum large and small sample sizes for the study area through a computer program developed for fixed cost and variance sampling with the meter. A cost ratio of 20 to 1 was used as outlined in Currie et al. (1973). Based on this analysis, an 8 to 1 ratio of metered to clipped plots was

adopted in 1971. A total of 864 plots were meter-estimated, of which 109 were clipped.

The relation of the herbage and stem components of big sagebrush to the capacitance measurement was measured in 1969. Seventy plots were carefully selected to embrace a wide range of sagebrush production. On each plot the corners were marked, and capacitance of total vegetation was measured. Then the sagebrush plants present were thoroughly stripped of their leaves and succulent stems, and all other herbaceous material was clipped. A second capacitance reading of the stem material was taken, the stems were then removed, and a final reading of the plot for any residual due to soil or litter was made.

All plots were clipped according to the 3-dimensional technique described in Currie et al. (1973). The clipped samples were weighed immediately to obtain fresh weights, then oven dried at 105°C for 24 hours and reweighed. Total weights were assumed to be the sum of the herbage and stem components. The several weight categories were regressed on their corresponding meter readings by a stepwise technique to identify the contribution of each component to the meter estimate.

Utah

The common winterfat site near Milford, Utah, is located on a broad, fairly level, alluvial fan at an elevation of 5,250 ft (1,600 m). Precipitation averages slightly less than 7 inches (18 cm) annually, with wide fluctuations both annually and seasonally. About 40% occurs in winter, commonly as light snow, with the balance as localized and often intense summer storms. The winterfat plants in the area make up a nearly pure stand of sparse shrubs with open spaces between the plants. Grasses are equally sparse, but the community is in generally good condition. The relation of the meter reading to the herbage and stem components of common winterfat was evaluated in 1967 by the technique described previously.

Colorado

The three big sagebrush stands measured near Kremmling, Colo., are all located on moderately sloping terrain at elevations of 7,600–7,900 ft (2,320–2,410 m). One site, located on a long southerly aspect, receives about 11 inches (28 cm) of precipitation annually. The other two sites, one on a gently sloping upland, the other on a long westerly aspect, receive about 18 inches (46 cm) annually. About 50% occurs as snow, with the balance received as rainfall, usually from convectional storms. Snow accumulation does not persist long on the southerly site, but usually occupies the other two from December to March.

Sagebrush plants on the southerly site average 18 inches (46 cm) in height, with a sparse understory. On the other two

sites, sagebrush plants range from 1–3.5 ft (30–107 cm) with a well-developed understory of herbaceous plants.

Vegetative yield on all sites was sampled in 1969 to establish pretreatment relationships. Five hundred plots were sampled with the meter; 100 of these were clipped at each of the three study areas. The clipping procedure was identical to that used at the Saratoga site, as was separation of material into herbaceous and woody components.

In 1970, fertilizer and herbicide treatments were applied. Sampling was conducted in each treatment plus a control at the rate of 375 metered and 75 clipped plots at each of the three study areas in 1970 and 1971. These data were analyzed to predict dry herbaceous yields at each site and to establish optimum small to large sampling ratios as well.

California

The test conducted on fourwing saltbush plants was made at Riverside in southern California. These plants had been established in a trial of plant species for fire resistance and herbage production. They were row planted in an enclosure, and ranged from 12–34 inches (30–86 cm) tall and 6–30 inches (15–76 cm) in diameter.

The objective of the meter test was to estimate total yield of plant parts over 6 inches (15 cm) above the ground on an individual plant basis. The meter was placed on 6-inch blocks over each of 20 selected plants. Plants larger than the meter sensing area were tied with string to confine them within the sensed area. After reading and clipping, total fresh and dry weights were measured. Correlations of meter readings and total yields (fresh and dry weight) were calculated.

Results

The relations of the herbage, stem, and total yield components to the different meter readings for the Wyoming and Utah tests are given in Table 1. Reading A in the table is the first meter reading made on all the vegetation in the plot. Reading B is the second reading taken after the leaves and succulent stems of the brush and all other herbaceous material had been clipped, leaving only the old stem material. After the stems were clipped, a final reading (Reading C) was made of the residual capacitance due to soil or litter.

In the comparisons for Wyoming (Table 1), herbage yields, both fresh and dry, were estimated with the highest precision. In order, these were by Reading A, Reading A minus Reading C, and Reading A minus Reading B. Figure 1 shows the regressions of total dry matter yield and herbage dry matter yield on the first meter reading (Comparisons 1 and 3 in Table 1). The large plot-to-plot variability of the old stem material in

Table 1. Mean yields (g/plot), confidence intervals (95% level), and coefficients of determination (r^2) for simple regressions of plant components and associated meter readings.

	Wyoming ¹		Utah ²	
	Fresh	Dry	Fresh	Dry
1. Total yield vs Reading A	248 ± 17.5 (0.89)	144 ± 14.7 (0.79)	79.4 ± 12.6 (0.85)	47.6 ± 11.1 (0.85)
2. Total vs (Rdg A – Rdg C)	248 ± 25.7 (0.89)	148 ± 20.8 (0.81)	79.4 ± 9.27 (0.92)	47.6 ± 8.04 (0.92)
3. Herbage yield vs Reading A	90.2 ± 4.49 (0.94)	32.1 ± 1.52 (0.93)	15.1 ± 3.27 (0.73)	11.2 ± 2.09 (0.79)
4. Herbage vs (Rdg A – Rdg C)	84.5 ± 4.42 (0.97)	30.4 ± 1.71 (0.95)	15.1 ± 3.06 (0.76)	11.2 ± 2.17 (0.78)
5. Herbage vs (Rdg A – Rdg B)	90.2 ± 4.99 (0.92)	32.1 ± 1.86 (0.90)	15.1 ± 3.65 (0.66)	11.2 ± 2.57 (0.69)
6. Stem yield vs Reading B	158 ± 12.8 (0.88)	112 ± 10.9 (0.83)	64.3 ± 11.3 (0.82)	36.5 ± 10.9 (0.81)

¹ Sample size = 70 except comparisons 2 and 4 ($n = 44$).

² Sample size = 20.

Fig. 1. Scatter diagrams and regressions of total dry matter (DM) yield and herbage dry matter yield on the first meter reading in the Wyoming test.

the sagebrush type undoubtedly accounts for the greater deviations from regression for total dry matter yield as is seen in the variance estimates in Table 1. For the Utah comparisons, total fresh yield versus Reading A minus Reading C had the highest precision, followed by total fresh yield versus Reading A. For the dry weight comparisons, total yield versus Reading A minus Reading C had the highest precision followed by the herbage yield estimates for all three herbage comparisons (variables 3, 4, and 5 in Table 1).

These results indicate that the herbage dry matter component in these low-shrub types can be estimated very efficiently with the capacitance meter, even with a single reading on the plot. Although the residual reading (C) improves the r^2 values somewhat, it is not efficient in these types to bother with residual readings. Carpenter et al. (1973) obtained similar results in comparisons of plant components and different meter readings in sagebrush lands in Colorado.

A further analysis of the discrimination of the meter between the stem and herbage components in sagebrush is shown in Table 2. The increase in R^2 from the stem component (fresh and dry) is very small, indicating that the meter is mainly sensing the plant parts with the highest water content. Johns and Watkin (1965) found the same relation of dead and dry herbaceous material versus fresh material in their tests.

Once it had been established that herbage dry matter yields could be estimated efficiently with the capacitance meter, it became necessary to derive estimates of required sample sizes for the study areas. The sample of 109 clipped and 864 metered plots (109/864) used at the Wyoming site in 1971 was derived from analysis of the three previous years' records. This

Table 2. Contributions of herbage and stem components to the multiple correlation coefficient (R^2) in a stepwise multiple regression (Wyoming test). Mean values are for $n = 70$.

Components	Mean (g/plot)	R^2	Increase in R^2
Fresh herbage	90.2	0.94	
Fresh stem	158.0	0.95	0.01
Dry herbage	32.1	0.93	
Dry stem	112.0	0.94	0.01

Table 3. Double-sampling ratios (actual and estimated) and coefficients of determination (r^2) for predicting herbage dry matter yields in Wyoming and Colorado.

Location and year	Treatment ¹	r^2	Small to large sampling ratios	
			Actual	Required ²
Wyoming, 1968	—	0.75	128/407*	80/615
Wyoming, 1969	—	0.77	64/320*	94/772
Colorado, 1969	S1	0.53	100/500	81/381
	S2	0.76	100/500	40/317
	S3	0.54	100/500	65/310
	—	0.41	44/264*	95/353
Wyoming, 1970	—	0.41	44/264*	95/353
Colorado, 1970	Si-F	0.77	75/375*	52/416
	S2-F	0.80	75/375	30/262
	S3-F	0.73	75/375	34/252
	S1-H	0.42	75/375*	97/369
	S2-H	0.50	75/375	58/258
	S3-H	0.34	75/375	64/204
	—	0.67	109/864	77/491
	S1-F	0.66	75/375	59/365
	S2-F	0.58	75/375	58/303
	S3-F	0.72	75/375	35/252
Wyoming, 1971	S1-H	0.56	75/375	72/365
	S2-H	0.65	75/375	49/299
	S3-H	0.36	75/375	57/192
	—	0.67	109/864	77/491

¹ Experimental unit designations for overall study. Used here only to show sampling variability between treatment units.

² Sample sizes needed to estimate within 10% of the mean at the 95% confidence interval.

* Sample size too small.

double-sampling ratio of 1 clipped to 8 metered plots yielded an estimate of high precision for herbaceous yield: 20.6 ± 1.62 g/plot, a standard error of less than 8% at the 95% confidence level.

The estimate of the woody and partially dead stem yield was much poorer because the dry woody material has a wide range of weight values but little corresponding relationship to capacitance. Reliable estimates of stem yields would be impractical to obtain. Due to the woody stem component, estimates of total vegetative yields in the sagebrush type, as expressed by total dry weight, are also weak, although acceptable precision could still be obtained if necessary. Based on the 1971 sample, estimation of total vegetative yield to within $\pm 10\%$ of the mean at the 95% confidence level would require approximately four times as many clipped samples (395) and a doubling of metered samples (1,686), effectively a 1 to 4 ratio.

Estimates of herbaceous yields on a 1 to 5 double sampling ratio at the Colorado sites also exceed the necessary levels of precision. With the exception of site 1 in 1970 (Table 3) the sample size of 75/375 was sufficient to detect the results of fertilizer and herbicide treatments on herbaceous yields at a high level of sensitivity. Estimates of stem yield and total vegetative yield followed patterns similar to those observed at the Wyoming location.

The test on fourwing saltbush in California gave r^2 values of meter readings and fresh weight of 0.95. The r^2 for dry weight was 0.90 and for water weight, 0.96. Although the sample size was small ($n = 20$), this test indicated that the capacitance meter could be used to estimate shrub yields of nursery-grown plants.

Discussion

In low-shrub lands of the western United States, the capacitance meter has proved very useful for estimating the total aboveground and herbaceous dry matter yields. As discussed in Currie et al. (1973), a double sampling technique

is necessary for the most efficient use of the meter and to obtain reliable yield estimates.

In Wyoming the size of the 1971 sample generously exceeded that necessary to estimate the herbaceous dry matter yield at the desired level of precision. We have decided to continue this intensity of sampling, however, since it is convenient to obtain within the two-stage sampling network employed, and the larger sample size provides a safety factor for abnormally dry years. In addition, herbaceous dry matter yields of two subpopulations (watershed areas being compared) can still be estimated within $\pm 10\%$ of the mean at the 95% confidence level with a modest increase in clipped samples

	Actual 1971	Required
Combined	109/864	77/491
Population a	77/608	91/615
Population b	32/256	38/217

By separating the combined sample into two subpopulations,

with each estimate at very high sensitivity we can detect how nearly any management treatment imposed on the big sagebrush type affects herbaceous dry matter yields.

Literature Cited

- Carpenter, L. H., O. C. Wallmo, and M. J. Morris.** 1973. Effect of woody stems on estimating herbage weights with a capacitance meter. *J. Range Manage.* 26:151-152.
- Currie, P. O., M. J. Morris, and D. L. Neal.** 1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 2. Sown ranges. *J. Br. Grassl. Soc.* 28:155-160.
- Johns, G. G., and B. R. Watkin.** 1965. A modified capacitance probe technique for estimating pasture yield. II. The effect of different pastures, soil types and dew on the calibration. *J. Br. Grassl. Soc.* 20:217-226.
- 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.