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USES AND CAPABILITIES OF ELECTRONIC CAPACITANCE INSTRUMENTS FOR ESTIMATING STANDING HERBAGE

PART 2. SOWN RANGES

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ABSTRACT

An electronic capacitance meter was used to estimate herbage yield from sown ranges in western USA. On an area in Arizona where the grass stand had been sown broadcast, an r^2 of 0·47 was obtained between the meter value and oven-dry weight estimate. Excluding those plots with very large amounts of standing dead organic matter (OM), or very succulent plants which had not been sown, improved yield estimates.

Tests on pastures in Colorado in which seed had been drilled and the meter tested to evaluate performance in relation to drill rows showed that a common regression could be used for estimating yield. Methods of placing the meter in relation to row directions are described which avoid a biased estimate of total pasture yield. Cutting the herbage in a 3-dimensional manner improved the r^2 values over those obtained by the usual 2-dimensional cutting procedure. Separation of dead OM from living plant material did not significantly change the r^2 values and showed that dead OM had very little influence on the meter reading. This dead OM can contribute significantly to variation of the estimate about the regression line, however, and if differences in dead OM are substantial, sample sizes may need to be increased or sampling stratified to obtain an accurate yield estimate.

Pertinent literature on the evolution of electronic capacitance instruments for estimating herbage yields has been presented in Part 1 of this series (3). The present evaluation is restricted to the herbage yield estimates from mechanically sown pastures. The Neal Electronics Model 18-612 meter was used to make the yield estimates.

MATERIALS AND METHODS

The meter was tested on a warm-season species, weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), at Tonto Springs near Prescott, Arizona, and a cool-season species, Sherman big bluegrass (*Poa ampla* Merr.), at the Manitou Experimental Forest near Colorado Springs, Colorado.

The Tonto Springs site had been occupied by chaparral, but was converted to lovegrass by root plowing and broadcast sowing. The study site is located on rolling granitic outwash at an elevation of 5000 ft (1520 m). Precipitation averages approximately 17 in. (43·2 cm) annually, about 50% of the amount received being rain or snow in winter (October-April). The remaining annual moisture supply is received as summer rain (May–September) from convectional storms.

Ranges sown to big bluegrass at Manitou were drilled in rows spaced 12 in. (30·5 cm) apart by established procedures (2). This site is also situated on granitic soils, but at a higher elevation of 7800 ft (2380 m). Precipitation averages approximately 15·5 in. (39·4 cm) annually, about 75% of this amount being received during the growing season from April through August.

The broadcast lovegrass sowing at Tonto Springs was sampled once in April 1968. A total of 134 plots, each 1×2 ft ($30{\cdot}5 \times 61{\cdot}0$ cm), were estimated with the meter. Plot locations were selected to give a range of plant composition from 0 to 100% by weight of weeping lovegrass. Herbage was hand cut with shears to between ½–1 in. (1·27–2·54 cm) stubble height and weighed in the field. Cutting was done using the 3-dimensional techniques described and

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evaluated later in this paper. Cut samples were separated by species, oven dried at 105°C for 24 hours, and reweighed.

Eighteen pastures at the Manitou Experimental Forest were sampled during comparable 2-week periods in August 1967, 1968, and 1969. These pastures, each 5 ac (2·02 ha), are part of a larger grazing study. They are divided into two locations designated Nursery and Sinclair, with nine pastures at each location.

In 1967, herbage on 2880 plots (160 in each pasture) was estimated with the meter. The meter was placed in the four positions shown in Fig. 1 to test the influence of spacial arrangement of plants growing in 12-in. drill rows in relation to meter probes which are 9 in. centre to centre across on the short side but also have an effective sensing field of 12 in. Ten plots were clipped for each position shown, and an additional 30 plots estimated with the meter for each position. This herbage was also cut to a $\frac{1}{2}$–1 in. stubble height, immediately weighed, then reweighed after it had been oven dried.

Plants at the Sinclair location were cut using the standard 2-dimensional cutting procedure whereby the plant material harvested need only be rooted within the plot frame. A 3-dimensional procedure was used at the Nursery location on the assumption that this would more closely approximate to the herbage mass being sensed by the instrument. In this cutting procedure, blades, stems, or seedstalks which originate outside the plot but are within the cubic volume sensed by the instrument are cut off and saved as part of the plot yield (Fig. 2). Conversely, plant material from within but which projects out of this 3-dimensional plot area is cut off and discarded.

A computer program (Dub-Sam 2)* was developed for fixed cost and variance sampling with the meter. It followed procedures described by Cochran (1). This analysis was applied to the 1967 Nursery data for 3-dimensional sampling to derive the large and small sample sizes in 1968 and 1969. In each of the last 2 years, 3240 samples were obtained. This total represented 180 meter-estimated plots for each pasture, of which 36 were cut by the 3-dimensional technique.

To obtain an unbiased estimate, the meter was systematically placed in each of 12 positions corresponding to the 12 numerals on a clock face. Although only six positions have meaning in relation to drill rows because the remaining six are isometric forms, all 12 positions were recorded in sequence throughout a pasture for ease of sampling. Every fifth plot was cut to obtain the regression estimates of yields. These cut samples, 648 each year, were saved and later separated in the laboratory into the following components: Sherman big bluegrass plus other species; and standing dead organic matter (OM). All component samples were oven dried at 105°C for 24 hours before weighing. Living plant material and dead OM were used as independent variables in a stepwise regression to evaluate the contribution of each component to the meter estimate.

RESULTS

Tonto Springs. A significant relationship between meter reading (X) and oven-dry weight (Y) from the broadcast lovegrass sowings at Tonto Springs showed that the meter could be used to obtain estimates of herbage yield (Fig. 3). When all 134 plots were included in the regression, the coefficient of determination, r^2, was only 0·47, which indicated that less than half of the variation in the yield estimate was being accounted for by the meter reading. Although selected estimates would not normally be removed from a regression analysis, those marked x and o in Fig. 3 were deleted to illustrate a point in the use of the meter. These plots represented selected samples which would occur infrequently in a random sample. The x-labelled plots contained either a large amount of the half shrub *Gutierrezia sarothrae* (Pursh) Britt and Busby, or standing dead OM in excess of 100 g/plot in the high-yielding lovegrass plots. For these two instances, dry weight was very large in relation to the meter reading. For the points marked o, species such

*This programme, developed by Dr J. L. Kovner, Principal Biometrician, may be obtained from the Rocky Mountain Forest and Range Experiment Station, 240 West Prospect, Fort Collins, Colorado 80521, USA.

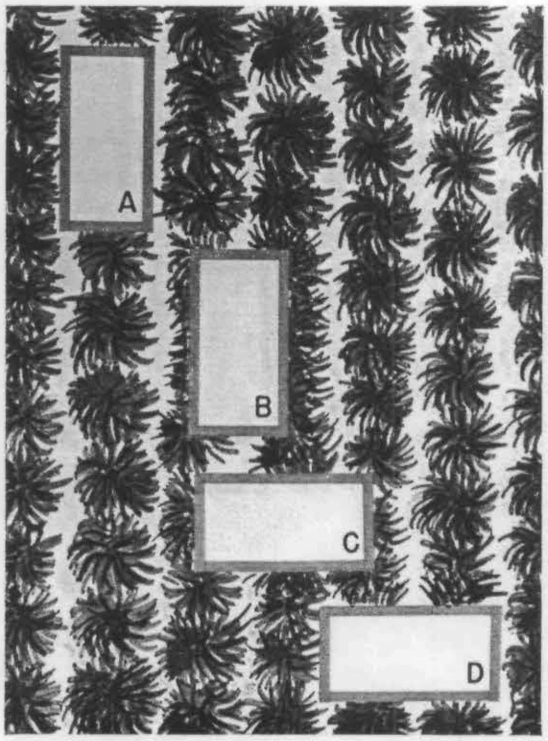

Fig. 1. The meter was placed in the positions shown in relation to drill rows. Forty plots were estimated for each position in each of the 18 pastures.

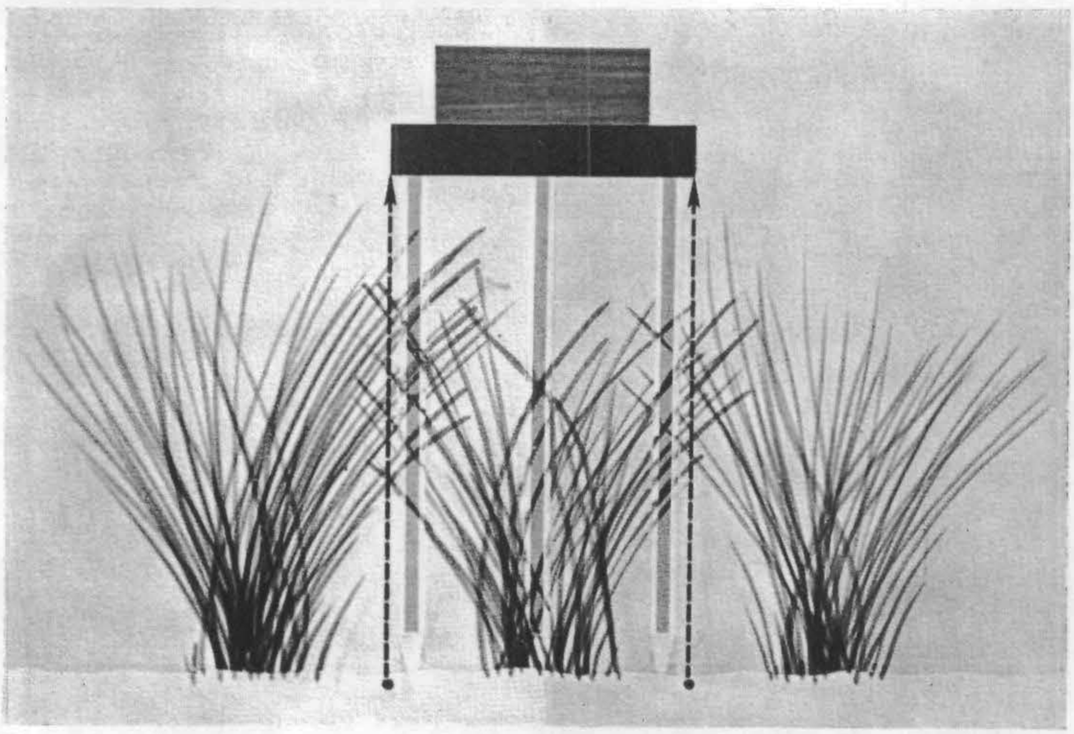

Fig. 2. A 3-dimensional cutting procedure was followed at the Nursery location. Plant segments extending outside the space sensed by the probes were discarded while plant segments growing outside but projecting into the space sensed by the probes were retained.

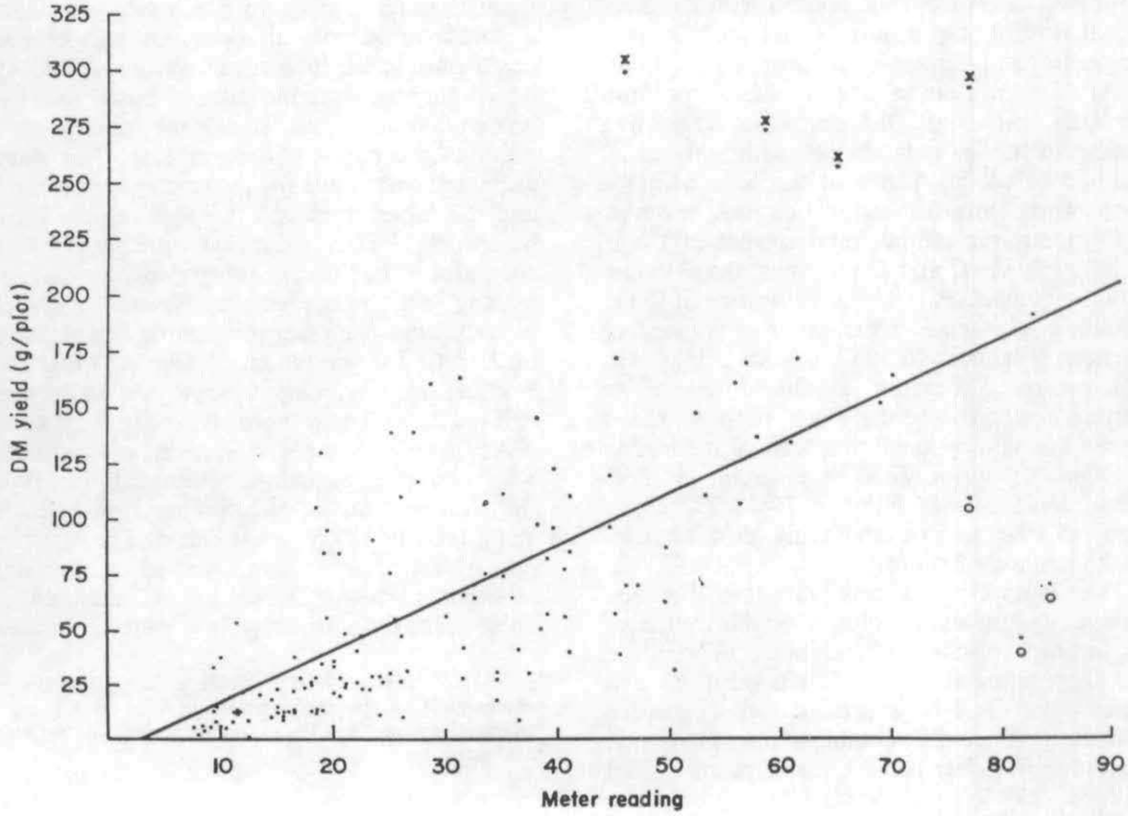

Fig. 3. Regression estimate of DM yield (Y) in relation to meter reading (X) for lovegrass sown broadcast at Tonto Springs, Arizona, USA.

as *Sisymbrium, Sphaeralcea,* or infrequently encountered annuals, dominated the plots selected for low lovegrass yield. These species were extremely green and succulent and resulted in high meter readings for small amounts of dry-weight yield.

Plot values with these identifiable characteristics were removed and the data re-analyzed to determine how much they influenced the yield estimates. The value of r^2 increased to 0·54 with a decrease in the standard error ($S_{\bar{y}.x}$) from 3·87 to 2·97. Mean meter reading (X) changed from 29·8 to 27·6, while the yield estimate (Y) decreased from 63·9 to 56·6 g/plot. These results illustrate that care must be used in sampling such mixed populations. An adequate sample must be obtained for each subset, or subsets should be stratified to obtain an unbiased estimate.

Manitou Experimental Forest. Cutting the vegetation in three dimensions to include all plant tissue sensed by the meter probes significantly improved the r^2 values over those obtained by cutting in the customary 2-dimensional manner (Table 1). The most substantial increase was for the B position where the meter was placed with the probes between two rows rather than across one or more rows (Fig. 1). This

TABLE 1. Coefficient of determination (r^2) between fresh and dry weight yields and meter placement in relation to drill rows by two cutting methods

		Meter position			
		A	B	C	D
2-dimensional cut	Fresh	0·43	0·12	0·30	0·41
Units 1–9 (Sinclair)	Dry	0·38	0·12	0·28	0·36
3-dimensional cut	Fresh	0·58	0·63	0·54	0·64
Units 10–18 (Nursery)	Dry	0·51	0·62	0·52	0·64

improved the r^2 from the poorest with 2-dimensional cutting to a level providing the best estimate with 3-dimensional cutting.

As can be seen in Fig. 1, the A position provides the least difference in vegetation arrangement in comparison with the usual method of cutting plants at the base within a plot frame. Three-dimensional cutting, however, still gave a substantial improvement in the r^2 values. For the C and D positions, the r^2 values almost doubled. Part of this difference in the r^2 values could result from inherent variability between locations. In 1967, this variability was not measured because of the difference in cutting methods tested. When both locations were harvested by the 3-dimensional method in 1968 and 1969, locations were similar in 1968, but differed in variability in 1969. Therefore, care must be used in attributing all differences to the method of cutting.

The Nursery had less variation between estimates of a and b, plus a smaller value of $S_{\hat{Y}}$ for each of the four positions. Also, since the regressions for the different positions had similar a, b, and $S_{\hat{Y}}$ values, it was concluded that the data could be combined into a common regression for deriving the mean pasture yield of 4155 ± 130 lb/ac. Selecting or using only one or two positions which had the highest r^2 or lowest $S_{\hat{Y}}$ values would not be appropriate since this could lead to a biased estimate of pasture yield. For example, on the Nursery location r^2 values for positions B and D were highest and the values for $S_{\hat{Y}}$ were lowest and third lowest, respectively. If data for the B position were used exclusively, however, they overestimated the bare ground or low-yielding vegetation between drill rows and resulted in a mean yield of 4019 ± 95 lb/ac. On the other hand, the use of the D position estimate gave a high pasture estimate of 4429 ± 108 lb/ac because the space between drill rows was not taken into account. Pasture yields in 1968 and 1969 were therefore estimated by using a sequential, 12-position, clockwise arrangement of meter locations, and cutting by the 3-dimensional procedure.

The total number of samples to be estimated in each pasture, and the ratio of cut samples to meter-estimated samples, were derived from the double sampling program which estimates from a particular sample an optimum sample size based on a specified cost and variance (Fig. 4). The 'optimum' sample size is based on the assumption that no significant change will occur in the population parameters. For these estimates, cost values for the small or cut sample and the large or meter-estimated sample must be specified. The amount of time required to cut a plot *v.* the time necessary to obtain a meter reading was measured for several pastures under routine sampling procedures. A cost ratio of 21·8 to 1·0 was obtained from these trials. For use in the computations this ratio was reduced to a slightly more conservative 20 to 1.

An average sample size from each of the 5-ac (2·02 ha) pastures estimated in 1967 showed that 1 out of each 5 plots should be cut and a total of 180 plots estimated. These values vary from one experimental unit to another and between years. As shown by the example in Table 2, the ratio for cut (SS) to meter-estimated

TABLE 2. Fixed variance sample estimates for determining yield on the same pasture in each of 3 years*. Individual pastures are the experimental unit for deriving yield estimates

Year	SS n'	LS n	Yield lb/ac	Error† percentage of $\hat{Y}$
1967	27	138	$4{,}757 \pm 395$	8·0
1968	49	282	$2{,}840 \pm 318$	11·0
1969	36	178	$1{,}694 \pm 160$	10·0

*Winter treatment Pasture 2 Nursery location
†95% confidence limits

(LS) samples was very near the 1-5 ratio, but this particular pasture was slightly oversampled in 1967. Only 138 plots were required rather than 160 which were taken. In 1968, a much larger total sample was indicated, and the analysis showed that 49 plots should be cut out of the 282 estimated, or a ratio of 1 to 6. Both the ratio and total for 1969 were very near the initial predictions. Likewise, the average for the 3 years was similar to the initial analysis value. The most important feature was that the error of the pasture yield estimate was small for individual years, with a range from only 8% to 11% at the 95% confidence interval.

There was almost no benefit in improving

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                              DOUBLE SAMPLING PROGRAM

                           MEF1701-14 POAM-HERBAGE 1969

                                     WNTR N-2

COMPUTATIONS FOR SMALL SAMPLE (X WITH Y VALUE ONLY)               N =  36

              SUM                   MEAN         CORRECTED SUM OF SQUARES
                                                    AND CROSS-PROD.
    X      .80900000E+03        .22472222E+02       .36029722E+04        X = METER READING
    Y      .13093000E+04        .36369444E+02       .73310964E+04        Y = TOTAL DRY WGT.
    XY                                              .38400694E+04

REGRESSION CONSTANT,    A  =  .12418415E+02      COEFFICIENT OF DETERMINATION, RSQR =  .55827517E+00
REGRESSION COEFFICIENT, B  =  .10658060E+01      CORRELATION COEFFICIENT,          R =  .74717814E+00

MEAN SQUARE DEVIATION FROM REGRESSION, SYX2  =  .95244921E+02


COMPUTATIONS FOR COMBINED SAMPLE (ALL X VALUES)                   N =  180
        MEAN OF X  =  .21444444E+02
        STANDARD DEVIATION OF X  =  .82752726E+01
        STANDARD ERROR OF THE MEAN OF X  =  .61680240E+00

FINAL VALUES
        Y  =  .35274033E+02
        VARIANCE OF Y  =  .31057802E+01
        STANDARD DEVIATION OF Y  =  .17623224E+01
        FINAL ESTIMATE OF Y  =  .35274033E+02  (+ OR -)  .35246448E+01   Grams / Plot

EFFICIENCY RATIO  =  .20180472E+00        C  =  1000.00          P  =  .10          T  =  2.0


COST ESTIMATES USED TO COMPUTE EFFICIENCY RATIO  FIXED COST SAMPLE VALUES   FIXED VARIANCE SAMPLE VALUES

        COMBINED SAMPLE  =   1.00               LARGE SAMPLE  =  199          LARGE SAMPLE  =  178
        SMALL SAMPLE     =  20.00               SMALL SAMPLE  =   40          SMALL SAMPLE  =   36
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Fig. 4. Sample page of final output for parameters evaluated in Dub-Sam Programme. Decimal location is established by moving point number of places shown by ± values which follow the estimator numbers.

meter estimates by separating living plant material, Sherman big bluegrass plus small amounts of other species, from the standing dead OM (Table 3). In 1968, the correlation (r) of meter reading and dead OM for the Nursery and Sinclair locations combined was 0·42. In 1969, r was only 0·12 for the same variables. For the same two years, the r values for living plant material and dead OM were 0·40 and 0·03, respectively, while the r values for meter reading and living plant material were 0·69 and 0·71. Thus, even in years when there is a lot of dead OM, meter reading and dead OM are not highly correlated. These data also indicated that the meter's sensing circuitry was relatively insensitive to the inert organic material which contained a low moisture percentage and little if any soluble electrolytes. The largest increase was for the Sinclair location in 1968, where including dead OM in the multiple regression improved r^2 by only 0·030. Otherwise, r^2 values increased less than 0·015.

Although dead OM does not usually contribute significantly to the meter reading, it may contribute to the weight of material harvested and increase the scatter of points about the regression line. This was evident both at Tonto Springs, and again at the Sinclair location where dead OM contributed 65% to mean plot yield in 1968. When amounts of dead OM vary widely, an increase in both large and small sample n may be necessary to obtain yield estimates with the precision specified.

CONCLUSIONS

The electronic capacitance meter can be used satisfactorily for obtaining yield estimates of sown ranges for routine herbage production estimates and treatment comparisons on experimental pastures. Double-sampling estimates

TABLE 3. Contribution of living plant material and standing dead OM* to the coefficient of determination in a stepwise regression for sown ranges

Mean values are for $n=324$ for each location in each year. The dependent variable (Y) is meter reading in these regressions.

		Nursery			Sinclair			Total		
Year	Source	Mean g/plot	Multiple r^2	Increase in r^2	Mean g/plot	Multiple r^2	Increase in r^2	Mean g/plot	Multiple r^2	Increase in r^2
1968	Living plant material	21·54	0·546		17·50	0·504		19·52	0·476	
	Dead OM	30·51	0·551	0·005	32·81	0·534	0·030	31·66	0·502	0·027
1969	Living plant material	31·34	0·630		30·19	0·372		30·76	0·509	
	Dead OM	8·57	0·639	0·009	6·36	0·387	0·015	7·46	0·518	0·009

*Each succeeding step in the analysis includes the variable above it until F value is insufficient for further testing. Thus the r^2 value for dead OM includes the amount contributed by living plant material.

showed that generally one cut plot out of each five meter-estimated plots provides a good small-sample to large-sample ratio. A computer program is available to determine optimum sample size for either fixed-cost or fixed-variance criteria. Cutting the small sample plots by the 3-dimensional scheme to approximate more closely to what the meter senses doubled the r^2 values and improved the regression equations. The meter is relatively insensitive to organic matter which is low in moisture or electrolytes in solution. Thus standing dead material has a minimal effect on the meter reading. It can, however, contribute significantly to variation of regression estimates. Very green, succulent plants also can cause variational extremes. Although either succulent or relatively dry herbage can be efficiently estimated with the meter, stratification into rather homogeneous units or more intensive sampling may be required to estimate a heterogeneous population.

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