Estimation of Herbage on California Annual-Type Range

JACK N. REPPERT, MEREDITH J. MORRIS, AND CHARLES A. GRAHAM[1]

A satisfactory estimate of herbage yield on California annual-type ranges, as in other areas, is often not easily obtained. Researchers and wildland managers want more efficient and precise methods of determining herbage yield. They need improved methods to evaluate correctly grazing and range improvement treatments as reflected in vegetation responses.

In 1958 we investigated the relation between herbage yield and plant height or herbaceous cover index, or both, at the San Joaquin Experimental Range in Madera County, California. The objectives were to determine (1) whether height or ground cover characteristics could be used to estimate herbage yield, and (2) the feasibility of using the average weight and density of individual plants to find yield per unit of area.

The value of using clipped plots to estimate herbage yield has long been recognized (Culley, *et al.*, 1933). But this method has various limitations, causing a search for factors with strong relations to harvested plots that could efficiently replace clipping as an estimate of yield. Several researchers (Pasto, *et al.*, 1957; Précsényi, 1957; Evans and Jones, 1958) have felt that an estimate of plant height or ground cover or both might be related closely enough to yield for use as an indirect measure of this parameter. Working in the California annual-type, Evans and Jones (1958) tested the relation between percentage ground cover times height against herbage yield at several stages of growth. They found that these two factors accounted for 28.9 to 97.6 percent of the variability in yield. To Evans and Jones this method appeared promising as an index of yield responses to fertilization. But they chose not to place the height-ground cover factor on the same terms (i.e. pounds per acre) as herbage yield by developing a correction term.

Pasto, *et al.*, (1957) reported correlation coefficients of cover and yield of .728 and .733 for bluegrass and orchardgrass-Ladino clover pastures. Multiple correlation coefficients involving cover and height at .912 and .875 were even higher.

Little work has been reported in the literature on estimating unit area herbage yield by using the factors of average plant weight and average plant density (i.e. number per unit-area). Several workers have reported methods of determining density from actual counts on known areas and by more involved procedures, including the point-centered quarter method. Many researchers, from Crafts (1938) to Reed and Peterson (1961), have investigated weight characteristics of individual plants and in the process arrived at estimates of average plant or "shoot" weight. Nevertheless, they did not have as a major objective the combination of these two factors for an estimate of yield.

Description to the Study Area

The experimental area lies in the annual-type range of the

[1] *Reppert and Graham are Range Conservationists (Research), Pacific Southwest Forest & Range Experiment Station, Forest Service, U. S. Department of Agriculture, Coarsegold, California, and Morris is Mathematical Statistician, Rocky Mountain Forest & Range Experiment Station, Forest Service, U. S. Department of Agriculture, Fort Collins, Colorado.*

Sierra Nevada foothills. It has an average annual precipitation of 19 inches, mostly falling from October through May. The shallow granitic soil has a low water holding capacity, but supports an abundant stand of annual grasses and forbs. The 1957-58 precipitation totaled 32.04 inches; excessive amounts fell during winter and early spring. Late spring was rather dry, resulting in a herbage yield slightly above average.

An unimproved 78-acre range unit, ungrazed since February 1958, was studied in May 1958. The area consisted of the following three range site groups:

Range site group	Description
I	Bottom or swale and adjacent gentle slopes
II	Open rolling slopes
III	Rocky, brushy rolling slopes

Nearly three-fourths of the range unit was made up of the third site group and the remainder well divided between the other two groups.

Procedure

Ninety-four clipped square-foot plots were systematically located along a system of transect lines 200 feet apart, crossing the study area in an east-west direction. Along another set of transect lines running in a north-south direction, also 200 feet apart, 524 step points were located. Both clipped-plot and step-point locations were determined by pacing along transect lines and taking a plot or point at a predetermined, constant pace interval. Of the 94 clipped plots, an exception was made for 4, which were "extra ones" taken in site group I at half the constant interval.

For the step point method 150 to 200 single points were taken in each of the three site groups. To do this, we took additional stratified sampling locations in site groups I and II along supplemental transect lines parallel to and 100 feet from the primary set. Appropriate site classification was recorded for each sampling-unit location. All plots were located on "grazable soil" (an area accessible to grazing cattle, i.e., not covered by rocks or low growing shrubs, and having soil at least 3 inches deep). Plots or plants were harvested for estimates of yield at both square-foot plot locations and step-point locations. Several estimates of plant height and herbaceous ground cover were also made at the same locations and used to determine their relation to yield.

A point frame somewhat similar to that described by Tinney, *et al.*, (1937), was placed over each square-foot plot (Figure 1). The frame consisted of 30 pins inclined at 45 degrees. On each square-foot plot, a sample of 30 first hits on the vegetation was taken and plant heights for the species first hit by each pin recorded.

FIGURE 1. Inclined-point frame used to select plants for height measurements on plots later clipped.

The points were distributed systematically over the square-foot plot, following Goodall's recommendations (1952). Leaves or inflorescences were fully extended and measured to the tip. This measurement resembles what Heady (1957) called plant length. When the point missed a plant and hit litter or bare ground, we selected the nearest plant at ground level for height measurement so that 30 plants were measured on each square-foot plot. The total number of direct hits on plants served as one estimate of the herbaceous ground cover.

The point frame was built to duplicate the step-point method, as often used in the California annual-type, in selecting a plant hit. A hit occurred when the moving point contacted a plant any place from 7 inches above the ground to ground level. Seven inches is a common starting place of a pin in the step-point method when the observer holds his foot at approximately a 45° angle with the ground. We felt that the inclined pins would also make reading easier (Van Keuren and Ahlgren, 1957).

After we removed the point frame from the square-foot plot, an ocular estimate of the percentage herbaceous cover was made by looking vertically down upon the plot and projecting the plant parts to ground level. The herbage within the plot was then clipped to a half-inch stubble, bagged separately, air-dried, sorted as to species, and weighed to the nearest one-tenth gram.

A sharp pin held at a 45° angle and lowered toward the ground from a notch in the toe of the observer's shoe located the step point. The observer kept his foot at an angle to avoid trampling. He recorded the species hit and its height (as described for the point frame). If no herbage was hit, then a record of rock, litter, bare soil, erosion pavement, moss, or lichens was made. At points where no vegetation hits occurred, he tallied the height of the nearest plant encountered within a 180° arc ahead and along the line of the transect. An ocular estimate of the percentage herbaceous ground cover was

Table 1. Regression coefficients (b), standard deviations (s_b), and correlation coefficients (r) between air dry weight, in grams, and simple variables listed

Site group	Total plot locations	Average height (Method: pointframe)			Cover (Method: ocular estimate)		
		b	s_b	r	b	s_b	r
III	61	[1]1.857	.1190	.897	28.637	5.916	.533
All site groups combined[2]	94	2.712	.2123	.800	56.640	5.490	.732

[1]All regression coefficients are statistically signficant at the .001 probability level.

[2]In proportion to their respective areas in the range unit.

made on a square-foot plot at every tenth step-point.

At every step-point the plant hit was measured for height and cut at the ½-inch level for later weighing. Then we placed a ¾-inch diameter loop around the plant "stump," counted all other plants growing within the loop, and used this count as the estimate of plant density. Yield for the three site groups of the range unit was computed by the formula: Yield = estimated average plant weight X estimated average plant density.

These yield figures were compared with production obtained from the clipped plots for any indication of similarity in results as estimated by the two approaches.

Results and Discussion

Relations of variables to air-dry weight

Average plant height was more closely related to air-dry weight than were estimates of ground cover (Table 1). Ocular estimates of herbaceous ground cover by vertical projection showed only a fair relation to yield. Cover estimates by inclined point were nearly always 100 percent, showed little relation to yield, and are not shown in the table.

By calculating the product of plant height and ocular estimate of cover, a small improvement was made in the relation to yield (Table 2). Squaring the correlation coefficients provided an estimate of the amount of variation in yield that is due to the height and cover variables. In this instance, 81 percent of the variation in yield was accounted for in site group III and 83 percent in a mixture of all sites. Height times cover by the inclined-point frame did not improve the relation over that obtained by height alone.

A slightly better relation was obtained when we computed a multiple regression for the three variables of average height, ocular cover, and height times ocular cover (Table 3). About 84 percent of the variation in yield was then accounted for by these variables.

All of these relations between yield and the other variables were at best too low to be of much practical value as an acceptable indirect measure of herbage yield. Height showed the best relation of the single variables tested (Table 1) and height times ocular cover improved the relation to a modest extent (Table 2). Even so, from 17 to 36 percent of the variation in yield remained unaccounted for.

Characteristics of height measurements and cover estimates

Different plant species varied in their average heights within one site group and between site groups (Table 4). An estimate of average plant height (all species) for a site or range unit was determined from a sample of all height classes in the stand. The number of measurements taken for each species by height class determined the average height and variance estimates for all species combined. The inclined pin, as used to pick plants for measurement, was characterized as a nonrandom selection method of the array of plant heights. However, the proportional contribution of separate species to average height approximates the proportional contribution of these species to total yield (Table 5). Wilson (1960) reported that pins inclined at some optimum angle may closely approach this goal. Actually we found a tendency to overestimate broadleaves compared with grasses. We thought that in finding the average height most highly related to yield, a proportional species contribution to height, as described above, should exist.

The two methods of estimating cover differed in that the ocular method involved vertical projection of plants to ground surface,

Table 2. Regression coefficients (b), standard deviations (s_b), and correlation coefficients (r) between air dry weight, in grams, and combinations of variables listed

Site group	Total plot locations	Average height X cover (Method: ocular cover)			Average height X cover (Method: cover by point frame)		
		b	s_b	r	b	s_b	r
I	18	....	....	....	3.648[1]	.7984	.751
II	15	....	....	....	2.167	.5393	.745
III	61	2.676	.1705	.898	1.825	.1145	.526
All	94	3.469	.1622	.912	2.573	.2107	.786

[1]All regression coefficients statistically significant at the 1 percent probability level or less.

Table 3. Partial regression coefficients (b), standard deviations (s_b), and multiple correlation coefficients (R) between air dry weight, in grams, and variables listed

Site group	Total plot locations	Average height (Method: point frame)		Cover (Method: ocular estimate)		Average height X ocular cover		
		b	s_b	b	s_b	b	s_b	R
III	61	.457	.4309	−9.369	5.709	**2.438**	.774	.916
All site groups combined[1]	94	−**1.068**[2]	.5340	−12.582	6.761	**5.064**	.640	.919

[1]In proportion to their respective areas in the range unit.
[2]Boldface regression coefficients statistically significant at the 5 percent level or less.

whereas the point frames, inclined as they were, involved angular projection. Either index was expected to be related to plot weight except in cases when the cover index approached 100 percent most of the time although plot weights varied considerably. This happened for the inclined-point frame, which was not surprising because both Goodall (1952) and Winkworth (1955) had reported that use of inclined pins would result in higher estimates of cover than vertical ones. Actually 93 percent of the inclined pins of the point-frame method made direct hits on vegetation—an obvious overestimation of herbaceous cover which rendered the method insensitive to plot weight changes.

In some situations, a good enough relation between a measurement (e. g. height) and herbage yield may develop to indicate that the indirect measurement could be used to predict yield. However, the usefulness of such a factor as height or height times ocular cover as an indirect measure of yield depends upon the precision of the estimates of both height and cover and on the "stability" of the regression coefficient. Two estimates of height and cover from the same area sampled by two schemes involving different placement and frequency of sampling have been compared (Table 6). A regression developed for a certain average height—for example, 12 inches—may not hold true when the average height — for example, 16.5 inches—of the plants in the same site differs. A new regression coefficient may be needed.

Table 4. Coefficient of variation (CV) for height measurements

Site group	Statistic[1]	Plants by step point: Soft chess	All grass	Filaree	Forbs[2]	All broad-leaves	All species
	n	54	84	13	15	54	154
I	$\bar{x}$	13.7	15.3	13.6	9.1	16.0	16.5
	CV	48.8	45.8	43.4	35.4	51.2	53.4
	n	80	124	18	10	36	160
II	$\bar{x}$	13.4	14.0	12.6	10.0	11.8	13.5
	CV	52.8	49.5	43.7	53.1	44.4	49.0
	n	67	116	50	36	94	210
III	$\bar{x}$	10.2	11.7	7.1	7.3	7.1	9.6
	CV	58.5	60.8	52.6	56.7	53.1	64.9
Sum[3]	n	106	177	56	42	111	289
all	$\bar{x}$	10.8	12.2	7.8	7.4	7.9	10.6
sites	CV	51.8	55.2	55.7	52.9	54.4	59.4

[1] n = number of height measurements
$\bar{x}$ = mean height (in inches) $\quad CV = \dfrac{\text{standard deviation}}{\text{mean}} \times 100$ (expressed in percent)
[2]Forbs are broadleaves excluding legumes and filaree.
[3]Summation by proportion of sites within the range unit.

Comparisons of results of two methods of estimating site and range unit herbage yield

The plant density-weight method gave estimates of herbage production 6.5 to 7 times those indicated by clipped plots (Table 7). These estimates were different even though no estimate of shoot variance was made. Despite these great differences in estimates of yield, this fact remains. The relative productivity estimate of the different sites was similar, as shown when site and total yields by the two methods were expressed as percentages of site I (Table 7). That density estimates were high was apparent, but the reason was less obvious. The method of making density counts did not permit the occurrence of zero counts within a loop because a minimum of "one" was assured by placing a loop around a plant "stump." By arbitrary removal of "one" count from each loop the density was lowered more than the overcount bias, but production still remained 3.5 to 4.5 times that indicated by clipped plots. Therefore, other factors such as plot edge effect raised the density estimates. For future work, definition of plant "shoots" on a more or less single stem basis as the unit of measure, instead of whole plants, may lower the variance of the weights. Also specifying a minimum size of shoot under which it would be ignored would eliminate a myriad of tiny stunted plants that contribute little to herbage yield but substantially to density and plant or shoot variance.

As far as time is concerned, the difference in sampling frequency makes critical comparison difficult. However, it took about twice as much field time to lo-

Table 5. Species contribution to measurements of average plant height compared with species contribution to total herbage yield

Method	Soft chess	All grass	All filaree	Forbs[1]	All broadleaves
	— — — — — — (Percent) — — — — — —				
Point frame plant hits for height	32.0	53.3	21.3	14.3	44.4
Weight composition from clipped plots	33.1	62.6	14.2	7.1	32.1

[1] Excludes filaree and legumes.

cate the 524 points and use the plant density-weight method as it took to clip the 94 square-foot plots. On the other hand, weighing and compiling the plant density-weight data took less time than similar processes with clipped plots. The harvested-plot method had some advantage in taking slightly less total time to get an estimate of total yield.

Table 6. Estimates of height and cover, alone and combined, from two methods of sample placement and frequency; clipped plots and step points

Site	Height (inches)		Ocular cover (percent)		Height X ocular cover		Height X cover by inclined pins	
group	Clip plots	Step points	Clip plots	Step points	Clip plots	Step points	Clip plots	Step points
I	12.0	16.5	72.8	69.0	9.0	11.4	11.8	16.5
II	12.5	13.5	63.7	52.5	7.3	7.1	11.0	13.2
III	8.6	9.6	48.6	46.8	4.5	4.5	8.0	9.2
All[1]	9.6	11.6	55.3	51.9	5.8	6.4	9.2	11.3

[1] Calculated with the same site proportion as the 94 clipped plots: 19.1 percent, I; 16.0 percent, II; 64.9 percent, III.

Summary and Conclusions

A range unit and its component range sites at the San Joaquin Experimental Range in the annual-plant type of California, were sampled for yield by the standard procedure of clipping square-foot plots. Before harvest, an inclined-point frame of 30 points was taken on each plot to select objectively plants for height measurement. Two estimates of herbaceous ground cover were made: one ocularly as a vertical projection of aerial plant parts to the ground surface, the other by the point frame as an angular projection of plant parts to the ground surface. By the step-point method, we made another sample of the same range unit and range sites and obtained other estimates of height and cover. In an additional test, another estimate of yield was made in conjunction with the step-point procedure. Each plant "hit" and measured for height was also harvested and its density estimated by counting the number of plants within a ¾-inch diameter loop. We then combined average plant weight and density estimates to give herbage yield estimates which were compared with estimates from clipped plots.

Simple regression coefficients were statistically significant for height, ocular cover, height times ocular cover, and height times cover by inclined pins. Cover as estimated by inclined pins was not responsive to yield variation because estimates tended always to be near 100 percent. Correlation coefficients were low enough that the methods were of little value in estimating absolute herbage yield. As an index of relative yields, however, height times ocular cover could serve a useful purpose. A multiple regression of yield on height, ocular cover, and height times ocular cover showed some improvement in the relation, accounting for 84 percent of the variation associated with yield. However, determination of a significant regression with high correlation is not enough—it must be tested under many conditions of changing variables (i.e. height and cover) so that the degree of stability of the regression coef-

Table 7. Comparison of two methods of estimating herbage yield

Method	Statistic[1]	Site group I	II	III	All[2]
Clipped plot (94 plots)	$\bar{x}$	3,286	1,935	1,110	1,659
	$s_{\bar{x}}$	412	214	108	139
	relative yield	100	59	34	50
Average density-average plant weight	$\bar{x}$	23,272	12,517	7,343	11,213
(524 step points)	relative yield	100	54	32	48

[1] $\bar{x}$ = mean yield (in pounds per acre)
$s_{\bar{x}}$ = standard error of the mean (in pounds per acre)
relative yield = the yield of each site group expressed as a percentage of site group I

[2] Combined in the same proportions as the 94 clipped plots, 19.1, 16.0, and 64.9 percent respectively for site groups I, II, and III.

ficient can be established.

Collecting plants for weight in place of measuring height was tested. By determining density and plant weight, we estimated yield which, in this study, was several times higher than the estimates from clipped plots. However, this method was sensitive to yield by range sites and indicated a relative site productivity similar to that obtained from harvested plots. Improvement in the method of estimating both density and plant weight must be made to develop a method that will estimate absolute yields of a magnitude similar to those from clipped plots. As conducted in this study, the plant density-weight method has little value except as an index of relative yield. This method of yield determination offers possibilities in the future as a useful procedure, if it can be improved to provide more accurate estimates.

LITERATURE CITED

CRAFTS, EDWARD C. 1938. Height-volume distribution in range grasses. Jour. Forestry 36(12): 1182-1185, illus.

CULLEY, M. J., R. S. CAMPBELL, AND R. H. CANFIELD. 1933. Values and limitations of clipped quadrats. Ecology 14(1): 35-39.

EVANS, R. A., AND M. B. JONES. 1958. Plant height times ground cover versus clipped samples for estimating forage production. Agron. Jour. 50(9): 504-506.

GOODALL, D. W. 1952. Some considerations in the use of point quadrats for the analysis of vegetation. Austral. Jour. Sci. Res. Ser. B 5(1): [1]-41, illus.

HEADY, HAROLD F. 1957. The measurement and value of plant height in the study of herbaceous vegetation. Ecology 38(2): 313-320, illus.

PASTO, JEROME K., JOHN R. ALLISON, AND JOHN B. WASHKO. 1957. Ground cover and height of sward as a means of estimating pasture production. Agron. Jour. 49(8): 407-409.

PRÉCSÉNYI, S. 1957. The correlation between ground-cover and vegetation yield. Portug. Acta Biol. Ser. B. 6(1): 94-96.

REED, MERTON J., AND ROALD A. PETERSON. 1961. Vegetation, soil, and cattle responses to grazing on northern great plains range. U. S. Dept. Agr. Tech. Bul. 1252, 79 pp., illus.

TINNEY, FRED W., O. S. AAMODT, AND HENRY L. AHLGREN. 1937. Preliminary report of a study on methods used in botanical analyses of pasture swards. Amer. Soc. Agron. Jour. 29(10): 835-840, illus.

VAN KEUREN, R. W., AND H. L. AHLGREN. 1957. A statistical study of several methods used in determining the botanical composition of a sward: I. A study of established pastures. Agron. Jour. 49(10): 532-536.

WILSON, J. WARREN. 1960. Inclined point quadrats. New Phytol. 59(1): 1-8, illus.

WINKWORTH, R. E. 1955. The use of point quadrats for the analysis of heathland. Austral. Jour. Bot. 3(1): [68]-81, illus.