# An Evaluation of the Calibrated Weight-Estimate Method for Measuring Production in Annual Vegetation

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**Highlight:** *A double sampling technique, of visual weight estimates calibrated by harvesting, was applied to the measurement of biomass and production curves in grazed and ungrazed semiarid annual grassland. Good levels of accuracy can be achieved in such vegetation with a time expenditure significantly lower than by harvesting only. Some methodological problems were encountered and solved by modifications of the method. In some conditions the method can be used for estimating animal intake.*

In a study of plant and animal production on semiarid annual grasslands at Migda in Israel (Tadmor et al., 1974), frequent, extensive, and accurate measurements of plant biomass were needed. To determine the seasonal growth curve and the differences in it between plots with different grazing and fertilization treatments, plot means had to be estimated with an accuracy of 10-15% every 2 weeks. The annual vegetation sampled showed great local variability in yield and composition, particularly in early growth stages, when the coefficient of variation of biomass in 25 X 25-cm squares within a field may be 100-150%. Thus sampling by harvesting alone to the required accuracy would have imposed a prohibitive work load. Therefore, an attempt was made to apply the double sampling technique of visual weight estimates calibrated by harvesting of a subsample to the annual vegetation concerned. This method is based on the observation that a trained estimator can achieve consistent estimates of biomass (Pechanec and Pickford, 1937), which can be converted to true values by using a calibration curve obtained on the same day (Wilm et al., 1949; Brown, 1959; Morley et al., 1969). The statistical aspects of the method have been discussed in *Range Research, Basic Problems and Techniques* (National Research Council, 1962).

The extensive application of this method to grazed and ungrazed annual vegetation allows a thorough evaluation of its performance in this vegetation type, in terms of accuracy and speed. It also led to the examination of some methodological problems which have not been discussed before: in particular, estimation of dry or fresh weight, nonlinearity in calibration, the effect of heterogeneity in composition, and the possibility of using the method for measuring animal intake. This paper deals with these problems and with a general evaluation in view of the experience at Migda.

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## Description of Methods

### Estimating Fresh Weight

In green herbaceous vegetation, and with inexperienced estimators, there is some advantage in expressing estimates as fresh weight (FW), even if the final aim is to measure dry weight. This enables a period of "training" estimations before the actual estimations every day, in which the estimators can immediately check and correct their accuracy and consistency. The work thus proceeds in three stages.

#### *Training*

At the beginning of each day's work, or upon moving into a new vegetation type, the estimator puts the sampling quadrat

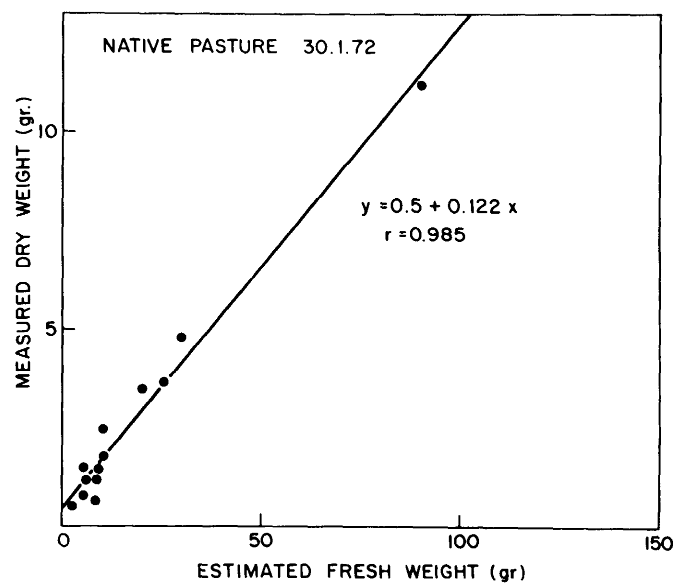


Fig. 1. *Linear regression of measured dry weight on estimated fresh weight.*

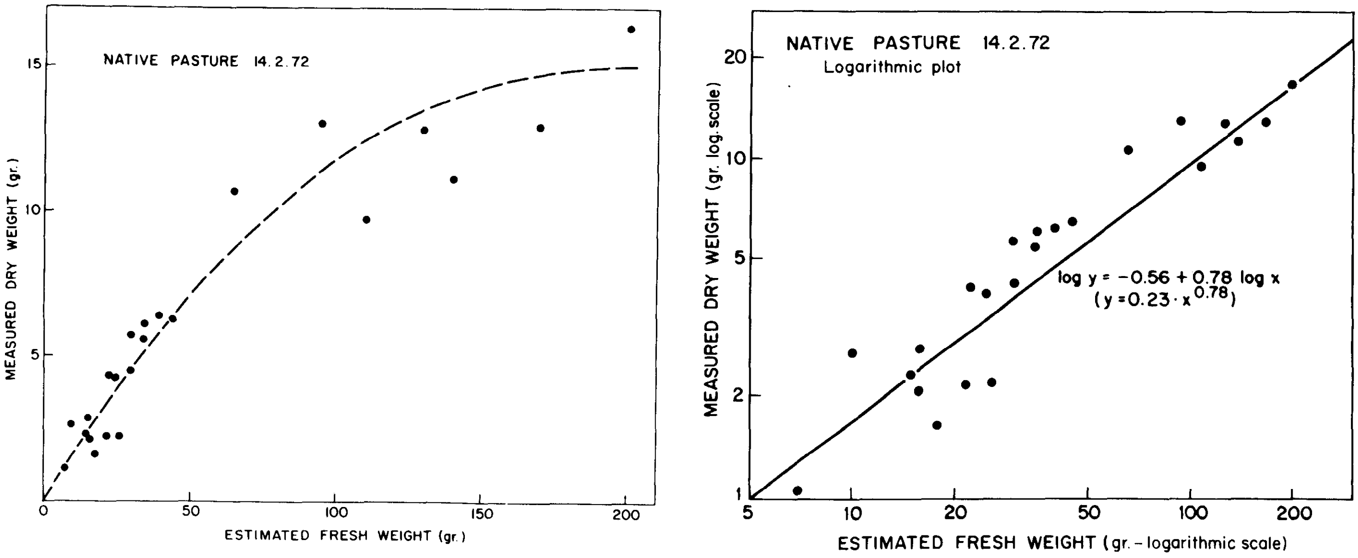


**Fig. 2.** *Measured dry weight against estimated fresh weight. a. Linear plot showing nonlinear relation. b. Logarithmic plot and regression.*

(a wire frame of 25 X 25 cm) on places with different plant density, height, and composition in the field. He writes down a visual estimate of the fresh weight of plant material within each frame. This material is then clipped at ground level and weighed immediately in the field on a spring-scale (protected from wind). After each plot the estimator checks himself and adjusts subsequent estimations accordingly. This is repeated until reasonably consistent estimates are attained. About 20-30 training plots may be needed for an unexperienced estimator in a variable field, and as few as 10 for an experienced one. Training may take ½ to 1-½ hours.

*Estimation and subsample harvesting*

Sampling plots are distributed in the field according to some unbiased design. Normally, the portable sampling frame is placed at constant paced intervals along linear transects. Usually two estimators work as a team; to assure independence of their estimates, the one who is also the recorder writes down his estimate silently before the second one announces his. The quadrat number, the two estimates of fresh weight, and, if required, data on composition are written directly in a computer coding sheet.

A predetermined proportion of the estimated quadrats (every fifth, or every tenth, etc.) is clipped immediately after its estimation. The material is stored in a paper bag (or plastic bag if fresh weight is also of interest) with quadrat number (and/or estimated weight) marked on it.

The number of quadrats estimated and the proportion harvested depend on the accuracy required. Usually in each field or treatment, 30 to100 quadrats were estimated and 10 to 25 of them harvested.

*Calibration*

The harvested samples were weighed after oven-drying at 75-80°C (or both before and after drying if fresh weight was required). The actual dry weights of calibration samples ($y_c$) were plotted against their visual estimates of fresh weight ($x_c$) (Fig. 1), and a calibration equation fitted by regression. In many cases a linear regression

(1) $y_c = a + bx_c$

turned out to be adequate (Fig. 1). In some cases, nonlinearity was apparent in the plot (Fig. 2a); then a logarithmic equation

(2) $\log y_c = a + b \log x_c$

usually gave better results (Fig. 2b).

The calibration equation is then used to adjust or convert the mean visual estimate of fresh weight in all quadrats (harvested and nonharvested), into the best estimate of mean actual dry weight, $\bar{y}_e$. In the linear case, this is simply

(3) $\bar{y}_e = a + b\,\bar{x}_e$

or, since $a = \bar{y}_e - b\bar{x}_c$ :

(4) $\bar{y}_e = \bar{y}_c + b\,(\bar{x}_e - \bar{x}_c)$

If the logarithmic regression has to be used:

(5) $$\bar{y}_e = \frac{e^a}{N} \sum_{i=1}^{N} (x_{ei})^{b}$$

where $x_{ei}$ is each individual visual estimate and N the number of such estimates.

In cases when fresh weight itself is of interest, and the same procedure is used, except that $y_c$ and $y_e$ are then fresh weight (Fig. 3). If the mean dry matter content of the fresh material is estimated separately by harvesting, the final result can then be converted into dry weight.

**Table 1. Accuracy of some regressions of dry weight on estimated fresh weight in an annual pasture: the effects of growth stage, estimator, and type of equation.**

| Date and growth stage | Estimator[1] | Linear equation[2] r² (%) | Linear equation[2] $c_{x.y}$ (%) | Logarithmic equation[2] r² (%) | Logarithmic equation[2] $s_{x.y}$ |
|---|---|---|---|---|---|
| Jan. 30, 1972 | A(3) | 94 | 28 | 88 | .16 |
| (green, low) | B(2) | 92 | 30 | 89 | .17 |
| Feb. 13, 1972 | C(2) | 80 | 26 | 86 | .13 |
| (green, growing) | D(1) | 75 | 30 | 85 | .13 |
| March 7, 1972 | A(3) | 38 | 22 | 64 | .10 |
| (± green, tall) | B(2) | 26 | 25 | 58 | .11 |
| March 29, 1972 | A(3) | 73 | 21 | 85 | .08 |
| (tall, 10% dry) | B(3) | 62 | 25 | 80 | .09 |
| April 14, 1972 | A(3) | 53 | 26 | 44 | .13 |
| (peak yield, 30% dry) | F(1) | 18 | 34 | 20 | .16 |

[1] Estimator training levels: 1—first time, 2—has estimated 1-3 times before, and 3—has estimated 4 or more times before.

[2] $r^2$ = proportion of variance accounted for by regression (%); $s_{x.y}$ = standard deviation from regression; $c_{x.y}$ = $s_{x.y}$ - relative deviation from regression, in percent of mean.

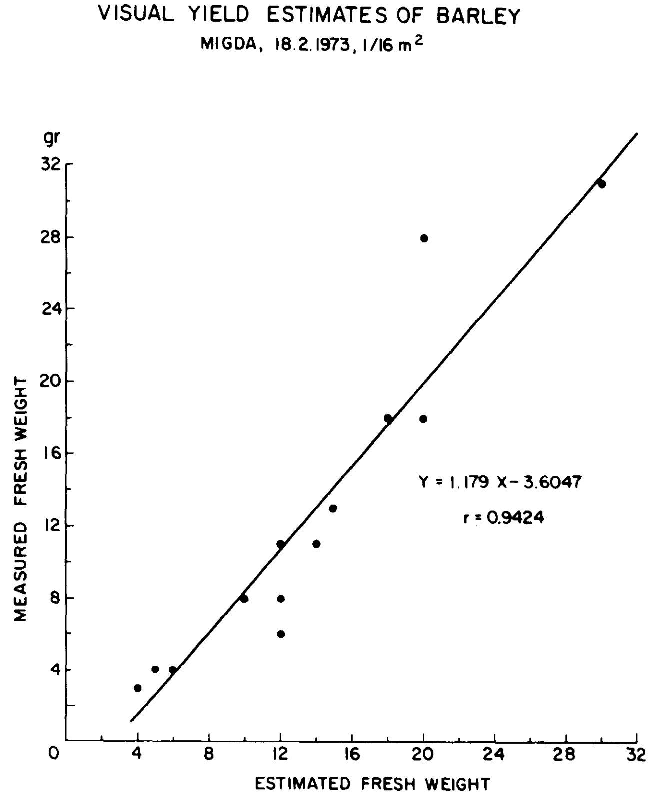


**Fig. 3.** *Regression of measured against estimated fresh weight: barley crop.*

### Estimating Dryweight

In some conditions, when water content of the plants was fairly constant, the method of estimating yield through fresh weight gave reasonably accurate results (Table 1). However, when water content varied greatly during the day or within a field, the method became very inaccurate for estimating dry weight (DW). On a warm day after a dewy night, the ratio dry/fresh weight may vary from 8-10% in the morning (when training is done) to 15-20% in the afternoon. At the end of the growing season, the rate of drying out is often very variable within a field, and the dry/fresh weight ratio may vary between 20% and 50% (or 40% and 90%) in one field at a given time. In these conditions, even the most skilled estimators have been found to achieve only very low correlations (0.5–0.7) between their FW estimate and the true DW, simply because the correlation between true FW and DW is also low. The correlation between *measured* fresh and measured dry weight in April was only 0.75 (but 0.98 in January).

Direct visual estimation of the dry weight of both green and dry material was found to overcome the problems in these conditions. In all other conditions it was as good as or slightly better than estimation through FW (Table 2), once the observers learned to "see" a green vegetation in terms of its dry matter and once they learned to estimate consistently without the training and checking period in the morning (Fig. 4 and 5).

The daily training stage is of course inapplicable when green or partly green vegetation is estimated directly in DW, and the estimators know the results only some days later, after drying. The procedure in direct estimation of dry weight starts immediately with actual estimation and subsample harvesting and is otherwise exactly as in the previous section. Calibration and adjustment calculations are as before, except that $x_c$ and $x_e$ are now visual estimates of dry weight.

At calibration, any inconsistencies in the estimates of an untrained estimator are evaluated and the relations between them and other properties of the sample (cover, height, composition, and phenology) are examined. If any consistent relations are found, this information can be used by the estimator to correct his estimates the next time. After a few sampling dates, he either achieves a reasonable degree of consistency or is declared unfit for dryweight estimation.

## Performances and Problems

### Accuracy

The success of the calibration method may be measured in terms of the correlation coefficient, *r*, the proportion of variance accounted for, $r^2$, or the variance or standard error associated with the regression, $s^2_{y.x}$ or $s_{y.x}$.

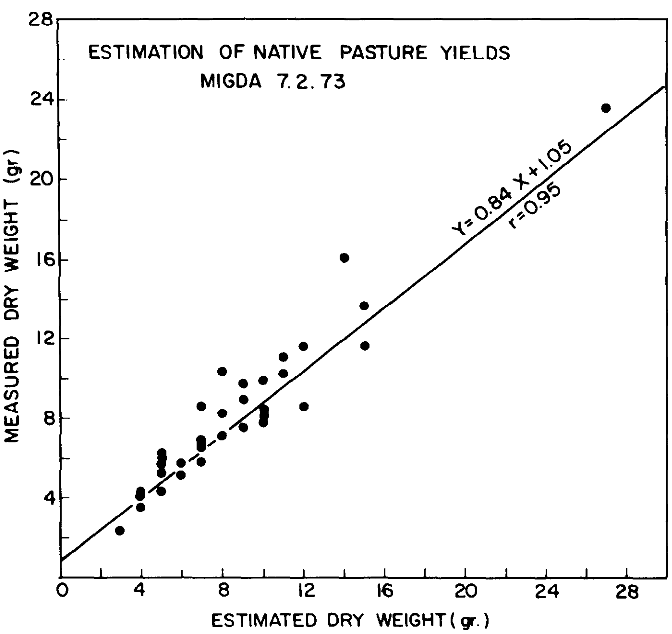


**Fig. 4.** *Regression of measured against estimated dry weight: pasture.*

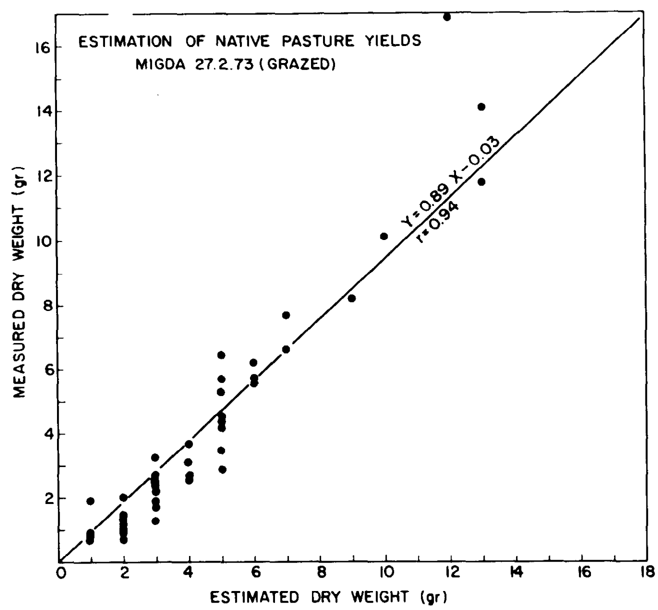


**Fig. 5.** *Regression of measured against estimated dry weight: grazed pasture.*

Table 2. Accuracy of some regressions of dry weight on estimated dry weight.

| Date and growth stage | Estimator[1] | Linear equation[2] | | Logarithmic equation[2] | |
|---|---|---|---|---|---|
| | | $r^2$ (%) | $c_{x.y}$ (%) | $r^2$ (%) | $s_{x.y}$ |
| Dec. 27, 1972 | D(3) | 91 | 21 | 90 | .11 |
| (green, low) | G(1) | 88 | 24 | 90 | .11 |
| Feb. 6, 1973 | D(3) | 75 | 22 | 82 | .08 |
| (green, growing) | H(2) | 47 | 33 | 67 | .11 |
| March 7, 1973 | D(3) | 72 | 17 | 72 | .07 |
| (green, tall) | G(2) | 63 | 20 | 62 | .08 |
| March 27, 1973 | D(3) | 90 | 17 | 88 | .07 |
| (near peak yield, 20% dry) | G(3) | 83 | 22 | 73 | .10 |

[1] Estimator training levels: 1—first time, 2—has estimated 1-3 times before, and 3—has estimated 4 or more times before.
[2] $r^2$ = proportion of variance accounted for by regression (%); $s_{x.y}$ = standard deviation from regression; $c_{x.y}$ = $s_{x.y}$ - relative deviation from regression, in percent of mean.

In the 1971/72 season, estimation through FW was used. The correlation coefficient between estimated FW and actual DW (in samples of n = 25) varied from $r$ = 0.96 in February (all vegetation green) to $r$ = 0.61 in March-April (highly variable moisture content). Thus the proportion of variance accounted for by the regression varied from 94% to 38% (Table 1). In 1972/73 direct estimation of DW was used (Table 2) and the results were more consistent: $r$ = 0.85 and $r^2$ = 72% to 91% (in samples of n = 20).

The total sampling variance associated with a field mean estimated by the double sampling technique is (National Research Council, 1962):

$$s^2_T = b^2 \frac{s^2_{xe}}{N} + \frac{s^2_{y.x}}{n} + \frac{s^2_{y.x}}{n} \frac{(\bar{x}_e - \bar{x}_c)^2}{s^2_{xc}}$$

where:

$s^2_T$ = total variance of estimate,
$s^2_{xe}$ = variance of visual estimates in total sample,
$s^2_{xc}$ = variance of visual estimates in calibration sample,
b = slope of regression of $y_c$ on $x_c$,
$s^2_{y.x}$ = variance in $y_c$ not accounted for by regression on $x_c$,
n = number of calibration plots, and
N = total number of estimated plots.

The total sampling variance is thus a sum of three terms, the first of which expresses the inherent variability of the field and may be decreased by increasing N. The last term expresses the error due to the fact that the mean of the harvested subsample may be different from the total estimated sample; with 100 estimates and 20 calibrations per field it was usually found to be negligible. The second term, $\frac{s^2_{y.x}}{n}$, is the error introduced by the calibration regression. The standard deviation from regression. $s_{y.x}$, was between 15% and 30% of the mean (Table 2) thus with n = 20 the standard error associated with the calibration was only 3% to 7%. The total standard error $s_T$ was between 5% and 13% of the mean, with n = 20, N = 100. The ratio of 5 estimates to 1 harvested plot was thus appropriate, as it distributed sampling variance (and also time requirements) roughly equally between visual estimates and harvesting.

This level of accuracy enables the method to be used for fairly accurate estimates not only of actual biomass but also of *differences* between treatments or sampling times. For instance dry matter intake by sheep in a 5-day period could be estimated by the difference in biomass before and after grazing, with a standard error of 15–20%; the result agreed well with an independent measurement of intake by tritiated water turnover (Benjamin et al., 1973).

### Time Requirements

A team of two trained workers can estimate 300 to 400 plots and harvest 60 to 80 of them in one working day of 8 hours. Thus 3 to 4 fields or treatments can be estimated in a day. This is about 25–30% of the field time required to achieve similarly accurate measurements by harvesting alone. There is a similar reduction in laboratory work.

### Estimator Training and Skill

The achievement of the levels of accuracy reported above requires a team of estimators who have been practising frequently and who have some minimal level of natural skill or "eye" for consistent estimations.

A person with such natural skill can do useful work on his first day in the field, but several days of work in a given vegetation type usually improves the consistency of his estimates. After a year of experience in different vegetation types and seasons, a skilled estimator can give reliably consistent and accurate estimates under almost any conditions.

### Plot Size

The choice of plot size depends to some extent on the patchiness and structure of the vegetation. The smaller the plot, the less work required in clipping. In low herbaceous vegetation, 25X25-cm or 30X30-cm frames have been found appropriate. In tall dense vegetation, considerable "edge effect" is involved in pushing the frame down, with plants bending and breaking in various directions. To reduce the relative importance of this effect, 50X50-cm frames are usually used in such vegetation; this results of course in rather bulky clipped samples.

## Some General Problems

The method is highly successful when the sampled field is fairly homogeneous in species composition and phenological stage, even though it may be highly variable in biomass, cover, and height. It seems that in these conditions the estimator can use his visual impression of cover, height, or a combination of the two as good correlates of yield. The consistency of estimates within a field on a given day decreases markedly when differences in cover and height are confounded by marked local differences in the proportions of species with different forms or habits (prostrate/erect, leafy/stemmy, broad/narrow leaves); by local differences in the phenological stage, if these stages differ markedly in appearance and distribution of dry matter within the plant (vegetative only/flowering/fruiting). A skilled, experienced, and alert estimator can usually make the necessary mental adjustments and still attain quite good results, even in these conditions; otherwise, regressions may be so bad that only additional clippings can increase accuracy. A possible solution to this problem is stratifying both estimates and calibrations by composition or phenological stage.

Herbaceous vegetation which is very tall and dense (cover near 100%, height over 30 cm, biomass above 400 g/m$^2$) is difficult to estimate, as the observer loses his correlation between cover, height, and biomass. In dry, heavily grazed or trampled vegetation, a large proportion of aboveground biomass may be on the ground or just above it, and in a condition which is hovering between "standing biomass" and "litter." This litter or quasi-litter seems more difficult to estimate accurately; it is certainly more difficult to collect. Therefore it may be advisable to estimate it separately from the standing biomass proper and also use separate calibrations for the two components.

### Special Problems in Estimating Grazed Areas and Animal Intake

As mentioned above, the method is also potentially useful for estimating of biomass in heavily grazed stands and for short-term estimations of animal intake by differences between grazed and ungrazed plots (or the same plot before and after grazing). However, some special problems arise with this application of the method.

Firstly, unless the grazing period is very short and the grazing intensity very high, pasture growth during the period may be considerable compared to the amount grazed. Then the results have to be corrected for growth.

Secondly, even within small areas, grazing by animals is usually very uneven, some patches being grazed heavily, others lightly or not at all. This not only increases the variability between quadrats but may also affect the consistency of estimates, since the observer may have a different relation of estimated to actual yield for the grazed patches. Both effects mean that a larger sample of estimation and calibration quadrats has to be used in grazed areas to cover all variations in biomass and degree of utilization and to achieve the desired accuracy.

Another problem is caused by the plant material which is disturbed and bent in various directions or broken and moved around by the grazing animal, but not consumed. When a sampling frame is placed on trampled vegetation, it is somewhat difficult to decide just what is inside it. For instance, if a plant is rooted within the quadrat but has been bent so that most of its foliage is outside it, should it be "straightened" back into the quadrat or not? This problem can be minimized by deciding on a consistent procedure (whatever it is) and using it in all quadrats.

Our experience is that at least in some conditions it is possible to overcome these problems and get rather accurate estimates of intake from differences in estimated biomass (Benjamin et al., 1973).

## Literature Cited


**Benjamin, R. W., A. A. Degen, A. Brieghet, and H. Takhan. 1973.** The determination of feed intake under grazing conditions from the water turnover of sheep. ed. H. F. Mayland. Symp. on Water-Animal Relat., Kimberley, Ida. p. 83-94.

**Brown, D. 1959.** Methods of surveying and measuring vegetation. Commonwealth Agr. Bur. Bull. 42.

**Morley, F. W. H., D. Bennett, and G. T. McKinney. 1969.** The estimation of pasture yields in large grazing experiments. CSIRO, Div. Plant Ind., Field Sta. Rec. 3:43-47.

**National Research Council. 1962.** Range Research: Basic Problems and Techniques. (Chapter 9: Sampling methods). Nat. Acad. Sci. Nat. Res. Counc. Pub. No. 890. Washington, D.C.

**Pechanec, J. F., and G. D. Pickford. 1937.** A weight estimate method for the determination of range and pasture production. J. Amer. Soc. Agron. 29:894-904.

**Tadmor, N. H., E. Eyal, and R. Benjamin. 1974.** Plant and sheep production on semi-arid annual grasslands in Israel. J. Range Manage. 27:427-432.

**Wilm, H. G., D. F. Costello, and G. E. Klipple. 1949.** Estimating forage yield by the double sampling method. Agron. J. 36:194-203.





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