Comparison of the Reference Unit Method and Dimensional Analysis Methods for Two Large Shrubby Species in the Caatinga Woodlands

ROBERT D. KIRMSE AND BRIEN E. NORTON

Abstract

The reference unit technique was compared with the dimensional analysis approach for estimating large shrub foliage biomass in Northeast Brazil. The techniques were tested on coppicing jurema (*Mimosa acutistipula* Benth.) and pau branco (*Auxemma oncocalyx* [Fr. Alem.] Taub.). Both methods provided good estimates of foliage weight. The coefficients of determination for the reference unit approach ranged from .890 to .985. The r^2 values obtained in applying the dimensional analysis method were .937 and .948. Improvements in estimates with the reference unit method were obtained when (1) a branch unit of 19% of total plant foliage was used versus a unit of only 7%, (2) the branch unit resembled the appearance of the branching of the plant being estimated, and (3) estimations of 3 judges were averaged.

Total foliage production on shrubs and trees is one of the most difficult parameters to measure or estimate on native rangelands. The woody material and variable growth form renders most traditional sampling methods, largely derived for agronomic conditions, impractical for shrubs. As a consequence, vegetation sampling technique manuals have made only passing reference to or given insignificant information on biomass estimation of shrub foliage or current growth (Brown 1954, NAS 1962, Newbold 1967, Pieper 1973, t'Mannetje 1978). Efficient estimations of browse availability are required for research on brush control and grazing animal diet studies.

Shrub measurement techniques used in other semiarid areas of the world were examined with the prospect of adapting a suitable method for the caatinga species. The criteria for selection were that the method be nondestructive, time efficient, and relatively precise. Traditional 'clip-and-weigh' methods (e.g., Whittaker 1961) were eliminated from consideration because of the labor and cost required (Gimingham and Miller 1968, Rutherford 1979), and because the associated research design did not permit destructive sampling. The twig count method of Shafer (1963) and methods relating foliage weight to the dimensions of individual branches (Whittaker 1962, Ovington et al. 1963, Provenza and Urness 1981) were considered inappropriate because of the high density of coppicing branches sprouting from the stumps of the test species.

Two sampling techniques were selected for testing on large shrubs of Northeast Brazil. The first of these employs the principle of matching standards against samples (Hutchinson et al. 1972, Andrew et al. 1979), such as estimating the number of multiples of the reference unit (e.g., leafy branch) present in the entire plant. This technique was tested by Andrew et al. (1981) on 2 small Australian shrubs (*Atriplex vesicaria* Heward ex Benth. and *Maireana sedifolia* F. Muell.) and compared favorably with other techniques for estimating shrub biomass. The second technique, dimensional analysis, requires establishing a relationship between easily obtained plant dimensions and foliage weight. A number of studies have shown that canopy volume is highly correlated with foliage weight (Cook 1960, Ludwig et al. 1975, Uresk et al. 1977, Lyon 1968, Kelley and Walker 1976, Bryant and Kothmann 1979, Guy 1981).

Study Area and Methods

The study area was located in Ceara State of Northeast Brazil (3.5° south latitude, 41° west longitude), much of which is dominated by semiarid tropical woodland, called the *caatinga* (Pfister et al. 1983). The test plants were jurema (*Mimosa acutistipula* Benth.) and pau branco (*Auxemma oncocalyx* [Fr. Alem.] Taub.), 2 common and widely distributed species. Morphological characteristics, habitat preferences and management values of these 2 species are described by Kirmse et al. (1983). Jurema is a thorny, small evergreen leguminous tree and pau branco is a deciduous tree; both readily coppice after being cut near ground level and develop a shrubby growth form. Fifteen coppicing jurema and pau branco plants were selected over a range of sizes. They graded in height from .45 to 2.00 m for jurema and .55 to 1.70 m for pau branco and represented the range of sizes available for goat browsing. The jurema plants had been cut 2 years previously; the pau branco plants were first year resprouts. The field data were collected in May, 1980, during the latter part of the rainy season.

Reference Unit Technique

The technique was tested by 3 observers (judges), 1 of which had 2 years previous experience sampling sagebrush (*Artemisia tridentata* Nutt.) biomass with the reference unit method. Prior to the beginning of the trial the experienced judge trained the inexperienced observers. This training involved estimating and verifying foliage biomass of 3 jurema shrubs of different sizes and was completed in 2 hours.

Jurema

The reference unit method was easily adapted to jurema because the growth form of a resprouted plant provided clearly distinguishable branches (Fig. 1). The procedure involved 3 steps:

1) Representative branches, selected from plants not being tested, provided the reference units. The leafy growth on the branch comprised the reference unit *per se*. Andrew et al. (1979) suggested that the preferred size of the reference unit be 10-20% of the foliage weight of the average sample plant. Three branches (units) were used for jurema in this study. The smallest weighed 36 g (dry weight of foliage) and represented 7% of the average foliage weight of the 15 test plants. Two larger branches, each representing about 19% of the average plant, were also used for estimating jurema. Of these larger units, one had compacted branching and dense foliage typical of the test plants and the other had more dispersed foliage. For convenience, these 3 reference units will be referred to as small, large-compacted, and large-dispersed.

2) The number of times the foliage of the reference unit was replicated in the test plant was counted. Only the leaves were considered in the biomass estimations. The estimations were conducted in early morning in order to avoid any bias associated with wilting and curling of the leaves on these reference
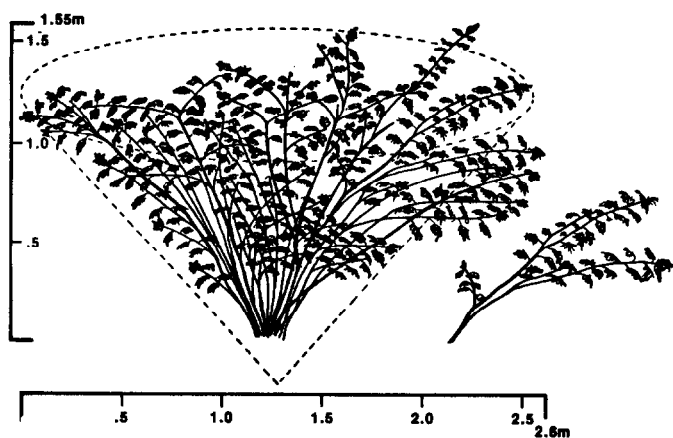
Fig. 1. *The inverted conical growth habit of a coppicing jurema* (Mimosa acutistipula). *The branch to the right represents a typical unit used for the reference unit method.*

units. Each judge independently estimated the 15 jurema plants with the 3 different units. The reference unit counts were not shared among judges during the sampling period.

3. The leaves from the reference unit were stripped and dried at 105°C for 24 hours and weighed. The total dry leaf biomass of each jurema plant was estimated by multiplying the number of units counted for a plant by the weight of the dry foliage in the reference unit. Actual foliage weight on each of the 15 test plants was obtained by stripping all the leaves and determining dry weight.

Pau branco

The reference unit approach described for jurema was not suitable for pau branco because of its compact, dense, and unsegmented growth form (Fig. 2), and therefore an entire plant was used instead
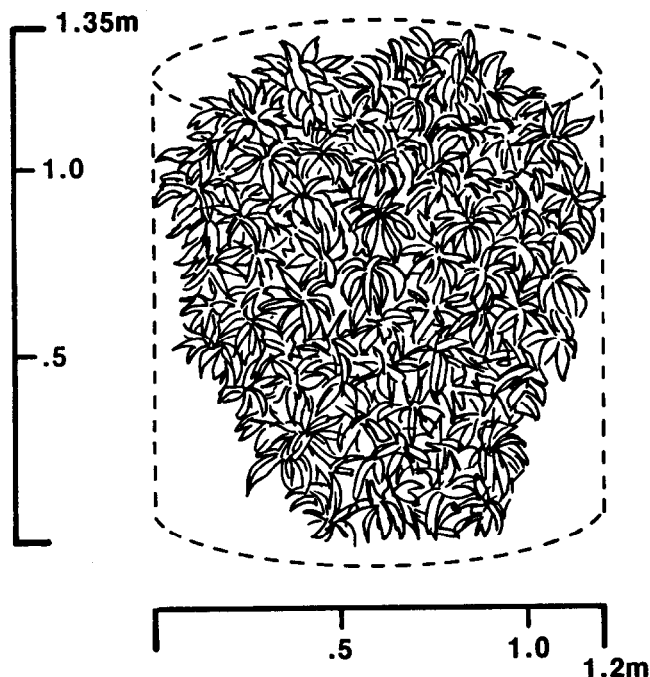

Fig. 2. *The cylindrical growth habit of a coppicing pau branco* (Auxemma oncocalyx).

of a branch. Otherwise the procedure for estimating pau branco foliage biomass was similar to the procedures described for jurema. The reference plant was 1 m high and growing roughly in the center of the group of test plants. The 15 test plants ranged from 4 to 19 m distance from the reference plant, and all were within visible range. Each judge independently estimated the foliage of the 15 test plants as a multiple or a fraction of the reference plant. Estimated weight per pau branco plant was calculated by multiplying the dry weight of leaves on the reference plant by the multiple or fraction estimated for the test plant.

The above procedures provide biomass data on an individual plant basis only. Standing crop per unit area can be determined by estimating the multiples of the reference unit within a sample plot or by calculations that incorporate estimates of plant density. These reference unit estimates were compared with the actual weights in the analysis described below.

Dimensional Analysis

The 3 judges worked together to obtain dimensional measurements of the 30 test plants. Two diameters (the longest and that perpendicular to the longest) and the foliage height were measured for each plant.

Canopy volume was calculated using these dimensional measurements. Jurema plants that resprout after cutting develop an inverted conical growth habit (Fig. 1) similar to *Larrea tridentata* Vail. (Ludwig et al. 1975). The jurema canopy volume was calculated as:

$$\text{canopy volume} = 1/3 \ \pi r^2 \ h$$

where:

r = radius as 1/2 the average of the 2 diameters
h = height

The shape of the pau branco canopy is cylindrical (Fig. 2), so volume was calculated using the formula:

$$\text{canopy volume} = \pi r^2 \ h$$

where:

r = radius as 1/2 the average of the 2 diameters
h = height

Statistical Analysis

The relationship between the actual weight (dependent variable) and the estimated weight (independent variable) for the reference unit estimation, and the actual weight and the canopy volume (independent variable) for the dimensional analysis were established using simple linear regressions. Differences in the intercepts and slopes were tested on the regression equations for the 3 judges and, for jurema, the 3 unit sizes, to determine if pooling of data points were possible. Multiple regression techniques were used to determine the effects of judges, unit size (for jurema), and distance from the unit (in the case of the reference plant method for pau branco). The suitability of the regression models was inferred from graphic display of the data. If curvilinearity was apparent, log transformations and polynomial models were used to obtain the best fit. The preferred equations were selected on the basis of the coefficient of determination (r^2) and a plot of the residuals was used to examine the consistency of error terms (Neter and Wasserman 1974).

Results and Discussion

The test of regression coefficients for the estimation of jurema showed no significant difference in slopes or intercepts among the 3 judges ($p > 0.05$) but there was a significant difference in the estimation using the 3 different reference unit sizes (Table 1). This indicated that it would be possible to combine regression equations rather than to fit one for each judge. The equations presented, therefore, are for combined individual estimations for each unit size (n = 45). Another component of the analysis included an averaging of the estimations of the 3 judges for each unit size (n = 15 for each unit size). Averaging estimations resulted in an increase in their r^2 values of about 4% over the individual estimations. Although all 3 reference branches provided reasonably good estimations (r^2 ranging from .927 to .985) the larger units resulted in

Table 1. Prediction equations (Y = actual weight in grams, X = estimated weight in grams, V = canopy volume in cm³), coefficients of determination (r²), standard error of the estimate (S y•x), coefficients of variation (C.V.), and number of samples (N) for the reference unit and dimensional analysis methods of estimating jurema *(Mimosa acutistipula)* biomass.

	Regression equation[1]	r^2	Sy•x	C.V.	N
Reference Unit[2]					
small unit[2]					
Pooled data over judges[3]	Y=-33.2+1.54(X)	.927	142	27	45
Averaged data over judges[4]	Y=-59 +1.61(X)	.970	95	18	15
large-compact unit[2]					
Pooled data over judges	Y= 48.8+.851(X)	.954	112	22	45
Averaged data over judges	Y= 33.8+.878(X)	.985	68	13	15
large-dispersed unit[2]					
Pooled data over judges	Y= 23.7+.971(X)	.938	130	25	45
Averaged data over judges	Y= 2.3+1.01(X)	.979	80	15	15
Dimensional Analysis					
	Y= 38.5+0.000359(V)	.948	126	24	15

[1]None of the y intercepts are significantly different from zero ($P>0.01$).
[2]Significantly different at $P<0.05$).
[3]Combined individual data for the three judges.
[4]Estimations by the three judges averaged for each plant.

higher r^2 values, and the large-compacted branch gave the highest values. This supports the idea that there is an advantage to selecting a unit with an appearance closely resembling the foliage of the shrubs being estimated.

Similar to jurema, the individual estimations of the judges for pau branco biomass could be combined into one regression equation (Table 2). The regression analysis showed the plant to unit

Table 2. Prediction equations (Y = actual weight in grams, X = estimated weight in grams, V = canopy volume in cm²), coefficients of determinations (r²), standard error of the estimate (Sy•x), coefficients of variation (C.V.), and number of samples (N) for the reference plant and dimensional analysis methods of estimating pau branco *(Auxemma oncocalyx)* biomass.

	Regression equation[1]	r^2	Sy•x	C.V.	N
Reference Unit					
Pooled data over judges[2]					
linear	Y=-82.9+.704(X)	.890	213	27	45
quadratic	Y=-131+1.20(X)-.00168(X²)	.933	168	21	45
Averaged data over judges[3]					
linear	Y= 35.7+.751(X)	.949	151	19	15
quadratic	Y=-169+1.24(X)-.000174(X²)	.977	107	13	15
Dimensional analysis					
	Y= 95.7+.000886(V)	.937	161	20	15

[1]None of the y intercepts are significantly different from zero ($P>0.05$).
[2]Combined individual data of the three judges.
[3]Estimations by the three judges averaged for each plant.

ratio (P:U is the weight of the foliage of the test plant relative to the weight of the foliage of the reference plant) had a significant positive effect on the error of estimation (p = 0.008). Examination of the residuals showed that more precise estimates were obtained where the P:U was close to unity. There was a tendency to underestimate foliage biomass with higher P:U ratios. These results demonstrate the importance of selecting a reference plant similar in size to the average plant being estimated.

The distance of the reference plant from the plants being estimated had no significant effect on the error of estimation ($p>0.05$). For this study all plants were located within a convenient viewing

distance from the reference plant (<19 m). As with the reference unit method, a slight increase in the coefficient of determination was obtained by fitting a regression equation to the averaged values of the 3 judges.

Measuring plant dimensions required about the same amount of time in this study as sampling with a reference unit (about 1.5 min per plant per person). The critical aspect of methodological efficiency, however, is the development of regressions to correct for personal bias in the case of the reference unit technique and to correlate dimensions with biomass in dimensional analysis. For the latter method, a specific regression is required for each species, and possibly for different age classes and for different seasons within a species to account for changes in foliage density. The bias of estimation in the reference unit method is a function of the personal characteristics of the estimator, and a regression developed to correct it could be applied to a group of species with similar foliage appearance. The generality of the bias for an individual estimator has not been tested by the authors but emerges as a hypothesis on the basis of experience with several dozen students learning the reference unit method. Given that this approach requires fewer regressions for field application than dimensional analysis, to achieve the same level of accuracy, the authors propose that the most efficient procedure for biomass estimation would be the reference unit method.

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