Biomass Estimation in a Young Stand of Mesquite (*Prosopis* spp.), Ironwood (*Olneya tesota*), Palo Verde (*Cercidium floridium*, and *Parkinsonia aculeata*), and Leucaena (*Leucaena leucocephala*)

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Abstract

Simple methods for estimating standing biomass in a stand of tree legumes containing the genera *Prosopis, Cercidium, Olneya, Leucaena,* and *Parkinsonia* are reported. Fresh and dry biomass were related to height and stem diameter measurements for 212 leguminous trees ranging in biomass from 0.04 to 17.8 kg using linear regression. The dry matter content of the above-ground biomass of these genera ranged from 40 to 56% and the stem dry matter percentage ranged from 70 to 96%. The best functional form of the model was $\log_{10}$ dry weight (kg) = 2.55 log basal diameter (cm)-1.25, which had an r^2 of 0.956 for 212 samples.

The leguminous trees and shrubs such as mesquite *(Prosopis)*, palo verde *(Parkinsonia aculeata* and *Cercidium floridium)* and ironwood *(Olneya tesota)* occur on at least 30 million hectares in southwestern United States (Parker and Martin 1952) and may constitute a significant biofuels resource for southwestern United States. Easy methods for estimating this biomass from diameter and height measurements would facilitate biomass estimation in experimental plots designed to screen for biomass productivity and in regional surveys attempting to quantitate the biofuels resource potential. Whisenant and Burzlaff (1978) have reported highly significant regression equations relating stem area at ground level, stem area 60 cm above the ground, and canopy area with the fresh standing biomass of native mesquite *(Prosopis)* stands in Texas.

Whittaker and Marks (1978) suggested that parabolic cone volume, which is the product of area and height measurements, is the preferred variable for estimating biomass with linear regressions. Whittaker and Marks (1975) clearly point out the utility of converting height and trunk diameter measurements and biomass determinations into log-log form to allow the regression to find the preferred power, e.g., linear, quadratic, or cubic, for the desired expressions. We have examined linear regressions similar to that reported by Whisenant and Burzlaff (1978) and parabolic cone volume expressions and log-log regressions suggested by Whittaker and Marks (1975) in deliberately established mesquite biomass plantation in southern California. Coefficients for converting fresh weight to dry weight and for partitioning dry matter into leaf and woody tissue have also been examined.

Methods

Part of a 9-month-old tree legume biomass varietal trial in the California Imperial Valley was harvested for these determinations. Two hundred and twenty trees representing four replicates of 55 entries were harvested in December with a chain saw at ground level and weighed within 0.5 hours. North American *Prosopis* native to California and Arizona constituted 117 of the trees, South American *Prosopis alba* and *P. chilensis* constituted 63 of the trees, and other tree legumes *Leucaena leucocephala* (Hawaii Giant K-8), *Parkinsonia aculeata, Olneya tesota, Cercidium floridium,* and *Prosopis tamarugo* constituted the remaining 32 trees. The origin of the South American *Prosopis* accessions was described in an earlier paper (Felker et al. 1981) with the exception of a few accessions collected from southern Californian ornamentals. Seed of *Parkinsonia aculeata, Olneya tesota,* and *Cercidium floridium* were obtained from plants growing in southern California. The stem diameters, heights, and fresh biomass for the 9-month-old plants ranged from 0.16 cm to 7.65 cm, 26 cm to 446 cm, and from 0.04 to 17.8 kg, respectively. *Prosopis tamarugo* had the smallest biomass, height, and stem diameter; *Parkinsonia aculeata* had the greatest height (446 cm); and *Prosopis alba* had the greatest fresh biomass.

After weighing the trees in the field, four replicates of each of the genera involved, i.e., *Prosopis chilensis, Prosopis albc, Cercidium floridium, Parkinsonia aculeata, Prosopis glandulosa* var. *torreyana, Leucaena leucocephala, Olneya tesota,* and the South American-introduced ornamental *Prosopis alba,* were reduced to 10 to 30-cm lengths and placed in burlap bags in a 35° C forced air drying oven. The larger pieces came to constant weight at 35° C after 8 weeks and then were subjected to an additional 24-hr 100° C drying period during which they lost less than 1%. The entire trees in burlap bags were reweighed for moisture content determinations. The leafy material from the oven-dried samples was manually separated from the stems and twigs and reweighed.

Linear regressions were computed for several variables. It was suspected that different genera might differ considerably in their growth habit, moisture content, and percentage of leafy material. Accordingly, the results are grouped into South American species, North American native species, and all other genera. As shown in Table 4 this proved to be a reasonable assumption. At the time of harvest the natives were at least partially defoliated while the South American lines were in full leaf.

Results and Discussion

A comparison of various expressions relating stem diameter ($2r$), basal area (πr^2), and stem volume ($\pi r^2 h/3$) to fresh weight of the harvested trees are given in Table 1. Linear regressions with stem volume ($\pi r^2 h/3$) have been reported to be the preferred variable for developing linear regressions with biomass because it incorporates both height and basal area components (Whittaker and Marks 1975). Linear regressions between stem volume and fresh biomass for the desert tree legumes had lower r^2 values than for basal area versus fresh biomass. In view of the difficulty in

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Table 1. Regression equations relating basal area, stem diameter, and stem volume to fresh biomass.

Species	Equation parameter[1] X	Y	r^2	Y intercept	Slope
South American *Prosopis*	Basal area	Fresh wt.	.900	-.379	.342
North American *Prosopis*	(cm^2)	(kg)	.903	-.665	.366
Other species			.918	-.365	.404
All species			.913	-.537	.363
South American *Prosopis*	Log basal	Log fresh	.986	-.882	1.29
North American *Prosopis*	area	wt.	.936	-.989	1.42
Other species	(cm^2)	(kg)	.946	-.683	1.19
All species			.959	-.863	1.30
South American *Prosopis*	Log stem dia.	Log fresh	.986	-1.02	2.58
North American *Prosopis*	(cm)	wt.	.936	-1.14	2.85
Other species		(kg)	.946	-.807	2.38
All species			.959	-.999	2.60
South American *Prosopis*	Log stem dia.	Fresh wt.	.724	-1.23	11.60
North American *Prosopis*	(cm)	(kg)	.829	-3.99	13.51
Other species			.849	-4.94	18.73
All species			.772	-3.63	14.22
South American *Prosopis*	Stem dia.	Log fresh	.870	-.965	.341
North American *Prosopis*	(cm)	wt.	.886	-.934	.371
Other species		(kg)	.922	-.649	.293
All species			.877	-.804	.324
South American *Prosopis*	Stem vol.	Fresh wt.	.902	-.974	.00302
North American *Prosopis*	(cm^3)	(kg)	.860	-.097	.00390
Other species			.899	-1.19	.00290
All species			.902	-.770	.00312
South American *Prosopis*	Log stem vol.	Log fresh	.986	-2.18	.920
North American *Prosopis*	(cm^3)	wt.	.933	-2.72	1.11
Other species		(kg)	.931	-1.87	.827
All species			.953	-2.27	.948

[1]Equation parameters are for equation $y = mx + b$ where x and y are functions listed in the respective columns and r is the correlation coefficient. There are 63, 117, 32, and 212 trees harvested respectively for South America, North America, other and all species.

obtaining height and basal diameter measurements, further computations with stem volume variables were not examined.

As previously reported by Whisenant and Burzlaff (1978), a very good correlation was obtained for all legumes between basal area and fresh weight. The expression $y = 0.323x$ where y is the fresh weight in kg and x is the basal area in cm^2 was also obtained by these workers (Burzlaff, pers. comm.). It can be seen that this expression agrees quite well with the regression we have observed $y = 0.363x - 0.537$ for all legume species. The best linear regression between basal area and fresh weight yields a negative y intercept that predicts all stem diameters less than 1.3 cm have a negative biomass. The poor fit for the smaller trees suggested the expression between basal area and fresh weight could better be represented by an equation of higher power. A linear regression of log-log transformed biomass and stem area data had a higher r^2 and a slope of 1.30 indicating that an expression intermediate between linear and quadratic provided a better fit of the data. It is redundant to the use log of area, rather than log of diameter, since the squared term for the radius will appear as a constant in the regression equation. This is confirmed in Table 1 where log-log transformations of diameter versus biomass and area versus biomass have identical correlation coefficients.

The coefficients used to convert fresh biomass data to dry matter data are listed in Table 2. The dry matter contents were determined for four entire trees of each genus in the trial and for the other accessions included in a related biomass trial (e.g., 0163 and 0039). The percentage dry matter varied from a low of 40% for the *Leucaena leucocephala* to a high of 56% for the *Prosopis glandulosa* var. *torreyana*. At the harvest time, the *P. glandulosa* var. *torreyana* was considerably defoliated because of its winter deciduous habit and this is reflected in both a high dry matter and percentage stem matter content. The appearance of the *P. glandulosa* var. *torreyana* was deceptive as many senescent leaves still

Table 2. Moisture content and leaf and stem dry matter partitioning for several tree legume genera.

Accession	Dry matter[1] (%)	Stem dry matter: Stem + leaf dry matter (%)
Prosopis alba (0039)	49 ± 2 bc	71 ± 2 c
Prosopis alba (0163)	50 ± 2 b	80 ± 3 b
Prosopis chilensis (0009)	48 ± 1 bc	76 ± 4 bc
Prosopis glandulosa var. *torreyana* (0001)	56 ± 3 a	95 ± 1 a
Cercidium floridium (0324)	51 ± 1 b	96 ± 2 a
Leucaena leucocephala (0147)	40 ± 2 d	70 ± 1 c
Olneya tesota (0343)	50 ± 6 b	78 ± 3 bc
Parkinsonia aculeata (0322)	44 ± 3 cd	81 ± 5 b

[1]Moisture content and dry matter partitioning was determined for four entire trees of each of the above species. Means followed by same letter are not significantly different at 5% level. The dry matter contents are expressed as percent of fresh weight.

Table 3. Regression equations for *Prosopis* and other tree legumes relating $\log_{10}$ stem diameter to $\log_{10}$ dry matter.

Kind of tree	Equation parameter[1] m	b	n	r^2
South American *Prosopis*	2.558	-1.310	63	.986
North American *Prosopis*	2.847	-1.392	117	.936
Other species	2.286	-1.072	32	.935
All species	2.546	-1.25	212	.956

[1]Values are computed for regression equation $y = mx + b$ where $y = \log_{10}$ of dry biomass, $x = \log_{10}$ of stem diameter, r = correlation coefficient, and n = number of trees.

Table 4. Regression equations for individually measured, weighed, and oven-dried trees of several species relating $\log_{10}$ stem diameter to $\log_{10}$ dry biomass.

Species	Equation parameter[1] m^2	b	n	r^2
Prosopis alba (0039)	2.11	−1.02	4	0.83
Prosopis alba (0163)	2.31	−1.13	4	0.85
Prosopis chilensis (0009)	1.43	− .48	4	0.99
Prosopis glandulosa var. var. *torreyana* (0001)	2.74	−1.30	3	0.99
Cercidium floridium (0324)	1.97	−0.81	4	0.73
Leucaena leucocephala (0147)	2.11	−1.09	4	0.99
Olneya tesota (0343)	3.22	−1.23	4	0.36
Parkinsonia aculeata (0322)	2.14	−0.96	4	0.83

[1]Values are computed for regression equation $x = mx + b$ where $y = \log_{10}$ of dry biomass, $x = \log_{10}$ of stem diameter, r = correlation coefficient and n = number of trees.

appeared on the tree when it had a 95% stem plus wood percentage. The low leaf content of the *Cercidium* is not due to defoliation as it is evergreen, but is probably due to the extensive chlorophyll content of its trunk and stems which act as a surrogate for photosynthetic leaf surfaces.

To convert the fresh weights to dry matter, a factor of 0.56 was used for all North American native trees (117), and a factor of 0.49 was used for all the South American non-deciduous trees (63), except where the actual dry matter content was determined, e.g., *P. alba* (0163) and *P. chilensis* (0009). After conversion of all fresh weights to dry weights the regressions were recalculated in dry weight form using the best expression, i.e., log dry weight versus log diameter (Table 3). To examine possible differences among genera and life form, the expressions were grouped into similar taxa. Little differences between these major divisions are apparent and we suggest the overall expression be used.

Though regressions on only four points are of questionable value, regressions for the individually harvested, dried and reweighed accessions (0001, 0009, 0039, and 0163) were computed and compared with the overall regression in Table 3 because they are part of a preliminary companion study on water use efficiency (Felker et al. 1980). These values, reported in Table 4, exhibit considerable variation with the *P. chilensis* (0009) yielding the lowest slope (m) value. Surprisingly, the regression equation for the 4 *P. chilensis* trees does not yield markedly different results for the overall equation. For example, if the overall regression from Table 3 were used for the average 5.02 cm diameter for the 75 nine-month-old *P. chilensis* (0009) trees reported elsewhere (Felker et al. 1980), the average tree would have a dry biomass of 3.42 kg. If the equation for *P. chilensis* in Table 4 were used the average dry biomass would be 3.35 kg. The corresponding dry matter yields per hectare for the 1.52 m spacing are 14,725 and 14,423 kg ha^{-1}, respectively.

In a previous study (Felker et al. 1980) the fresh biomass, as calculated from the Whisenant and Burzlaff (1978) regression, was greater for *Leucaena leucocephala* (Hawaii Giant K-8) than for *Prosopis*. However, when the moisture contents reported here are taken into account, *Prosopis alba* and *P. chilensis* had greater dry matter production than the *Leucaena leucocephala*.

Conclusions

The linear regression relating basal area to fresh weight reported by Whisenant and Burzlaff (1978) closely agrees with our regression for the same variables. Unfortunately, this regression predicted negative biomass for trees of stem diameter less than 1.3 cm. Omission of the b term would have avoided negative biomass predictions for small stem diameters but the resulting equation would not have fit the remaining data as well. A log-log regression of basal stem diameter with biomass correctly predicted the biomass of trees with small stem diameters and yielded a higher r^2.

The regression equations reported here should only be used on immature trees with stem diameters in the range of 0.16 to 7.65 cm since that is the range on which the calibration regression was based. Trees with diameters larger than 7.6 cm may use equations developed by Whisenant and Burzlaff (1978). The separate regressions calculated for the "other" legumes *Olneya, Cercidium, Parkinsonia* and *Leucaena* were only based on measurements of four trees, but these separate regressions do not differ greatly from the combined regression for all trees. As a first approximation it is reasonable to use the regressions for "all legumes" for the genera other than *Prosopis* until more regressions are developed.

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