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Regression Equations to Predict Fresh Weight and Three grades of Lumber from Large Mesquite (*Prosopis glandulosa* var. *glandulosa*) in Texas.

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ABSTRACT

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In the southwestern United States, mesquite (*Prosopis*) is used as barbecue fuel and to make flooring, furniture and handicrafts. As a result of increasing demand there is a need for volume tables and regression equations to predict total weight and lumber volume per tree. Previous studies established regressions for small *Prosopis* in Texas (mean of 57 kg), and medium-sized trees (300–400 kg) in India and Kenya. In this study, ten trees ranging in height, weight, and canopy diameter from 4.2 m to 9.4 m, 136 kg to 2540 kg, and 4.4 m to 13.2 m, respectively, were harvested, weighed and stem volumes measured.

The highest correlations were obtained for: (a) the sum of stem basal areas to tree weight ($r=0.93$, $P=0.0001$); (b) the common logarithm of the sum of basal area to the common logarithm of tree volume ($r=0.95$, $P=0.0001$); (c) the common logarithm of north-south canopy diameter to the common logarithm of tree volume ($r=0.95$; $P=0.0001$); and (d) north-south canopy diameter to the common logarithm of tree weight ($r=0.90$, $P=0.0004$). Regressions relating total volume to basal area and canopy diameter were combined with previously described equations relating lumber yield from logs. Equations were then developed to predict the volume of lumber with a clear cutting surface to the tree basal diameter and canopy diameter.

INTRODUCTION

Management systems to improve the productivity of the existing semiarid forests are necessary because of the immense size of the semiarid areas and the costs involved in reforestation. As part of these management systems, techniques are required to determine the weight or volume of the trees and shrubs. In many semiarid regions, *Prosopis* is one of the leguminous trees and/or shrubs that is important for fuelwood and browse, soil enrichment through nitrogen

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fixation and production of pods for use as fodder in the dry season (Burley and von Carlowitz, 1984).

Since 1982, there has been considerable growth in businesses producing mesquite (*Prosopis glandulosa* var. *glandulosa* (L. Benson) M.C. Johnston) for the barbecue industry in the United States. Various products from mesquite have been sold through large retail grocery chains including chips (ca. 2 mm × 15 mm × 15 mm), chunks (ca. 30 mm × 70 mm × 70 mm) and sticks (70 mm × 70 mm × 300 mm). Mesquite sawdust has been incorporated into charcoal briquets by the two largest manufacturers in the United States (Kingsford and Royal Oak) for flavor enhancement. In 1986, Red Arrow Products and Griffiths Laboratories manufactured 'liquid smoke' from mesquite sawdust for incorporation into meaty products and barbecue sauces. In 1987 wholesale prices of mesquite chips and chunks packaged in bags were about \$300/t and mesquite sawdust for smoke applications was about \$120/t.

Due to mesquite's excellent stability, low volumetric shrinkage of 4–5%, hardness (Weldon, 1986) and attractive red/orange color it is being used increasingly to make flooring, furniture and handicrafts. Mesquite logs typically are twisted, have considerable windshake and are less than 2.25 m in length. Consequently, the wholesale price of lumber is high, i.e. no less than \$425/m^3 and typically 2–3 times that price.

Landowners in Texas, where mesquite occurs, have typically been ranchers with a desire to replace woody vegetation with grass for beef production. In view of the growing demand and value of mesquite, it would appear prudent to know its volumes and weights prior to making judgements on land clearing, land sales or mesquite wood sales. Estimation of mesquite stem volumes and weights is difficult because mesquite trees vary in form, and most are multiple-stemmed with low horizontal branches.

Regression equations for plantation-grown *Prosopis* have been developed to predict biomass in India (Bhimaya et al., 1967; Kalla, 1977), Kenya (Maghembe et al., 1983) and California (Felker et al., 1982, 1983). For native *Prosopis* stands, regressions have been developed to estimate the standing biomass in India (Kaul and Jain, 1967), Texas (Anonymous, 1972; Whisenant and Burzlaff, 1978), California (Sharifi et al., 1982) and Argentina (Braun et al., 1979). However, no regression equations exist for large mature trees such as occur in south Texas. Therefore weights, heights, diameters and volumes of ten mature trees were measured in a virgin stand. To allow prediction from either ground measurements or aerial photos, statistical relationships were examined between tree volumes versus basal diameters and canopy diameters. Equations on the lumber yield from mesquite logs developed by Rogers (1984) made it possible to link whole-tree measurements to useable-lumber volume.

MATERIALS AND METHODS

This study was conducted on the Thomas Ranch, in Kenedy County, Texas.

Ten mature mesquite trees, *P. glandulosa* var. *glandulosa* were selected that represented the range of tree sizes within a native stand. As is true in most semiarid areas, these large trees were generally separated from each other by at least one canopy diameter. Measurements were taken of height, number of stems per tree, green weight, canopy diameter in north-south direction, canopy diameter in east-west direction, and stem diameter at ground level. The stem segments were measured from fork to fork, recording length and diameter at small and large ends down to a 7.5-cm diameter. Volume per segment was calculated by multiplying the mean area of the small and large ends by the length of the segment. The volume of the felled trees were measured from a summation of the volumes of all the stem segments. Green weights of the entire trees were obtained by lifting the scales and suspended trees with a truck-mounted, hydraulic knuckle boom loader. Trees with multiple stems were weighed together; thus it was not possible to regress individual stems against stem weight or volume. Three precalibrated scales of 90 kg, 1810 kg and 9070 kg capacity were used.

Disks about 4 cm thick and ranging from 9 to 27 cm in diameter were taken from the main trunks for moisture-content and specific-gravity determination. The disks were transported in plastic bags to the laboratory, where they were measured and weighed. Moisture contents were determined after drying for 9 days at 66°C.

The diameters and lengths of the stem segments were used with Rogers' (1984) regressions to predict lumber volume per tree. Due to mesquite's extremely crooked form, and the presence of windshake and boring insects, Rogers (1984) measured the lumber volume in three categories: Grade 2 – clear surface with minimum dimensions of 5.1 cm (2 inches) × 15.2 cm (6 inches); Grade 1 – clear surfaces with minimum dimensions of 61 cm (24 inches) × 5.1 (2 inches); and total sawn lumber (TSL). Roger's (1984) equations, converted into metric units (diameters and lengths in cm and volumes in l) are as follows:

TSL (1) $y = 1.8648(\text{small diameter}) + 0.1703\ (\text{length}) - 36.0280 \quad R^2 = 0.71$

Gr2 (1) $y = 1.1564(\text{small diameter}) + 0.0845(\text{length}) - 19.9761 \quad R^2 = 0.53$

Grl (1) $y = 0.4818(\text{small diameter}) + 0.0233(\text{length}) - 9.2132 \quad R^2 = 0.45$

RESULTS

The tree dimensions are presented in Table 1. Heights, weights, and north-south canopy diameters ranged from 4.2 to 9.4 m, 136 to 2540 kg, and 4.4 to 13.2 m, respectively. The number of main stems per tree ranged from 1 to 4 and the total volume, obtained by summing each of the stem segments, ranged from 0.046 m^3 (19.7 board feet (bf)) to 1.489 m^3 (631 bf).

TABLE 1

Summary of tree heights, weights, and volumes

Tree No.	Basal diameter (cm/ft)	Height (m/ft)	Stems (no.)	Weight (kg/lb)	NS-canopy (m/ft)	Total tree volume (m^3/bf)	Total sawn-lumber volume (m^3/bf)	Grade 2 lumber volume (m^3/bf)	Grade 1 lumber volume (m^3/bf)
1	20	4.2	1	340	4.4	0.046	0.020	0.013	0.001
	0.66	14		750	14	20	8.4	5.6	0.6
2	30	6.8	4	655	6.8	0.292	0.181	0.102	0.018
	0.98	22		1450	22	124	77.0	43.0	7.7
3	40	7.0	1	1220	8.8	0.472	0.248	0.149	0.036
	1.30	23		2700	29	200	105.0	63.0	15.0
4	55	9.4	1	1630	10.8	0.974	0.409	0.252	0.069
	1.80	31		3600	35	413	173.0	107.0	29.0
5	32	8.2	4	1950	13.2	0.712	0.340	0.208	0.038
	1.10	27		4300	43	302	144.0	88.0	16.0
6	20	5.1	1	136	5.1	0.080	0.030	0.019	0.002
	0.66	17		300	17	34	13.0	8.0	1.0
7	46	7.7	4	2540	12.1	1.49	0.629	0.405	0.108
	1.50	25		5590	40	631	267.0	172.0	46.0
8	32	6.4	3	946	10.5	0.708	0.351	0.224	0.049
	1.10	21		2090	34	300	149.0	95.0	20.7
9	25	5.1	2	218	5.6	0.174	0.05	0.036	0.006
	0.82	17		480	18	74	21.0	15.0	3.0
10	33	7.2	1	465	8.8	0.306	0.130	0.087	0.021
	1.10	24		1030	29	130	55.0	37.0	8.7

Total volume was obtained by summing all the stem segments of the intact tree. Total sawn-lumber volume, Grade 2 lumber and Grade 1 lumber were obtained from regressions of Rogers (1984). Grade 2 and Grade 1 lumber had minimum clear surface (free from defects) of 5.1 cm × 15.2 cm and 5.1 cm × 61 cm, respectively. Where multiple stems occurred, the basal diameter listed is for the largest stem.

The total volume of the tree, obtained by summing the stem segments, was generally 2 times greater than the predicted total sawn lumber obtained from Roger's (1984) regressions. This is probably due to the loss in volume from the edge slabs in squaring up the cants.

Grade 2 lumber was typically only half of the total sawn lumber. Grade 1 lumber was often only 15–30% of the Grade 2 lumber. Total Grade 1 lumber ranged from 0.001 to 0.108 m^3 per tree, while total Grade 2 lumber ranged from

TABLE 2

Correlation of mesquite weight, diameter, canopy and height measurements on volume and weight

Parameter	Tree volume		Tree weight	
	r	*P*	*r*	*P*
Weight	0.94	0.0001	—	—
Sum of basal area	0.93	0.0001	0.93	0.0001
North-South canopy diameter	0.85	0.0021	0.89	0.0007
Height	0.74	0.0155	0.76	0.0110
Log of sum of basal area	0.84	0.0023	0.84	0.0026
Sum of basal diameter	0.74	0.0146	0.77	0.0098
East-West canopy diameter	0.65	0.0413	0.79	0.0070
Log of sum of basal diameter	0.73	0.0161	0.74	0.0144
	Log tree volume		Log tree weight	
	r	*P*	*r*	*P*
Log of sum of basal area	0.95	0.0001	0.89	0.0005
Log of N-S canopy diameter	0.95	0.0001	0.89	0.0005
North-South canopy diameter	0.92	0.0002	0.90	0.0004
Sum basal area	0.90	0.0003	0.90	0.0005
Log of tree height	0.89	0.0005	0.81	0.0043
Tree height	0.87	0.0012	0.81	0.0042
Log of sum of basal diameter	0.83	0.0033	0.77	0.0094
Sum of basal diameter	0.75	0.0131	0.74	0.0146

r is the correlation coefficient and *P* is the probability level for significant differences. Units are not provided since the correlations and probabilities are independent of the units used.

0.013 to 0.405 m^3 per tree. At the current wholesale price of \$850/m^3 for select and \$425 for non-select lumber, the value of the Grade 1 lumber from these ten trees would range from \$0.85 to \$91.80 and the value of the Grade 2 lumber would range from \$5.50 to \$172.

For green weight, the most highly correlated linear relationships occurred with volume ($r = 0.94$) and the sum of stem basal area ($r = 0.93$). There was also a positive correlation between N-S canopy diameter and the common logarithm of tree green weight ($r = 0.90$) (Table 2). The best correlations for volume (transformed) existed between the common logarithm of sum of stem basal area ($r = 0.95$) and common logarithm of N–S canopy diameter ($r = 0.95$).

Thus the best measurements to estimate weight and volume are basal area if measured on the ground and N-S canopy diameter if measured by aerial photography (Table 3).

TABLE 3

Regression equations for estimating weights and lumber volumes of mesquite from basal area and North-South canopy diameter

y	x	m	b	Standard error	r^2
Log Total tree volume	Log N-S Canopy diameter				
(bf)	(ft)	2.747	−1.754	0.315	0.905
(m^3)	(m)	2.747	−2.964	0.315	0.905
Log Total sawn lumber	Log N-S Canopy diameter				
(bf)	(ft)	2.930	−2.371	0.350	0.900
(m^3)	(m)	2.930	−3.486	0.350	0.900
Log Grade 2 lumber	Log N-S Canopy diameter				
(bf)	(ft)	2.885	−2.505	0.326	0.907
(m^3)	(m)	2.885	−3.643	0.326	0.907
Log Grade 1 lumber	Log N-S Canopy diameter				
(bf)	(ft)	3.551	−4.167	0.450	0.887
(m^3)	(m)	3.551	−4.963	0.450	0.887
Log Total tree weight	N-S Canopy diameter				
(lb)	(ft)	0.037	2.119	0.007	0.804
(kg)	(m)	0.124	1.777	0.022	0.804
Log Total tree volume	Log Basal area				
(bf)	(ft^2)	1.273	2.031	0.141	0.911
(m^3)	(m^2)	1.273	0.716	0.141	0.911
Log Total sawn lumber	Log Basal area				
(bf)	(ft^2)	1.374	1.664	0.139	0.925
(m^3)	(m^2)	1.374	0.453	0.139	0.925
Log Grade 2 lumber	Log Basal area				
(bf)	(ft^2)	1.345	1.468	0.136	0.924
(m^3)	(m^2)	1.345	0.228	0.136	0.924
Log Grade 1 lumber	Log Basal area				
(bf)	(ft^2)	1.651	0.723	0.197	0.898
(m^3)	(m^2)	1.651	−0.202	0.197	0.898
Total tree weight	Basal area				
(lb)	(ft^2)	1560	−304	220	0.862
(kg)	(m^2)	7580	−138	1074	0.862
Log Total tree weight	Log Basal area				
(lb)	(ft^2)	1.052	3.084	0.187	0.800
(kg)	(m^2)	1.052	3.827	0.187	0.800

Equations are of the form $y = mx + b$. Logarithms are to the base 10.

The mean density of 24 disks taken from eight of the trees was 0.82 ± 0.12 kg/l, with a range from 0.66 to 1.10. Other workers in Texas have observed great variation in physical properties of mesquite wood (e.g. Weldon, 1986).

DISCUSSION

Basal diameters were more closely correlated with biomass than heights as expected from previous studies with *Prosopis* (Bhimaya et al. 1967; Kalla, 1977;

Whisenant and Burzlaff, 1978; Felker et al., 1982). For example, the sum of the stem basal area had an *r* value of 0.934 whereas height only had an *r* value of 0.735.

Curiously enough, the correlation coefficients for the N–S canopy diameter were considerably different from the E–W canopy diameter. Since these trees did not have overlapping canopies from neighboring trees, the N–S canopy direction would give the greatest display to the sun. The differences in correlations between N–S and E–W diameter are likely to be more closely related to differences in light interception per tree. Nilsen et al. (1981) has observed that the orientation of *Prosopis* leaves changes throughout the day to track the sun for maximum light interception. Perhaps orientation of the canopy along the N–S direction is a further adaptation towards matching photosynthetic needs to the biomass of the plant.

Previously described regressions for plantation-grown *Prosopis* were based upon trees that varied greatly in size. The smallest plantation-grown trees were less than 20 kg dry-weight (Felker et al., 1983). These workers produced a regression equation that combined data over the first 3 years, for eleven *Prosopis* species grown in plantations (1352 pairs of observations). Kalla (1977) produced regressions for 12–15-year-old *Prosopis* in Jodhpur, India that had a mean dry-weight of 8.4 kg, with a range of 0.7–34.5 kg. Regressions for considerably larger plantation-grown trees (137 kg at 10 years of age) were also developed in India (Bhimaya et al., 1967).

Regressions for the largest plantation-grown *Prosopis* are those from Mombasa, Kenya (Maghembe et al., 1983). Eleven trees representing the full range of the size classes were felled, separated into various components and weighed. At 6 years of age in an area with a high water table and 1220 mm rainfall, the total dry standing biomass was 216 ton/ha. The largest tree in this study had a basal diameter of 31.7 cm, a height of 19.7 m and a dry weight of 388 kg. All of their regressions had correlation coefficients greater than 0.91 and were significant at $P = 0.01$.

Regressions for native *Prosopis* have been based upon trees that ranged from about 50 kg to nearly 500 kg. Whisenant and Burzlaff (1978) harvested 1223 mesquite trees in the Rolling Plains of Texas. These authors found that stem area at ground level, stem area at 60 cm above ground level, canopy area, and height, had correlation coefficients of 0.917, 0.929, 0.880 and 0.679, respectively, with tree green weight. These authors divided mesquite into three site classes, the largest of which had a mean tree fresh-weight of 57 kg.

In a survey of mesquite in several Texas countries (Anonymous, 1972), regressions were established between stem weight versus stem diameter and length. The largest stem weights in this table were 343 kg.

A dimensional-analyses study of mesquites in the California desert was conducted by Sharifi et al. (1982). These authors developed regressions for the weights of the branches, twigs, leaves, inflorescences, and pods. The largest

trees they harvested had a dry biomass of 189 kg. Braun et al. (1979) developed regressions for *Prosopis flexuosa* in an ecosystem dominated by this species in Argentina. They reported that the allometric equation:
dry weight $= 0.232995 \times \text{volume}^{1.035294}$, had an R^2 of 0.95 for *Prosopis flexuosa*; however, the size of trees measured was not given.

Prior to this study, the largest native *Prosopis* measured were *P. cineraria* in the Indian arid zone; allometric equations were based on 102 harvested trees that ranged in weight from 5 to 479 kg (Kaul and Jain, 1967).

Previous studies on trees ranging from 3 kg to 80 kg fresh weight found that the dry-weight of wood, stems and leaves is about 50% of the fresh-weight (Felker et al., 1983). Thus, the dry-weights of the trees in this study ranged from about 170 kg to 1200 kg. The trees measured here are the largest trees on which regression equations have been obtained to date.

It is interesting to compare the dimensions and weight of the largest tree in this present study to the largest tree in the plantation study of Maghembe et al. (1983), in which the largest tree had a basal diameter of 31.7 cm, a height of 19.7 m and a dry-weight of 388 kg. In contrast, the largest single-stemmed tree in this present study had a basal diameter of 55 cm, a height of 9.4 m, a fresh-weight of 1630 kg, and an estimated dry-weight of 815 kg. Thus, the native Texas *Prosopis* was 20 cm greater in basal diameter, 10 m shorter in height, and yet had over twice the biomass. The Maghembe et al. (1983) trees were only 6 years old and were grown under close spacings in a plantation. The Texas native *Prosopis* was probably greater than 50 years old and probably started out as an isolated tree with little competition. Possibly the close spacing of the plantation-grown *Prosopis* forced them into a more erect form.

The study illustrates that a large tree can have many times the timber-volume/canopy-area of a smaller tree. Assuming these trees had circular canopies, tree No. 4 had 10.6 l of volume/m^2 of canopy area while tree No. 6 had 4 l of volume/m^2 of canopy area.

Mesquite is rapidly increasing in importance as an income resource in the southwestern United States. However, the concept of stumpage fees is unknown by managers of 50 000-ha ranches. Mesquite is unlikely to be treated as a resource until volume (or weight) tables are available for use in negotiations of the value of the standing timber. Currently, mesquite is bulldozed, stacked and burned at a cost of about $400/ha. Net current returns on rangeland are about $6/ha per year and, thus, small volumes of lumber or stumpage fees could greatly increase returns to landowners.

Lumber and flooring sales are very small, with less than 6 manufacturers of flooring employing no more than 30 people in the State of Texas (Felker, personal observation). While craftsmen pay high prices for lumber ($450/$m^3$) these prices may drop as the volume increases. Nevertheless, the attractiveness of mesquite and its excellent wood qualities (Rogers, 1984; Weldon, 1986) should support considerable lumber sales with proper marketing. A concerted effort to increase the demand for solid wood products of mesquite could substantially increase economic returns to the landowners of southwestern United States.

Undeniably, much of the mesquite lumber of today is of short lengths with considerable defects such as cracks and worm holes. However, with thinning and pruning it should be possible to dramatically increase the yield of Grade 1 lumber from these logs. Conover and Ralston (1959) demonstrated that thinning northern hardwood saplings increased lumber volume decisively. Thinning young stands of mesquite will probably lead to trees with a consistently larger lumber volume than could be obtained without management. These thinning and pruning operations should be compatible with management systems that take advantage of mesquite's nitrogen-fixing abilities and its ability to provide large amounts of forage from its beans in mid-summer. Integrated management of mesquite for lumber, wildlife, cattle and soil enrichment appears to be a financial necessity.

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