

## SIZE-PHYTOMASS RELATIONS IN *PROSOPIS JULIFLORA* (SWARZ.) DC.

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### ABSTRACT

Allometric equations were developed to estimate aboveground phytomass of *Prosopis juliflora* (Swartz.) DC using regression models based on height, crown diameter, basal area of stem, stem diameter etc. These equations predicted phytomass of individual plants or the components of the plant. Dry firewood mass of *P. juliflora* (loge transformed) was best estimated with a quadratic model based on height, quadratic and power model based on stem diameter and through power models based on basal area and the crown cover of the plant. The multiplicative models were also equally good. Multiple regression model based on linear combination of untransformed independent variables viz. height, Canopy cover, stem diameter and basal area of the plants estimated log-transformed total fresh phytomass of the plant better than the log-transformed dry firewood component.

Key Words: Size-phytomass allometry, Firewood, Aboveground biomass, Power curves, *Prosopis juliflora*.

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### INTRODUCTION

Regression analysis which relates biomass to various structural dimensions of the plants provides a viable alternative to the expensive and destructive techniques of estimating biomass (Martin *et al.* (1982). Many regression equations have been worked out with plants by many authors (Whittaker and Woodwell (1968); Monk *et al.* (1970); Schreuder and Swank (1971); Swank and Schreuder (1974); Young (1976); Roussopoulos and Loomis (1979); Crow (1983); Pastor *et al.* (1984); Fownes and Harrington (1991); Elliot and Clinton (1993); Matte *et al.* (2003); Niklas *et al.* (2003); Khan *et al.* (2005); Fentu (2005); Kirui *et al.* (2006); Wang, 2006; Pokorný and Tomášková (2007); Litton and Kaufman (2008); Ghazehei *et al.* (2009); Tanaka *et al.* (2009); Khan *et al.* (2010), etc. Smith and Brand (1983) have compiled from literature the equations to estimate biomass in ninety eight species of herbs, shrubs and trees. Such equations are useful in predicting carrying capacities of various vegetation types based on browse estimate (Grigel and Moddy, 1980; Ohmann *et al.*, 1981), in determining maximum level of production of herbs, shrubs and trees (Martin, 1979), and in estimating the fuel wood availability (Roussopoulos and Loomis, 1979; Hierro, *et al.*, 2000; Zianis and Mencuccini, 2003; Ghazehei *et al.*, 2009; Tanaka *et al.*, 2009). Quite a few biomass studies have been conducted in genus *Prosopis* e.g., *P. pallida* (Padrón and Navarro, 2004), *P. glandulosa* var. *glandulosa* (El Fadl *et al.* (1989; Delf *et al.*, 1994), *Prosopis* spp. (Felker *et al.*, 1982), *P. caldenia* and *P. flexuosa* var. *depressa* (Hierro *et al.*, 2000), *P. juliflora* (Maghambe *et al.*, 1983; Sood and Bhatia, 1993). Maghambe *et al.* (1983) investigated biomass and nutrient accumulation in a six-year-old plantation of *Prosopis juliflora* at Mombasa base Kenya using simple linear regression and Sood and Bhatia (1993) investigated biomass production and partitioning in this species in a degraded site. Khan *et al.* (1986) reported *P. juliflora* to weigh aboveground biomass around  $48.06 \pm 6.9$  kg per plant after five years of transplantation in the coastal dunes of Pasni (Balochistan) when irrigated with saline water up to two years of transplantation. Here, we have undertaken to develop relevant equations with respect to size-phytomass relationship in *Prosopis juliflora* (Swartz.) DC. in its natural population in a halo-xeric environment of Karachi, Pakistan. The aim was to identify and employ the most suitable allometric model to estimate the plant mass on the basis of size and to establish distribution of mass in dry firewood and non-wood components.

### MATERIALS AND METHODS

The investigation involved a tree legume, *Prosopis juliflora* (Swartz.) DC. The aim of this study was to predict its aboveground biomass and of its components from easily measured morphometric variables such as plant height, stem diameter or crown cover, and basal area, etc. For parameterization, ten plants of *P. juliflora* of wide range of size (Table 1) were randomly harvested at the ground level from moderately saline sandy plain in University of Karachi and prior to their harvest their morphometric characters were measured. *P. juliflora* is generally multistemic. The stem diameter of each stem of the plant was measured at 10 cm from the ground and number of basal stems was recorded. The basal area was determined as the sum of the basal areas of stems of the sample plant as:

$$BA = \sum_{i=1}^n [(di^2 \cdot \pi) / 4],$$

Where,  $d_i$  is the diameter of  $i^{\text{th}}$  stem. The material of each plant was separated into two components a) Leaves + pods + twigs of  $\leq 1$  cm, and b) Stem + twigs  $> 1$  cm, representing the available fresh firewood. Both of the components were weighed with spring and pan balances in the field and recorded as fresh weights on the same day of the cutting of the plants. To determine dry firewood, the samples (200-500g) from component b were dried at  $70^\circ\text{C}$  for 72 hours and then weighed for dry firewood determination.

Regression models were tested to predict plant's aboveground biomass or the wood component. The selection of the best regression model was based on comparison of the coefficients of determination ( $R^2$  & adjusted  $R^2$ ), F, standard errors of estimates, and values of the t – test for the intercept and the coefficients of regression.

## RESULTS AND DISCUSSION

The plants of wide range of sizes were included in the sampling for parameterization (Table 1). The plants of 1.38 to 4.85m in height, 1.20 to 13.05 cm stem diameter and 1.56 to 114.91  $\text{m}^2$  crown cover were included in the sampling. The component 'a' of the plant composed of leaves and smaller twigs averaged to around  $19.9 \pm 12.40$  % of the total fresh phytomass and the component 'b' composed of woody material was found to be around  $79.34 \pm 11.14$  % of the total above ground fresh phytomass of the plant. The dry firewood component of the plants varied from 1.98 to 144.03 kg (mean =  $47.50 \pm 16.3$ , CV: 108.5%). Our results are in agreement with Maghembe *et al.* (1983) who reported that in a six-year old plantation of *P. juliflora* around 77% of the aboveground total biomass was accounted for by stem + large branches. The leaves + smaller branches made only 22.6% of the total biomass.

Table1. Some morphometric characteristics and actual biomass values of *Prosopis juliflora* plants growing in marginally saline ( $8.15 \text{ dS.m}^{-1}$ ), basic (pH: 7.85) sandy soil of the University of Karachi campus.

S. No.	H-Height (m)	Main Stem-SD (cm)	CR - Crown Cover ( $\text{m}^2$ )	ST	BA ( $\text{dm}^2$ )	Biomass (Kg)			
						Comp. "A" * (FW)	Comp. "B" ** (FW)	Total Fresh Biomass (TFM)	Dry fire Wood (DW)
1	1.40	4.16	13.45	3	0.408	4.50	10.75	15.25	6.54
2	2.00	4.24	17.90	3	0.424	4.60	9.75	14.34	5.55
3	2.15	5.57	25.78	2	0.487	1.25	21.50	22.75	14.50
4	3.50	8.44	43.95	4	2.235	35.00	94.50	129.0	60.13
5	4.20	13.05	97.48	2	2.676	65.00	174.50	239.5	111.03
6	4.00	12.42	114.91	3	3.631	75.00	215.00	290.0	144.03
7	4.85	11.78	71.62	2	2.178	50.00	102.50	152.5	65.22
8	2.05	5.88	28.73	3	0.815	3.65	27.50	31.15	18.14
9	1.50	1.78	1.78	4	0.099	0.08	3.75	3.83	2.39
10	1.38	1.20	1.56	3	0.034	0.18	3.12	3.30	1.98
Mean	2.703	6.85	41.72	2.90	1.30	23.93	66.29	90.16	47.50
$\pm$ SE	$\pm$ 0.12	$\pm$ 1.38	$\pm$ 2.63	$\pm$ 0.23	$\pm$ 0.40	$\pm$ 9.37	$\pm$ 24.4	$\pm$ 33.67	$\pm$ 16.3
Range	1.38-4.2	1.2 - 13.1	1.5 – 114.91	2 - 4	0.034 - 3.63	0.08 - 75.0	3.12- 215.0	3.3 - 290.0	1.98 - 144.03
CV (%)	48.2	63.55	95.75	25.44	97.56	123.86	116.44	118.09	108.50

H, Height (m); SD, Main stem diameter (cm); ST, Number of basal stems, BA, Basal area ( $\text{dm}^2$ ); CR, Crown Cover ( $\text{m}^2$ ). \*, Component A, Twigs  $\leq 1$  cm in diameter + leaves + pods, etc; \*\*, Component B, Stems + twigs  $> 1$  cm in diameter, TFM, total fresh biomass of plant (kg), DW, dry firewood (kg).

The method of linear correlation applied to the raw data of aboveground phytomass of the plant's components of phytomass as dependent parameters and the morphometric values as independent parameters, disclosed multi-collinearity amongst the parameters studied with the exception of parameter of number of stems per plant which showed no statistically significant correlation with any other parameter of plant growth (Table 2). The morphometric parameters like height stem diameter, cover of crown and the basal area showed highly significant correlations amongst themselves. These parameters also showed significant correlations with the components of the plant phytomass.

Linear regression ( $Y = a + bX$ ) of untransformed biomass components with morphometric parameters gave several statistically significant equations but of relatively low  $R^2$  particularly with height and stem diameter. Biomass components related with basal area and crown cover with substantially high values of  $R^2$  and adjusted  $R^2$  although almost all these equations had insignificant value of  $t$  for the intercept ( $a$ ) (Table 3). With simple linear model, BA and CR were better predictors than H and SD. The logarithmically (Ln) transformed biomass components, however, gave significantly high values of adjusted  $R^2$  (0.830 to 0.951) and  $F$  with only stem diameter (Table 4). With the exception of biomass component A, stem diameter accounted for 10.3 to 12.9 % more variation in logarithmically transformed biomass components than that in the case of untransformed biomass components. Other morphometric parameters couldn't perform well with any log-transformed biomass components, rather a decline in the predictive value of basal area and crown cover occurred. With this model, SD appeared to be a better predictor of biomass in *P. juliflora*. Table 5 presents correlation and regression analysis of logarithmically transformed variables –biomass components and the morphometric parameters both. Compared to the semi-log model given above, this model improved the predictive potential of the equations regarding the four biomass parameters while adjudging in terms of adjusted values of  $R^2$  i.e., around 4.8 % in case of height, around 2.4 in case of SD, 2% in case of BA and 8.3% in case of CR. The relationship of Biomass component A with CR was, however, much improved (c 19.6%). In spite of it adjusted  $R^2$  values remained generally below 0.95. The predictive potential of BA and CR, indeed was better in untransformed state of  $X$  and  $Y$  variables – with substantially higher values of  $F$  and workable values of adjusted  $R^2$  (Table 3).

Table2. Pearson correlation coefficients for actual phytomass components and the morphometric parameters of *P. juliflora* (n=10).

H	H								
SD	0.952	SD							$r_{(p < 0.05)} = 0.632$
BA	0.914	0.951	BA						$r_{(p < 0.01)} = 0.765$
CR	0.889	0.962	0.962	CR					$r_{(p < 0.001)} = 0.872$
ST	-0.404	-0.461	-0.215	-0.405	ST				
Comp. A	0.913	0.940	0.976	0.973	-0.291	Comp A			
Comp. B	0.857	0.922	0.975	0.981	-0.261	0.984	Comp B		
TFM	0.875	0.930	0.978	0.982	-0.271	0.992	0.999	TFM	
DW	0.846	0.914	0.972	0.980	-0.253	0.980	0.999	0.997	DW

Key to the acronyms as in Table 1.

Table 6 and 7 present the equations obtained on multiple correlation and regression of raw and logarithmically (Ln) transformed dry firewood biomass with various linear combinations of two or more morphometric parameters. Many of the combinations of morphometric parameters yielded significant predictive equation for raw or transformed dry firewood. Some of these equations had insignificant values of  $t$  for intercept or regression coefficient (s) or both. There were few equations with value of adjusted  $R^2 > 0.95$ . Equation # 10 (Table 7) for log-transformed dry firewood was, however, the best among these equations although it had marginally low value for height ( $t = -1.922$ ;  $p < 0.113$ ). Log-transformed fresh biomass of component B and total plant biomass were found to be significantly related with linear combinations of all morphometric parameters in hand in all respect as given by the following equations, respectively.

$$\begin{aligned} \text{Ln Biomass Comp. B (kg)} &= 1.279 - 0.519 \text{ Height (m)} - 0.272 \text{ Crown Cover (Sq. m)} + 0.511 \text{ SD (cm)} + \\ (\text{FW}) & \quad (t = -1.50) \quad (t = -2.194) \quad (t = -2.64) \quad (t = 4.601) \\ & \quad (p < 0.004) \quad (p < 0.08) \quad (p < 0.046) \quad (p < 0.006) \\ & \quad 0.1472 \text{ Basal Area (dm}^2\text{)} \pm 0.2522 \\ & \quad (t = 2.95) \\ & \quad (p < 0.032) \quad F = 83.76 (p < 0.0001), R^2 = 0.993; \text{ Adjusted } R^2 = 0.985 \end{aligned}$$

$$\begin{aligned} \text{Ln TFM (kg) FW} &= 1.336 - 0.550 \text{ Height (m)} - 0.0320 \text{ Crown Cover (Sq. m)} + 0.567 \text{ SD (cm)} + \\ & \quad (t = 5.948) \quad (t = -2.7021) \quad (t = -3.603) \quad (t = 5.927) \\ & \quad (p < 0.002) \quad (p < 0.0431) \quad (p < 0.015) \quad (p < 0.002) \\ & \quad 0.905 \text{ Basal Area (dm}^2\text{)} \pm 0.2171 \\ & \quad (t = 3.664) \\ & \quad (p < 0.015) \quad F = 127.032 (p < 0.0001), R^2 = 0.990; \text{ Adjusted } R^2 = 0.982 \end{aligned}$$

Table 3. Linear regression between biomass components and morphometric parameters of *P. juliflora* ( $Y = a + b X$ ).

Parameters (Y / X)	a	b	r <sup>2</sup>	Adj. r <sup>2</sup>	F	p	SE
Biomass Component A / H	- 32.171 t = -3.293 p < 0.011	20.754 t = 6.315 p < 0.0001	0.833	0.812	39.87	0.0001	12.85
Biomass Component B / H	- 70.919 t = -2.21 p < 0.058	50.7605 t = 4.71 p < 0.002	0.735	0.701	22.15	0.002	42.17
TFM / H	- 103.071 t = 2.482 p < 0.038	71.488 t = 5.117 p < 0.001	0.766	0.737	26.181	0.001	54.632
DW / H	- 46.005 t = -2.114 p < 0.067	32.910 t = 4.495 p < 0.002	0.716	0.681	20.21	0.002	28.628
Biomass Component A / SD	- 19.935 t = 3.040 p < 0.016	6.401 t = 7.80 p < 0.0001	0.884	0.869	60.880	0.0001	10.714
Biomass Component B / SD	- 45.742 t = 2.360 p < 0.0116	16.350 t = 6.740 p < 0.001	0.850	0.831	45.40	0.0001	31.689
TFM / SD	-65.697 t = -2.59 p < 0.032	22.747 t = 7.16 p < 0.0001	0.865	0.848	51.260	0.0001	41.492
DW / SD	- 29.982 t = 2.248 p < 0.055	10.644 t = 6.384 p < 0.0001	0.836	0.815	40.753	0.0001	21.775
Biomass Component A / BA	- 6.353 t = -1.966 p < 0.085	23.810 t = 12.645 p < 0.00001	<b>0.952</b>	<b>0.946</b>	<b>159.893</b>	0.0001	6.8625
Biomass Component B / BA	- 12.503 t = -1.462 p < 0.182	61.956 t = 12.432 p < 0.00001	<b>0.951</b>	<b>0.945</b>	<b>154.570</b>	0.00001	18.162
TFM / BA	- 18.961 t = -1.709 p < 0.126	85.730 t = 13.332 p < 0.0001	<b>0.957</b>	<b>0.952</b>	<b>177.732</b>	0.00001	23.437
DW / BA	- 8.616 t = -1.449 p < 0.185	40.550 t = 11.702 p < 0.00001	<b>0.945</b>	<b>0.938</b>	<b>136.928</b>	0.00001	12.629
Biomass Component A / CR	- 6.203 t = -1.832 p < 0.104	0.722 t = 12.019 p < 0.00001	<b>0.948</b>	<b>0.941</b>	<b>144.454</b>	0.00001	7.2016
Biomass Component B / CR	- 12.812 t = -1.832 p < 0.104	1.896 t = 14.416 p < 0.00001	<b>0.963</b>	<b>0.958</b>	<b>207.563</b>	0.00001	15.762
TFM / CR	-19.064 t = -1.923 p < 0.091	2.618 t = 14.865 p < 0.00001	<b>0.965</b>	<b>0.961</b>	<b>221.563</b>	0.00001	21.080
DW / CR	- 8.923 t = -1.781 p < 0.113	1.244 t = 13.991 p < 0.00001	<b>0.961</b>	<b>0.956</b>	<b>195.737</b>	0.00001	10.652

Key to the acronyms as in Table 1.

Table4. Linear correlation and regression analysis between logarithmically (Ln) transformed biomass parameters (Y) with raw morphometric parameters (Xi) such as height, stem diameter, basal area and crown cover of *Prosopis juliflora*. a)  $r$ ; b,  $R^2$ ; c) Adjusted  $R^2$ .

Parameters (Log <sub>e</sub> Y/ Xi)	Correlation Coefficients	Intercept 'a'	Slope 'b'	F (p) SE
Biomass Component A / H	a) 0.855 b) 0.731 c) 0.698	-2.685 t = -2.640 p < 0.030	+ 1.595 t = 4.67 p < 0.002	21.77 (p < 0.002) SE = 1.3365
Biomass Component B / H	a) 0.913 b) 0.834 c) 0.814	3.850 t = 0.756 p < 0.471	1.086 t = 6.35 p < 0.0001	40.26 (p < 0.0001) SE = 0.6693
TFM / H	a) 0.917 b) 0.840 c) 0.820	0.4350 t = 0.824 p < 0.435	1.153 t = 6.488 p < 0.002	42.10 (p < 0.0001) SE = 0.6950
DW / H	a) 0.911 b) 0.829 c) 0.808	-0.09503 t = -0.182 p < 0.860	+ 1.0959 t = 6.23 p < 0.001	38.8 (p < 0.0001) SE = 0.6877
Biomass Component A / SD	a) 0.921 b) 0.849 c) 0.830	-1.899 t = -3.094 p < 0.015	+ 0.515 t = 6.708 p < 0.0001	45.0 (p < 0.0001) SE = 1.002
Biomass Component B / SD	a) 0.977 b) 0.954 c) 0.948	0.938 t = 4.331 p < 0.003	0.348 t = 12.845 p < 0.0001	164.9 (p < 0.0001) SE = 0.3535
TFM / SD	a) 0.978 b) 0.956 c) 0.951	1.0290 t = 4.620 p < 0.002	0.368 t = 13.237 p < 0.0001	175.2 (p < 0.0001) SE = 0.3634
DW / SD	a) 0.975 b) 0.950 c) 0.944	+ 1.3439 t = 4.65 p < 0.0001	+ 0.0365 t = 7.11 p < 0.0001	50.7 (p < 0.0001) SE = 0.6144
Biomass Component A / BA	a) 0.887 b) 0.787 c) 0.760	-6.310 t = -1.125 p < 0.293	+ 1.775 t = 5.436 p < 0.0001	29.55 (p < 0.001) SE = 1.190
Biomass Component B / BA	a) 0.955 b) 0.912 c) 0.901	1.771 t = 7.723 p < 0.0001	1.219 t = 9.121 p < 0.0001	83.20 (p < 0.0001) SE = 0.4869
TFM / BA	a) 0.953 b) 0.909 c) 0.898	1.916 t = 7.756 p < 0.0001	1.287 t = 8.940 p < 0.00001	79.92 (p < 0.0001) SE = 0.5246
DW / BA	a) 0.954 b) 0.911 c) 0.899	+ 0.4582 t = 2.02 p < 0.078	+ 0.3512 t = 12.32 p < 0.0001	151.8 (p < 0.0001) SE = 0.3723
Biomass Component A / CR	a) 0.852 b) 0.725 c) 0.691	-0.535 t = -0.841 p < 0.425	0.0518 t = 4.593 p < 0.002	21.09 (p < 0.002) SE = 1.352
Biomass Component B / CR	a) 0.929 b) 0.863 c) 0.846	1.817 t = 6.356 p < 0.0001	0.03605 t = 7.107 p < 0.0001	50.5 (p < 0.0001) SE = 0.6077
TFM / CR	a) 0.925 b) 0.856 c) 0.837	1.969 t = 6.33 p < 0.001	0.3796 t = 6.833 p < 0.0001	47.37 (p < 0.0001) SE = 0.6610
DW / CR	a) 0.929 b) 0.864 c) 0.847	+ 1.3468 t = 5.55 p < 0.001	+ 1.1702 t = 9.02 p < 0.0001	81.4 (p < 0.0001) SE = 0.4976

Table 5. Linear correlation and regression analysis between logarithmically (Ln) transformed biomass and morphometric parameters. a) r ; b,  $R^2$ ; c) Adjusted  $R^2$ .

Parameters (Ln Yi / Ln Xi)	Correlation Coefficients	Intercept 'a'	Slope 'b'	F (p) SE
Ln Biomass Component A / Ln H	a) 0.874 b) 0.763 c) 0.734	-2.284 t = -2.64 p < 0.030	4.400 t = 5.08 p < 0.001	25.802 (p < 0.002) SE = 1.2544
Ln Biomass Component B / Ln H	a) 0.941 b) 0.886 c) 0.872	0.633 t = 1.650 p < 0.138	3.022 t = 7.88 p < 0.0001	40.26 (p < 0.0001) SE = 0.5554
Ln TFM / Ln H	a) 0.942 b) 0.887 c) 0.867	0.708 t = 1.75 p < 0.118	3.198 t = 7.908 p < 0.0001	62.53 (p < 0.0001) 0.5857
Ln DW / Ln H	a) 0.939 b) 0.889 c) 0.866	0.1540 t = 0.390 p < 0.707	3.0500 t = 7.703 p < 0.0001	59.3 (p < 0.0001) SE = 0.5735
Ln Biomass Component A / Ln SD	a) 0.945 b) 0.893 c) 0.880	-3.138 t = -4.893 p < 0.001	2.835 t = 11.409 p < 0.0001	66.75 (p < 0.0001) SE = 0.8435
Ln Biomass Component B / Ln SD	a) 0.964 b) 0.929 c) 0.920	0.222 t = 0.666 p < 0.524	1.964 t = 12.845 p < 0.0001	104.6 (p < 0.0001) SE = 0.4382
Ln TFM / Ln SD	a) 0.971 b) 0.942 c) 0.935	0.252 t = 0.791 p < 0.002	1.964 t = 11.409 p < 0.0001	130.2 (p < 0.0001) SE = 0.4185
Ln DW / Ln SD	a) 0.960 b) 0.922 c) 0.912	-0.256 t = -0.725 p < 0.0001	1.859 t = 9.706 p < 0.0001	94.20 (p < 0.0001) SE = 0.4655
Ln Biomass Component A / Ln BA	a) 0.948 b) 0.899 c) 0.886	2.329 t = 8.856 p < 0.0001	1.528 t = 8.427 p < 0.0001	71.104 (p < 0.001) SE = 0.8204
Ln Biomass Component B / Ln BA	a) 0.962 b) 0.925 c) 0.916	9.775 t = 25.292 p < 0.0001	0.989 t = 9.854 p < 0.0001	99.08 (p < 0.0001) SE = 0.4494
Ln TFM / Ln BA	a) 0.970 b) 0.941 c) 0.934	4.037 t = 28.75 p < 0.0001	1.055 t = 11.285 p < 0.00001	127.4 (p < 0.0001) SE = 0.4228
Ln DW / Ln BA	a) 0.957 b) 0.917 c) 0.906	3.325 t = 20.344 p < 0.0001	0.996 t = 9.384 p < 0.0001	88.02 (p < 0.0001) SE = 0.4803
Ln Biomass Component A / Ln CR	a) 0.948 b) 0.900 c) 0.887	-3.030 t = -4.990 p < 0.001	0.1527 t = 8.467 p < 0.0001	71.69 (p < 0.002) SE = 0.8169
Ln Biomass Component B / Ln CR	a) 0.948 b) 0.899 c) 0.886	0.352 t = 0.308 p < 0.391	0.973 t = 8.436 p < 0.0001	71.2 (p < 0.0001) SE = 0.5226
Ln TFM / Ln CR	a) 0.956 b) 0.915 c) 0.904	0.385 1.019 p < 0.338	1.039 t = 9.252 p < 0.0001	85.59 (p < 0.0001) SE = 0.5084
Ln DW / Ln CR	a) 0.944 b) 0.891 c) 0.877	-0.124 t = -0.302 p < 0.770	0.981 t = 8.089 p < 0.0001	65.39 (p < 0.0001) SE = 0.5493

Table 6. Equations of multiple correlation and regression between untransformed dry firewood component (DW) and morphometric parameters of *P. juliflora*.

DRY FIREWOOD (DW)	
DW = -22.526 -9.942H + 13.478 SD ± 22.839 t = -1.16 t = -0.54 t = 2.36 p < 0.297 p < 0.618 p < 0.05 R <sup>2</sup> = 0.842; Adj. R <sup>2</sup> = 0.797; F = 18.66 (p < 0.002)	EQ. # 1
DW = 5.906 + -9.976 H + 50.334 BA ± 12.106 t = 0.473 t = 1.306 t = 6.143 p < 0.651 p < 0.233 p < 0.0001 R <sup>2</sup> = 0.956; Adjusted r <sup>2</sup> = 0.943; F = 75.36 (p < 0.0001)	EQ. # 2
DW = -2.121 - 4.554 H + 1.376 CR ± 10.961 t = -0.202 t = -0.745 t = 6.897 p < 0.845 p < 0.480 p < 0.001 R <sup>2</sup> = 0.964; Adjusted R <sup>2</sup> = 0.953; F = 92.70 (p, 0.0001)	EQ. # 3
DW = - 5.505 - 1.235 SD + 44.760 BA ± 13.369 t = - 0.527 t = -0.373 t = 3.771 p < 0.605 p < 0.720 p = 0.007 R <sup>2</sup> = 0.946; Adjusted R <sup>2</sup> = 0.930 F = 61.67 (p < 0.0001)	EQ. # 4
DW = 1.884 - 4.358 SD + 1.700 CR ± 9.7356 t = 0.232 t = -1.605 t = 5.746 p < 0.823 p < 0.152 p = 0.001 R <sup>2</sup> = 0.971; Adjusted R <sup>2</sup> = 0.963; 116.44 (p < 0.0001)	EQ. # 5
DW = -9.765 + 16.308 BA + 0.767 CR ± 1.581 t = - 2.154 t = 1.700 t = 2.627 P < 0.068 p < 0.133 p < 0.034 R <sup>2</sup> = 0.972; Adjusted R <sup>2</sup> = 0.964; F = 122.42	EQ. # 6
DW = 5.728 - 13.972 H + 2.381 SD + 46.139 BA ± 12.739 t = 0.436 t = -1.3098 t = 0.567 t = 4.062 p < 0.678 p < 0.239 p < 0.591 p < 0.007 R <sup>2</sup> = 0.958; Adjusted R <sup>2</sup> = 0.937; F = 45.482 (p < 0.0001)	EQ. 7
DW = -1.0270 + 5.470 H - 6.476 SD + 1.763 CR ± 10.205 t = -0.105 t = 0.608 t = -1.440 t = 5.391 p < 0.920 p < 0.565 p < 0.0200 p < 0.002 R <sup>2</sup> = 0.973, Adjusted r <sup>2</sup> = 0.959; F = 71.982 (p < 0.0001)	EQ. # 8
DW = 6.589 - 6.769 SD + 24.793 BA + 1.228 CR ± 4.6996 t = 1.675 t = -4.977 t = 5.077 t = 7.343 p < 0.145 p < 0.003 p < 0.002 p < 0.00001 R <sup>2</sup> = 0.995 Adjusted r <sup>2</sup> = 0.992; F = 367.00 (p < 0.0001)	EQ. 9
Fuel wood (kg) DW = 7.653 - 1.738 Height (m) - 6.1666 SD (cm) + 25.516 Basal area dm <sup>2</sup> + (t = 1.499) (t = - 0.376) (t = - 2.834) (t = 4.453) (p < 0.194) (p < 0.723) (p < 0.037) (p < 0.006) 1.194 Crown cover (sq. m) ± 4.9367 (t = 5.912) (P < 0.002) F = 235.882 (p < 0.00001); R <sup>2</sup> = 0.995, Adjusted R <sup>2</sup> = 0.991	EQ. # 10

In search of better model, non-linear models (quadratic, power, logarithmic and exponential) were also tested to estimate dry firewood in this species. The best-fit equations of this analysis are presented in Table 8 and 9 and Figures 1 to 4.

Table7. Equations of multiple correlation and regression between Logarithmically (Ln) transformed dry firewood component (Ln DW) and morphometric parameters of *P. juliflora*.

DRY FIREWOOD (Ln DW)	
Ln DW = 0.627 - 0.221 H + 0.414 SD $\pm$ 0.3852 t = - 1.857 t = - 0.688 t = 4.300 p , 0.106 p < 0.514 p < 0.004 R <sup>2</sup> = 0.953; Adjusted R <sup>2</sup> = 0.940; F = 71.116 (p < 0.0001)	EQ. # 1
Ln DW = 0.8920 + 0.280 H + 0.9570 BA $\pm$ 0.5048 t = 1.713 t = 0.880 t = 2.802 P < 0.131 p < 0.408 p < 0.026 R <sup>2</sup> = 0.919; Adjusted R <sup>2</sup> = 0.896; F = 39.964 (p < 0.0001)	EQ. # 2
Ln DW = 0.6210 + 0.4850 H + 0.0224 CR $\pm$ 0.5087 t = 1.141 t = 1.529 t = 2.168 p < 0.291 p < 0.170 p < 0.067 R <sup>2</sup> = 0.898; Adjusted R <sup>2</sup> = 0.869; F = 30.74 (p < 0.0001)	EQ. # 3
Ln DW = 0.663 + 0.2530 SD + 0.3690 BA $\pm$ 0.3657 t = 2.318 t = 2.795 t = 1.137 p < 0.054 p < 0.027 p < 0.293 R <sup>2</sup> = 0.958; Adjusted R <sup>2</sup> = 0.946; F = 79.304 (p < 0.0001)	EQ. # 4
Ln DW = 0.3840 + 0.3870 SD - 0.0041 CR $\pm$ 1.42 t = 1.162 t = 3.519 t = 0.342 p < 0.283 p < 0.010 p < 0.743 R <sup>2</sup> = 0.951; Adjusted R <sup>2</sup> = 0.937; F = 67.56 (p < 0.0001)	EQ. # 5
Ln DW = 1.291 + 1.040 BA + 0.006066 CR $\pm$ 0.5266 t = 5.82 t = 1.973 t = 0.378 p < 0.001 p < 0.089 p < 0.716 R <sup>2</sup> = 0.912; Adjusted R <sup>2</sup> = 0.887; F = 36.430 (p < 0.0001)	EQ. # 6
Ln DW = 0.868 - 0.256 H + 0.319 SD + 0.394 BA $\pm$ 0.3749 t = 2.243 t = -0.813 t = 2.587 t = 1.180 p < 0.066 p < 0.447 p < 0.041 p < 0.283 R <sup>2</sup> = 0.962; Adjusted R <sup>2</sup> = 0.943; F = 50.53 (p < 0.0001)	EQ. # 7
Ln DW = 0.536 - 0.286 H + 0.498 SD + 0.0074 CR $\pm$ 0.4053 t = -0.138 t = -0.801 t = 2.790 t = -0.570 p < 0.217 p < 0.454 p < 0.032 p < 0.589 R <sup>2</sup> = 0.956 Adjusted R <sup>2</sup> = 0.933; F = 42.95 (p < 0.0001)	EQ. # 8
Ln DW = 0.504 + 0.326 SD + 0.632 BA + 0.0161 CR $\pm$ 0.3516 t = 1.664 t = 3.116 t = 1.681 t = 1.255 p < 0.147 p < 0.021 p < 0.144 p < 0.256 R <sup>2</sup> = 0.967 Adjusted R <sup>2</sup> = 0.950; F = 57.73.00 (p < 0.0001)	EQ. # 9
Ln Firewood (kg) = 0.826 - 0.526 Height (m) - 0.0264 Crown Cover (Sq. m) + 0.508 SD (cm) + (DW) (t = 2.73) (t = -1.92) (t = -0.672) (t = 3.950) (p < 0.041) (p < 0.11) (p < 0.078) (p < 0.011)  0.850 Basal Area (dm <sup>2</sup> ) $\pm$ 0.2921 (t = 2.560) (p < 0.051) F = 63.65 (p < 0.0001), R <sup>2</sup> = 0.982; Adjusted R <sup>2</sup> = 0.965	
EQ. # 10	



Table 8. Best-fit non-linear regression equations for untransformed dry firewood component with morphometric parameters of *P. juliflora*.

FUEL WOOD (Untransformed data)	
Dry Fuel wood (kg) = 1.1668. Height $^{3.0505} \pm 0.57398$ $t(a) = 2.524$ $t(b) = 7.703$ $p < 0.0356$ $p < 0.001$ $R^2 = 0.881$ ; Adjusted $R^2 = 0.866$ ; $F = 59.32$ ( $p < 0.0001$ )	Power Curve
Dry Fuel wood (kg) = 1.5852.e $^{0.3512 (\text{Stem diameter})} \pm 0.37233$ $t(a) = 4.384$ $t(b) = 12.319$ $P < 0.0023$ $p < 0.00001$ $R^2 = 0.950$ ; Adjusted $R^2 = 0.943$ ; $F = 151.76$ ( $p < 0.00001$ )	Exponential Curve
Dry Fuel wood (kg) = 0.7738. Stem Diameter $^{1.8587} \pm 0.46511$ $t(a) = 2.830$ $t(b) = 9.706$ $p < 0.00001$ $p < 0.0223$ $R^2 = 0.922$ ; Adjusted $R^2 = 0.911$ ; $F = 59.32$ ( $p < 0.0001$ )	Power Curve
Dry Fuel wood (kg) = 27.7928. Basal Area $^{0.9961} \pm 0.48027$ $t(a) = 6.269$ $t(b) = 9.382$ $p < 0.002$ $p < 0.00001$ $R^2 = 0.917$ ; Adjusted $R^2 = 0.906$ ; $F = 88.02$ ( $p < 0.0001$ )	Power Curve
Dry Fuel wood (kg) = -1.9301 + 0.7275 (Crown) + 0.0046 ( <b>Crown</b> ) $^2 \pm 9.6268$ $T(a) = -0.313$ $t(b) = 2.281$ $t(c) = 1.672$ $p < 0.763$ $p < 0.0566$ $p < 0.1385$ $R^2 = 0.972$ ; Adjusted $R^2 = 0.963$ ; $F = 121.22$ ( $P < 0.00001$ )	Quadratic Curve
Dry Fuel wood (kg) = -8.9229 + 1.2435 Crown $\pm 10.6518$ $t(a) = -1.780$ $t(b) = 13.991$ $p < 0.113$ $p < 0.000011$ $R^2 = 0.961$ ; Adjusted $R^2 = 0.955$ ; $F = 195.74$ ( $p < 0.0001$ )	Linear

The Log-transformed dry firewood content of *P. juliflora* was found to be best related with height through quadratic model, with stem diameter both in quadratic fashion as well as through power equation, with basal area and crown cover through power equations. All these equations were highly significant in all respect - adjusted  $R^2$  around 0.97-0.98 (except for height which had showed somewhat low  $R^2$ ), very high F values indicating model validity and significant values of 't' for intercept and slope both.

Chaturvedi *et al.* (1991) reported that in *Acacia farnesiana*, a multistemic arid plant, measuring the growth parameters of the most prominent stem and counting the number of stems gives statistically accurate estimate of the biomass of the individual plant. Therefore, a multiplicative model of regression,  $W = a + b[n(D^2.H)]$  where W, weight of biomass; a intercept; b regression coefficient; n number of stems; D, diameter of the main stem and H, the height of the plant was also tested besides another multiplicative model,  $W = a + b(BA.H)$  where BA, basal area and H, height of the plant. The results of this analysis are presented in Figure 5 A and B. Both the multiplicative variables- ( $n(D^2.H)$  and  $BA.H$ ) were found to be highly significantly related to Ln DW through power equations. The simple linear regression models with these variables yielded significant relationship but of relatively lesser predictive values. The variables ( $n(D^2.H)$  and  $BA.H$ ) accounted for variation in Ln DW by surplus quanta of 12.4 and 14.9%, respectively in case of power model as compared to simple linear one.

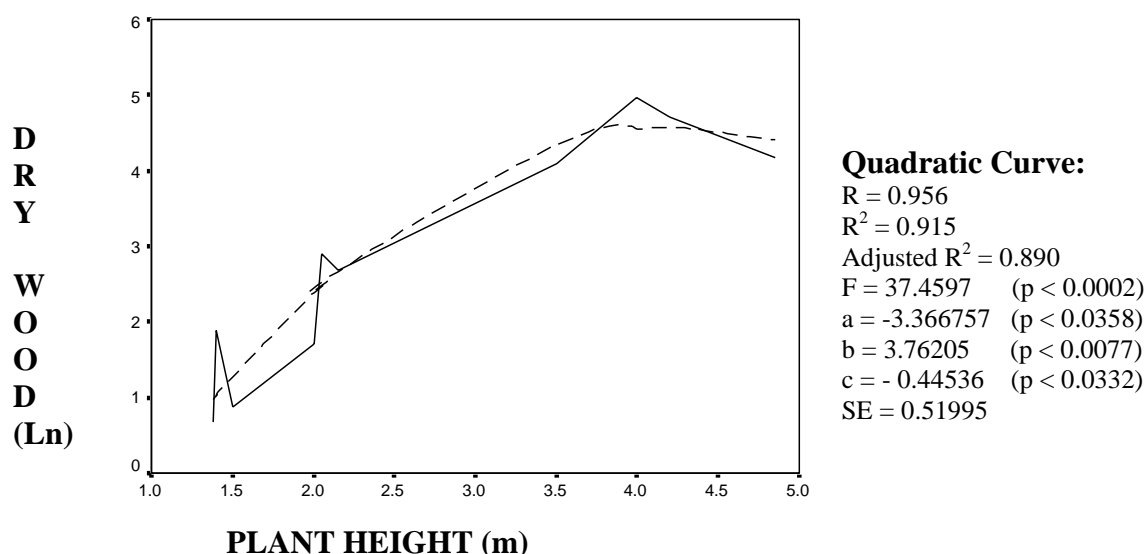


Fig.1. Quadratic relationship between  $\log_e$  dry wood (Kg per plant) and plant height (m). The broken line represents the fitted curve.

Table9. Best-fit non-linear regression equations for logarithmically (Ln) transformed dry fuel wood component (Ln DW) with morphometric parameters of *P. juliflora*.

FUEL WOOD – Log <sub>e</sub> Transformed (Ln DW)	
Dry Fuel wood (kg) = $-3.36676 + 3.76205 (\text{Height}) - 0.44536 (\text{Height})^2 \pm 0.51995$ $t = -2.592 \quad t = 3.700 \quad t = -2.645$ $p < 0.0358 \quad p < 0.0077 \quad p < 0.0332$ $R^2 = 0.915$ ; Adjusted $R^2 = 0.890$ ; $F = 37.46$ ( $P < 0.0001$ )	Quadratic Curve
Dry Fuel wood (kg) = $0.770162 \cdot \text{Height}^{1.270825} \pm 0.35646$ $t(a) = 4.061 \quad t(b) = 5.163$ $p < 0.0036 \quad p < 0.009$ $R^2 = 0.769$ ; Adjusted $R^2 = 0.740$ ; $F = 26.66$ ( $p < 0.0009$ )	Power Curve
Dry Fuel wood (kg) = $0.566843 \cdot \text{Stem Diameter}^{0.854925} \pm 0.10319$ $t(a) = 12.747 \quad t(b) = 20.139$ $p < 0.00001 \quad p < 0.0001$ $R^2 = 0.981$ ; Adjusted $R^2 = 0.978$ ; $F = 405.56$ ( $p < 0.00001$ )	Power Curve
Dry Fuel wood (kg) = $2.94244 \cdot \text{Basal Area}^{0.45756} \pm 0.12228$ $t(a) = 24.622 \quad t(b) = 16.926$ $p < 0.00001 \quad p < 0.00001$ $R^2 = 0.986$ ; Adjusted $R^2 = 0.969$ ; $F = 286.499$ ( $p < 0.00001$ )	Power Curve
Dry Fuel wood (kg) = $0.593135 \cdot \text{Crown Cover}^{0.45633} \pm 0.12879$ $t(a) = 10.438 \quad t(b) = 16.046$ $p < 0.00001 \quad p < 0.00001$ $R^2 = 0.970$ ; Adjusted $R^2 = 0.9669$ ; $F = 257.47$ ( $p < 0.00001$ )	Power Curve

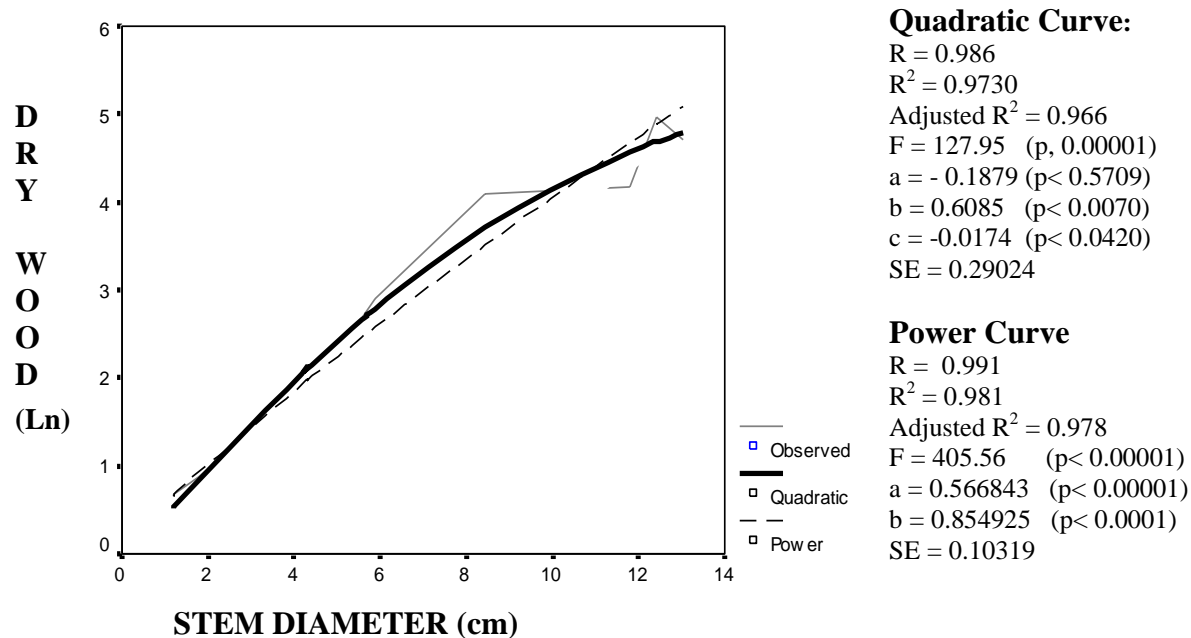


Fig.2. Relationship of Ln DW with Stem diameter. Broken line gives quadratic curve and solid black line the power curve.

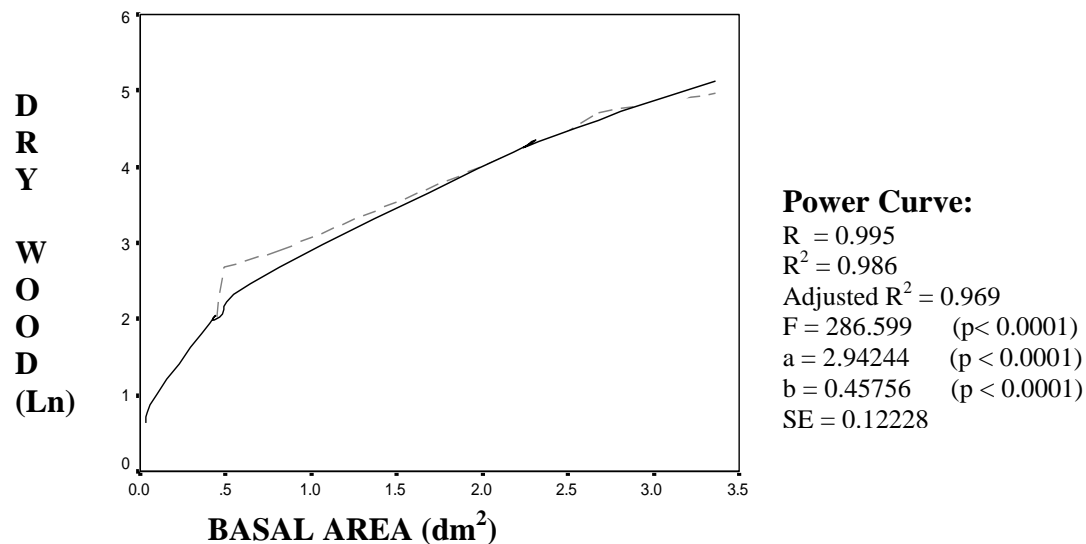


Fig.3. Relationship between  $\log_e$  dry wood (Kg per plant) and plant Basal area ( $\text{dm}^2$ ). Solid line represents the fitted curve.

If adjusted  $R^2 \geq 0.95$  is taken as the criterion for significant workable equation, in present studies, some 26 equations based on different models were significant in describing the biomass components or dry firewood content on the basis of morphometric variables. The best amongst these equations were those based on the power model because they were based on a single size parameter and, therefore, easy to work. Allometry is referred to as simple when it involves simple linear model of regression. Some authors prefer to use term allometry when estimation involves complex models such as logarithmic, quadratic, or power models. Singh (1975) observed that the relationship between two parts or organs or between an organ and the rest of the body, which do not grow at the same rate, is given by the allometric equation. Gardner *et al.* (1985) had the similar contention. On the other hand biomass of some stands has been successfully estimated by the linear regression:  $Y = a + b X$  (Whittaker and

Woodwell, 1968). Amongst various morphological plant parameters, DBH has been reported to be a better predictor of aboveground organ mass of Norway spruce than height (Pokorný and Tomášková, 2007). DBH provided better estimates of aboveground biomass in *Acacia abyssinica*, *A. seyal*, *A. tortilis*, *Eucalyptus globulus*, *E. grandis* and *E. saligna* (Fentu, 2005). Tanaka *et al.* (2009) also reported better allometric relations for aboveground biomass with DBH in logged-over tropical rainforests in Sarawak, Malaysia. DBH was reported as single successful predictor of range of prediction values of total aboveground biomass closer to lower and upper limits of the observed mean in *Dipterocarpus*, *Hopea*, *Palaquium* and *Shorea* of *Dipterocarp* forests in east Kalimantan, Indonesia with a log-log model:  $\log_e (\text{Total aboveground biomass}) = c + a \log_e (\text{DBH})$  (Basuki *et al.*, 2009). The diameter of the longest stem in several species was reported to be the best predictor of biomass in Argentine shrubs (Hierro *et al.*, 2000). Diameter at breast height in *Fagus moesiaca* (a tree in Vermio Mountain of Northern Greece), explained most of the variability in the dependent variables such as total aboveground stem biomass and branch biomass (Zianis and Mencuccini, 2003). Highly significant allometric regression, however, resulted from using basal diameter and crown depth in *Jatropha curcas* L (Ghezehei *et al.* (2009). Several authors have reported power models for biomass estimation on the basis of plants' morphometric parameters (Hierro *et al.* (2004) in *Prosopis caldenia* and *P. flexuosa* var. *depressa*; Padrón and Navarro (2004); Pokorný and Tamášková (2007) in young Norway spruce; Achten *et al.* (2010) in *Jatropha curcas* seedlings).

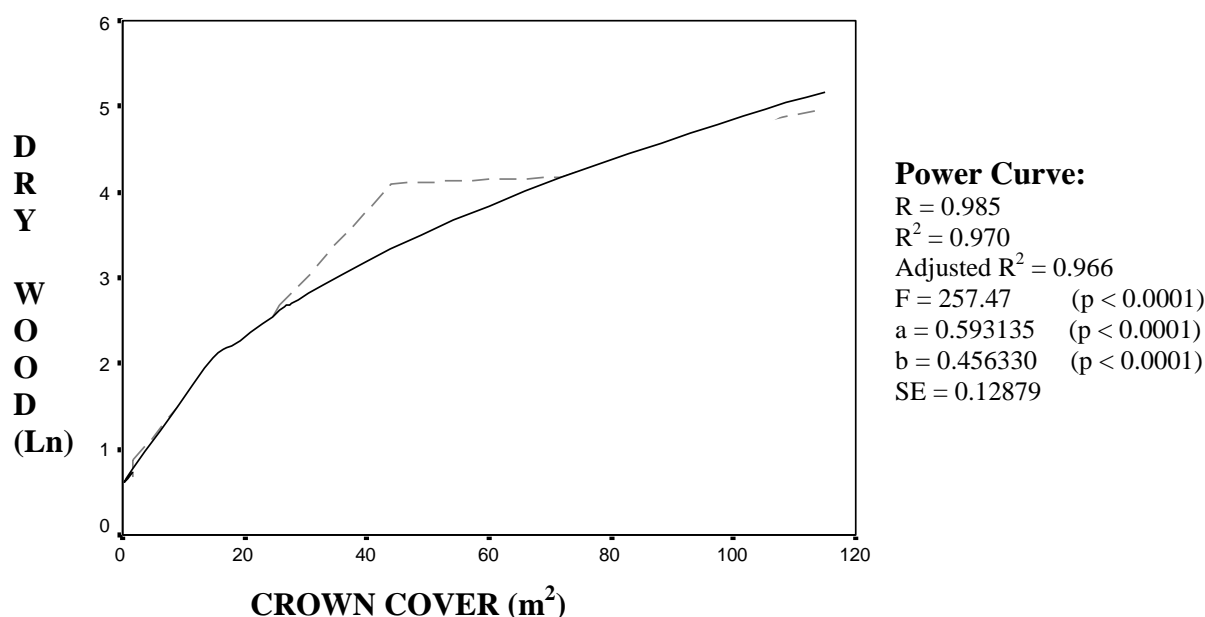


Fig.4. Relationship between  $\log_e$  dry wood (Kg per plant) and plant crown cover ( $\text{m}^2$ ). Solid line represents the fitted curve.

Sood and Bhatia (1993) presented equations to predict biomass in *P. juliflora* in single stemmed and multi-stemmed plants separately on the basis of multiplicative parameters as follows:

#### Multi stemmed plants:

Stem weight (kg) =  $-0.2627 + 0.1740 \ln D^2 H$  ( $r^2 = 0.990$ ) [Sood & Bhatia, 1993]

Total weight (kg) =  $0.1806 + 0.3383 \ln D^2 H$  ( $r^2 = 0.990$ ) [Sood & Bhatia, 1993]

#### Single stemmed plants:

Stem weight (kg) =  $-0.0287 + 0.2284 \ln D^2 H$  ( $r^2 = 0.970$ ) [Sood & Bhatia, 1993]

Total weight (kg) =  $0.0851 + 0.4705 \ln D^2 H$  ( $r^2 = 0.960$ ) [Sood & Bhatia, 1993]

In our studies multi-stemmed and single-stemmed plants were not treated separately. Taking the two types of plants together in a model the few best-fit equations to estimate dry fire wood in *P. juliflora* with the data in hand were power equations based on stem diameter, basal area and crown cover separately as follows:

Ln Dry fire wood = 0.566843. Stem diameter<sup>0.854925</sup>  $\pm 0.10319$ ;  $R^2 = 0.981$ ,  $F = 405.56$  ( $p < 0.0001$ )  
 Ln Dry fire wood = 2.94244. Basal Area<sup>0.457560</sup>  $\pm 0.12228$ ;  $R^2 = 0.969$ ,  $F = 286.599$  ( $p < 0.0001$ )  
 Ln Dry fire wood = 0.593135. Crown Cover<sup>0.456330</sup>  $\pm 0.12879$ ;  $R^2 = 0.966$ ,  $F = 25747$  ( $p < 0.0001$ )

The multiplicative variables in our data also gave power model relationship (as given below) better than the simple linear model as reported by Sood and Bhatia (1993).

Ln DW = 0.374266.  $[n (D^2)H]^{0.350406} \pm 0.14566$ ;  $R^2 = 0.961$ ;  $F = 199.54$  ( $p < 0.0001$ )  
 Ln DW = 2.049506.  $[BA.H]^{0.352233} \pm 0.14446$ ;  $R^2 = 0.962$ ;  $F = 203.02$  ( $p < 0.0001$ )

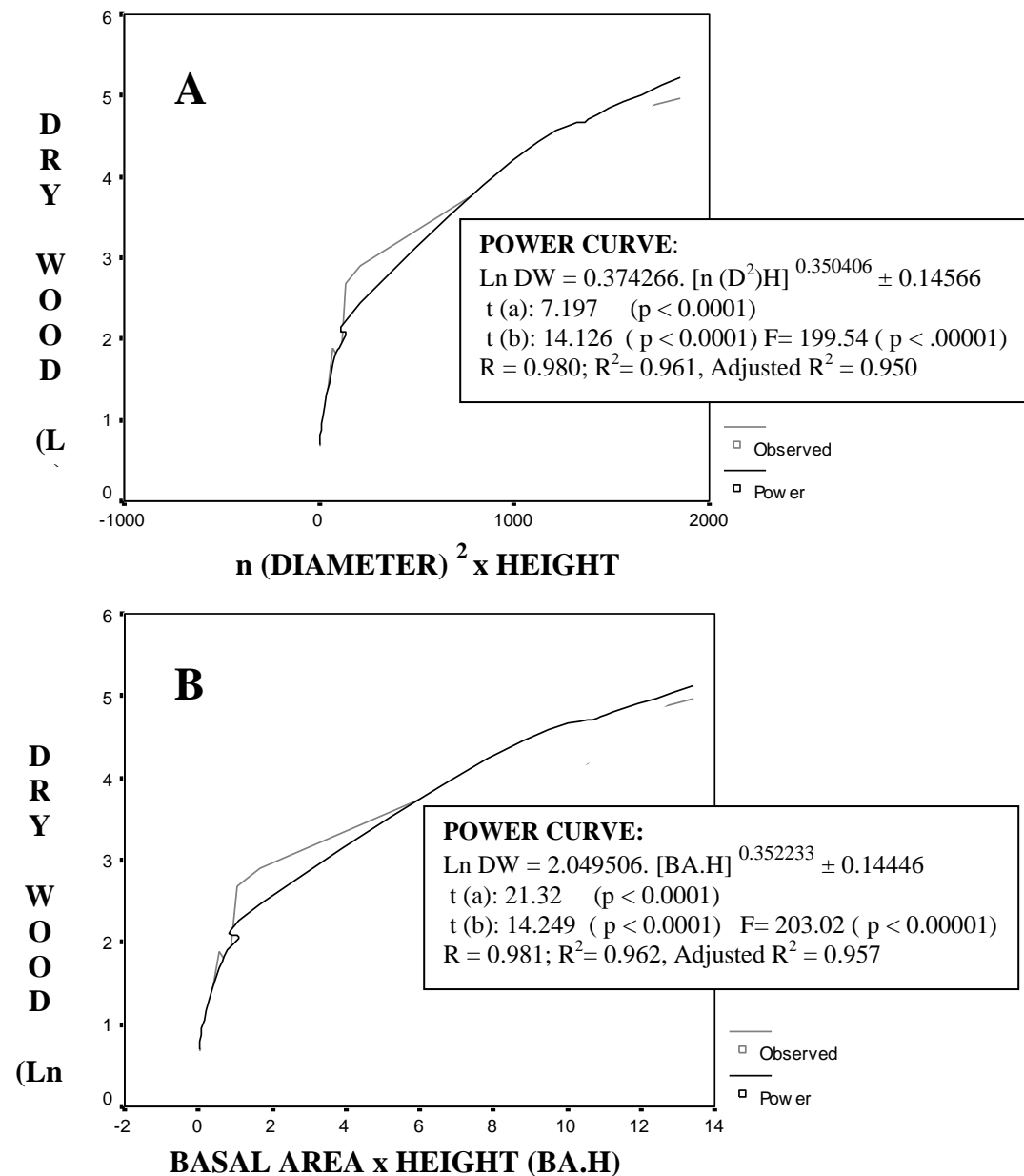


Fig.5. Relationship between dry firewood component (Ln DW) and multiplicative morphometric parameters in *P. juliflora*. Solid lines represent the fitted power curve.

The significant allometric equations between aboveground phytomass and morphometric characteristics of *P. juliflora* should hopefully be quite useful in aboveground phytomass estimation of populations of this species in comparable arid-saline ecosystems. These equations being based on logarithmic transformation of the dry firewood biomass, a correction factor should be considered because such transformation introduces a systematic underestimation of the dependent variable (Y) when converting the estimated log back to original untransformed scale Y. Such a bias was recognized by Fenny (1941). Several authors (Baskerville, 1972; Bauchamp and Olsen, 1973; Yanale and Wiant, 1981; Duan, 1983; Sprugel, 1993; Zianis and Mencuccini, 2003) indicated a bias in biomass estimation using logarithmic regression. The details regarding calculation of correction factor may be seen in Zianis and Mencuccini (2003).

## REFERENCES

- Akhten, W.M.J., W.H. Maes, B. Maes, B. Reubens, E. mathijs, V.P. singh, L. Verchhot, B. Muys (2010). Biomass production and allocation in *Jatropha curcas* L. seedlings under different levels of drought stress. *Biomass and Energy* 34: 667-676.
- Baskerville, G.L. (1972). The use of logarithmic regression in the estimation of plant biomass. *Can. J. For. Res.* 2: 49-53.
- Basuki, T.M., P.E. van Laake, A.K. Skidmore and Y.A. Hussin (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology & Management*. 257 (8): 1684 – 1694.
- Beauchamp, J.J. and J.S. Olse (1973). Correction for bias in regression estimates after logarithmic transformation. *Ecology* 54: 1402-1407.
- Brown, J.K. (1976). Estimating shrub biomass from basal stem diameters. *Can. J. For. Res.* 6: 153 – 158.
- Bryant, F. and M. Kothmann (1979). Variability in predicting edible browse from crown volume. *J. Range Management*. 32: 144-146.
- Castelan-Estrada, M., P. Vivin and J.P. Gaudillière (2002). Allometric relationships to estimate seasonal aboveground vegetative and reproductive biomass of *Vitis vinifera* L. *Ann. Bot.* 89: 401 – 408.
- Cháidez, J de J.N. (2009). Allometric equation and expansion factors for tropical dry forest trees of Eastern Sinaloa, Mexico. *Tropical & Subtropical Agroecosystems* 10: 45-52.
- Chaturvedi, A.N., S. Bhatia and H.M. Behl (1991). Biomass assessment for shrubs. *Indian Forester* 117: 1032-1035.
- Crow, T.R. (1983). Comparing biomass regression by site and stand age for red maple. *Can. J. For. Res.* 13: 283-288.
- Duan, N. 1983. Smearing estimates: A non-parametric transformation method. *J. Am. Stat. Assoc.* 78: 605-610.
- Duff, A.B., J.M. Mayer, C. Pollock and P. Felker (1994). Biomass production and diameter of nine half-sib families of mesquite (*Prosopis glandulosa* var. *glandulosa*) and fast growing *Prosopis alba* half-sib family grown in Texas. *Forest Ecology & Management* 67: 257-266.
- El Fadl, M.A. , S. Gronski, H. Asah, A. Tipton, T.E. Fulbright and P. Felker (1989). Regression equations to predict fresh weight and three grades of lumber from large mesquite (*Prosopis glandulosa* var. *glandulosa*) in Texas. *Forest Ecology & Management* 26: 275-284.
- Elliot, K.J. and B.D. Clinton (1993). Equations for estimating biomass of herbaceous and woody vegetation in early-successional Southern Appalachian Pine-hardwood forests. US dept. Agriculture, Forest service, Southeastern Forest Exp. Station. Research Note NO. SE-365.
- Fanny, D.J. (1941). On the distribution of a variable whose logarithm is normally distributed. *J. R. stat. Soc. Series B*: 155-161.
- Fantu, W. (2005). *Aboveground biomass allometric equations and fuel wood properties of six species grown in Ethiopia*. Ph. D. Thesis. Faculty of Forestry,, Univesiti Putra Malaysia.
- Felker, P., P.R. Clark, J.F. Osborn, G.H. Cannell (1982). Biomass estimation on a young stand of mesquite (*Prosopis* spp.) ironwood (*Olneya tesota*), palo verde (*Cercidium floridum* and *Parkinsonia aculeata*) and leucaena (*Leucaena leucocephala*). *J. Range Management* 35(1): 87-89.
- Fownes, J.H. and R.A. Harrington (1991). Allometry of woody biomass and leaf area in five tropical multipurpose trees. *J. Trop. For. Sci.* 4(4): 317 – 330.
- Gardner, F.P., R.B. Pearce and R.L. Mitchell (1985). *Physiology of Crop Plants*. IOWA State Univ. Press, Ames. P. 187-208.
- Ghezehei, S.B., J.G. Annandale and C.S. Everson (2009). Shoot allometry in *Jetropha curcas*. *Southern Forests: A Journal of For. Sci.* 71(4): 279-286.
- Grigal, D.F. and N. R. Moody (1980). Estimates of browse by site classes for snowshoe hare. *Wildlife. Management*. 44 (1): 34 – 40.

- Hierro, J.L., L.C. Branch, D. Villarreal and K.L. Clark (2000). Predictive equations for biomass and fuel characteristics of Argentine shrubs. *J. Range Management*. 53: 617-621.
- Hughes, G., L. Verner and L. Blankship (1987). Estimating shrub production from plant dimensions. *J. range management*. 40: 367-369.
- Johnson, P.S. C.L. Johnson and N.E. west (1988). Estimation of phytomass for ungrazed crested wheatgrass plants using allometric equations. *J. Range Manage*. 41(5): 421- . Utah Agricultural Experimental Station Journal paper No. 3544.
- Khan, D., R. Ahmad and S. Ismail (1986). Case history of *Prosopis juliflora* plantation at Makran coast raised through saline water irrigation. In: R. Ahmad and A. San Pietro, Eds. *Prospects For Biosaline Research*. Dept. Botany, Univ. Karachi. Pp. 559-585.
- Khan, D., S.S. Shaukat and M.J. Zaki (2010). Size phytomass allometry in some halophytic or salt tolerant species of Karachi coast. *Int. J. Biol. & Biotech*. 7(3):325-338.
- Khan, M.N.I, R. Suwa and A. Hagihara (2005). Allometric relationship for estimating the aboveground phytomass and leaf area of mangrove *Kandelia candel* (L.) Druce trees in the Manko wetland, Okinawa island, Japan. *Trees- Structure & Function* 19 (3): 266 – 272.
- Kirui, B., J.G. Kairo and M. Karachi (2006). Allometric equation for estimating aboveground biomass of *Rhizophora mucronata* Lamk. (*Rhizophoraceae*) mangroves at Gazi Bay, Kenya. *East Indian Ocean J. Mar. Sci*. 5(1): 27-34.
- Litton, C.M. and J.B. Kaufman (2008). Allometric models for predicting aboveground biomass in two widespread woody plants in Hawaii. *Biotropica* 40(3): 313 - 320.
- Maghembe, J.A., E.M. Kariuki and R.D. Haller (1983). Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya. *Agroforestry Systems* (Biomedical & Life sciences and Earth Environmental Science) vol. 1 (1): 313- 321.
- Martin, W.L., T.L. Sharik, R.G. Oderwald, and D. Wm. Smith (1982). Phytomass: Structural relationships for woody plant species in the under story of an Appalachian oak forest. *Can. J. Bot*. 60(10): 1923-1927.
- Matte, T, I. Hajnsek and k. Papathanassiou (2003). Height-biomass allometry in temperate forests. 0-7803-7929-2/03/\$17.00( C )2003 IEEE.
- Mbaekwe, E.I. and J.A. Mackenzie (2008). The use of best-fit allometric model to estimate aboveground biomass accumulation and distribution in an age series of teak (*Tectona grandis* L.f.) plantations at Gambari Forest Reserve, Oyo State, Nigeria. *Tropical ecology* 49 (2): 259-270.
- Monk, C.D., G.J. child, S.A. Nicholson (1970). Biomass, litter and leaf surface area estimates of an oak-hickory forest. *Oikos*. 21: 138-141.
- Murray, R. and M. Jacobson (1982). An evaluation of dimension analysis for predicting shrub biomass. *J. Range Manage*. 35: 451-454.
- Niklas, K.J. (2006). A phyletic perspective of a variable on the allometry of plant biomass-partitioning patterns and functionally equivalent organ-categories. *New Phytol*. 171: 27-40.
- Niklas, K.J., J.J. Midgley and B.J. Enquist (2003). A general model for mass-growth-density relations across tree dominated communities. *Evol. Ecol. Res*. 5: 459-468.
- Niklas, K.J. (1993). The allometry of plant reproductive biomass and stem diameter. *Am. J. Bot*. 80(4): 461-467.
- Ohmann, L.F., D. F. Grigel and R. Brandar (1976). Biomass estimation for five shrubs from northeastern Minnesota. USDA Forestry Service Res. Note NC 133.
- Ohmann, L.F., D.F. Grigel, and L.L. Rogers (1991). Estimating plant biomass for undergrowth species in northeastern Minnesota forest communities. US Dept. Agriculture Forest Service, North Central Experimental Station, St. Paul, MN.
- Padrón, E.V. and R.M. Navarro (2004). Estimation of aboveground biomass in naturally occurring populations of *Prosopis pallida* (H. & B.K. Willd.) H.B.K. in the north of Peru. *J. Arid Environ*. 56: 283-292.
- Pastor, J., J.D. Abor and J.M. Melillo (1984). Biomass prediction using generalized allometric regression for some Northeast tree species. *Forest Ecology & Management* 7: 265-274.
- Pereira, J.M.C., N.M.S. Sequeira and M.B. Carreiras (1995). Structural properties and dimensional relations of some Mediterranean shrub fuels. *Int. J. Wildl. Fire* 5: 35-42.
- Pokorný, R and I. Tomášková (2007). Allometric relationship for surface area and dry mass of young Norway spruce aboveground organs. *J. For. Sci*. 53(12): 548 – 554.
- Rittenhouse, L.R. and F.A. Sneva (1977). A technique for estimating big sagebrush production. *J. Range Management*. 30: 68-70.
- Roussopoulos, P.J. and R.M. Loomis (1979). Weights and dimensional properties of shrubs and small trees of the Great Lakes conifer forest. U.S. Forest Service. Res. Pap. NC. 178.

- Schreuder, H.T., W.T. Swank (1971). A comparison of several statistical models in forest biomass and surface area estimates. In: Young, H.E (ed.) *Forest Biomass Studies*. IUFRO, section 25: Growth and Yield. Misc. Publ. 132. Orono, ME: University of Maine: 125-138.
- Singh, M. (1975). The theory of production method. *Tropical Ecology* 16: 14-27.
- Smith, W.B. and G.J. Brand (1983). Allometric biomass equations for 98 species of herbs, shrubs and small trees. Res. Note Nc-299. North Central For. Exp. Station Forest Service. US Dept. agric. St. Paul Minnesota. Pp. 1-8.
- Sood, R. and S. Bhatia (1993). Biomass production and partitioning of *Prosopis juliflora* on a degraded ravenous site. In: J.C. Tewari, N.M. Pasiecznik, L.N. Harsh, and P./J.C. Harris, Eds.. *Prosopis species in the Arid and Semi-arid Zones of India*. Central Arid Zone Research Institute, Jodhpur, Rajasthan, India. Nov. 21-23, 1993. The *Prosopis* Society of India and the Henry Doubleday Research Association, pp. 51-54.
- Sprugel, D.G. (1983). Correcting for bias in log-transformed allometric equations. *Ecology* 64: 209-210.
- Swank, W.T. and H.T. Schreuder (1974). Comparison of three methods of estimating surface area and biomass for a forest of young eastern white pine. *For. Sci.* 20: 91-100.
- Tanaka, K., F. Ryo, H. Daisuke, K.J. Jawa, T. Sota, S. Katsutoshi and N. Ikuo (2009). Allometric equations for accurate estimation of above-ground biomass in logged-over tropical rainforests in Sarawak, Malaysia. *J. For. Res.* 14 (6): 365 – 372.
- Wang, C. (2006). Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. *Forest Ecology Management* 22 (1-3): 9-16.
- Whittaker, R.H. and G.M. Woodwell (1968). Dimensions and production relations of trees and shrubs in the Brookhaven forest. *J. Ecol.* 56: 1-25.
- Yanale, D.O. and H.V. Wiant (1981). Estimation of plant biomass based on the allometric equation. *Can. J. For. Res.* 11: 833-834.
- Young, H.E. (1976). A summary and analysis of weight table studies. In: Young, H.E. (ed.). *Oslo Biomass Studies*. Orono, ME: University of Maine. 251 – 282.
- Zianis, D. and M. Mencuccini (2003). Aboveground biomass relationships for beech (*Fagus moesiaca* Cz.) trees in Vermio Mountain, Northern Greece, and generalized equations for *Fagus* sp. *Ann. For. Sci.* 60: 439 – 448.

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