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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*.

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 ± 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:

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

Where, di is the diameter of i^{th} stem. The material of each plant was separated into two components a) Leaves + pods + twigs of ≤1 cm, and b) Stem + twigs > 1cm, 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^{o}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 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 ± 12.40 % of the total fresh phytomass and the component 'b' composed of woody material was found to be around 79.34 ± 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 ± 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 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 (m^2)	ST	BA (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 ± SE	2.703 ± 0. 12	6.85 ± 1.38	41.72 ± 2.63	2.90 ± 0.23	1.30 ± 0.40	23.93 ± 9.37	66.29 ± 24.4	90.16 ± 33.67	47.50 ± 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 (dm^2); CR, Crown Cover (m^2). *, Component A, Twigs < = 1 cm in diameter + leaves + pods, etc; **, Component B, Stems + twigs > 1cm 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-colinearity 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 = b X) 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							
BA	0.914	0.951	BA						
CR	0.889	0.962	0.962	CR					
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

$r_{(p < 0.05)} = 0.632$
$r_{(p < 0.01)} = 0.765$
$r_{(p < 0.001)} = 0.872$

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.

Ln Biomass Comp. B (kg) = 1.279 – 0.519 Height (m) - 0.272 Crown Cover (Sq. m) + 0.511 SD (cm) +
(FW) (t = -1.50) (t = -2.194) (t = -2.64) (t = 4.601)
($p < 0.004$) ($p < 0.08$) ($p < 0.046$) ($p < 0.006$)
0.1.472 Basal Area (dm^2) ± 0.2522
(t = 2.95)
($p < 0.032$) F = 83.76 ($p < 0.0001$), $R^2 = 0.993$; Adjusted $R^2 = 0.985$

Ln TFM (kg) FW = 1.336 - 0.550 Height (m) – 0.0320 Crown Cover (Sq. m) + 0.567 SD (cm) +
(t = 5.948) (t = -2.7021) (t = -3.603) (t = 5.927)
($p < 0.002$) ($p < 0.0431$) ($p < 0.015$) ($p < 0. 002$)
0.905 Basal Area (dm^2) ± 0.2171
(t = 3.664)
($p < 0.015$) F =127.032 ($p < 0.0001$), $R^2 = 0.990$; Adjusted $R^2 = 0.982$

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

Parameters (Y / X)	a	b	r^2	Adj. r^2	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	**0.952**	**0.946**	**159.893**	0.0001	6.8625
Biomass Component B / BA	- 12.503 t= -1.462 p < 0.182	61.956 t = 12.432 p < 0.00001	**0.951**	**0.945**	**154.570**	0.00001	18.162
TFM / BA	- 18.961 t = -1.709 p < 0.126	85.730 t = 13.332 p < 0.0001	**0.957**	**0.952**	**177.732**	0.00001	23.437
DW / BA	- 8.616 t = -1.449 p < 0.185	40.550 t = 11.702 p < 0.00001	**0.945**	**0.938**	**136.928**	0.00001	12.629
Biomass Component A / CR	- 6.203 t = -1.832 p < 0.104	0.722 t= 12.019 p < 0.00001	**0.948**	**0.941**	**144.454**	0.00001	7.2016
Biomass Component B / CR	- 12.812 t= -1.832 p < 0.104	1.896 t= 14.416 p < 0.00001	**0.963**	**0.958**	**207.563**	0.00001	15.762
TFM / CR	-19.064 t = -1.923 p < 0.091	2.618 t = 14.865 p < 0.00001	**0.965**	**0.961**	**221.563**	0.00001	21.080
DW / CR	- 8.923 t = -1.781 p < 0.113	1.244 t = 13.991 p < 0.00001	**0.961**	**0.956**	**195.737**	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_e 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) 0970 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	0.1.527 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)	
$DW = -22.526 \quad -9.942H + 13.478\ SD \pm 22.839$ $t = -1.16 \quad t = -0.54 \quad t = 2.36$ $p< 0.297 \quad p < 0.618 \quad p < 0.05$ $R^2 = 0.842$; Adj. $R^2 = 0.797$; $F = 18.66$ ($p < 0.002$)	EQ. # 1
$DW = 5.906 + -9.976\ H + 50.334\ BA \pm 12.106$ $t = 0.473 \quad t = 1.306 \quad t = 6.143$ $p < 0.\ 651 \quad p < 0.233 \quad p < 0.0001$ $R^2 = 0.956$; Adjusted $r^2 = 0.943$; $F = 75.36$ ($p < 0.0001$)	EQ. # 2
$DW = -2.121 \ - 4.554\ H + 1.376\ CR \ \pm 10.961$ $t = -0.202 \quad t = -0.745 \quad t = 6.897$ $p < 0.845 \quad p < 0.480 \quad p < 0.001$ $R^2 = 0.964$; Adjusted $R^2 = 0.953$; $F = 92.70$ (p , 0.0001)	EQ. # 3
$DW = - 5.505 – 1.235\ SD + 44.760\ BA \pm 13.369$ $t = - 0.527 \quad t = -0.373 \quad t = 3.771$ $p < 0.605 \quad p < 0.720 \quad p = 0.007$ $R^2 = 0.\ 946$; Adjusted $R^2 = 0.930$ $F = 61.67$ ($p < 0.0001$)	EQ. # 4
$DW = 1.884 – 4.358\ SD + 1.700\ CR \ \pm 9.7356$ $t = 0.232 \quad t = -1.605 \quad t = 5.746$ $p < 0.823 \quad p < 0.152 \quad p = 0.001$ $R^2 = 0.971$; Adjusted $R^2 = 0.963$; 116.44 ($p < 0.0001$)	EQ. # 5
$DW = -9.765 + 16.308\ BA + 0.767\ CR \pm 1.581$ $t = - 2.154 \quad t = 1.700 \quad t = 2.627$ $P < 0.068 \quad p < 0.133 \quad p < 0.034$ $R^2 = 0.972$; Adjusted $R^2 = 0.964$; $F = 122.42$	EQ. # 6
$DW = 5.728 – 13.972\ H + 2.381\ SD \ + 46.139\ BA \pm 12.739$ $t = 0.436 \quad t = -1.3098 \quad t = 0.567 \quad t = 4.062$ $p< 0.678 \quad p < 0.239 \quad p < 0.591 \quad p < 0.007$ $R^2 = 0.958$; Adjusted $R^2 = 0.937$; $F = 45.482$ ($p < 0.0001$)	EQ. 7
$DW = -1.0270 + 5.470\ H – 6.476\ SD + 1.763\ CR \ \pm 10.205$ $t = -0.105 \quad t = 0.608 \quad t = -1.440 \quad t = 5.391$ $p < 0.\ 920 \quad p < 0.565 \quad p < 0.0200 \quad p < 0.002$ $R^2 = 0.973$, Adjusted $r^2 = 0.959$; $F = 71.982$ ($p < 0.0001$)	EQ. # 8
$DW = 6.589 – 6.769\ SD + 24.793\ BA + 1.228\ CR \ \pm 4.6996$ $t = 1.675 \quad t = -4.977 \quad t = 5.077 \quad t = 7.343$ $p < 0.\ 145 \quad p < 0.003 \quad p < 0.002 \quad p < 0.00001$ $R^2 = 0.995$ Adjusted $r^2 = 0.992$; $F = 367.00$ ($p < 0.0001$)	EQ. 9
Fuel wood (kg) DW = 7.653 – 1.738 Height (m) – 6.1666 SD (cm) + 25.516 Basal area dm^2) + ($t =1.\ 499$) ($t = - 0.376$) ($t= - 2.834$) ($t = 4.453$) ($p < 0.194$) ($p < 0.723$) ($p < 0.037$) ($p < 0.006$) 1.194 Crown cover (sq. m) ± 4.9367 ($t = 5.912$) ($P < 0.002$) $F =235.882$ ($p < 0.00001$); $R^2 = 0.995$, Adjusted $R^2 = 0.991$	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*.

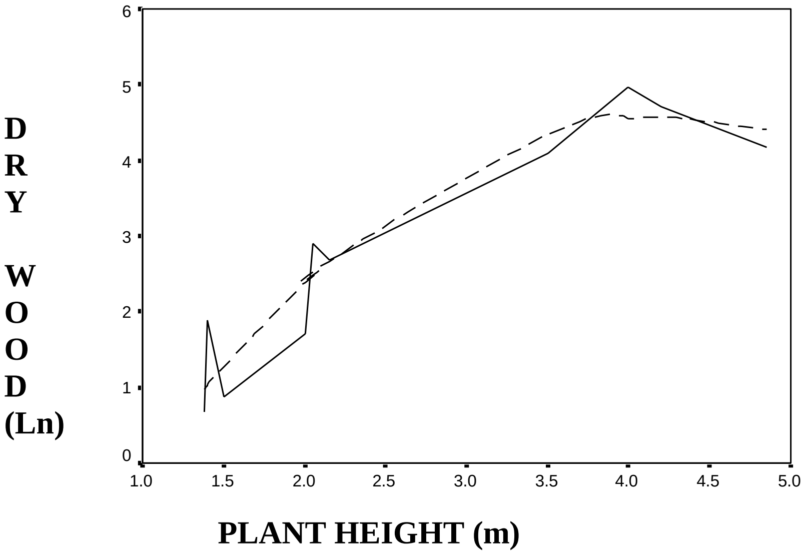
DRY FIREWOOD (Ln DW)	
Ln DW = 0.627 - 0.221 H + 0.414 SD ± 0.3852 t = - 1.857 t =- 0.688 t = 4.300 p , 0.106 $p < 0.514$ $p < 0.004$ R^2 = 0.953; Adjusted R^2 = 0.940; F = 71.116 ($p < 0.0001$)	EQ.# 1
Ln DW = 0.8920 + 0.280 H + 0.9570 BA ± 0.5048 t = 1.713 t= 0.880 t = 2.802 $P < 0.131$ $p < 0.408$ $p < 0.026$ R^2 = 0.919; Adjusted R^2 = 0.896; F = 39.964 ($p < 0.0001$)	EQ. # 2
Ln DW = 0.6210 + 0.4850 H + 0.0224 CR ± 0.5087 t= 1.141 t = 1.529 t = 2.168 $p < 0.291$ $p < 0.170$ $p < 0.067$ R^2 = 0.898; Adjusted R^2 = 0.869; F = 30.74 ($p < 0.0001$)	EQ. # 3
Ln DW = 0.663 + 0.2530 SD + 0.3690 BA ± 0.3657 t = 2.318 t = 2.795 t = 1.137 $p < 0.054$ $p < 0.027$ $p < 0.293$ R^2 = 0.958; Adjusted R^2 = 0.946; F = 79.304 ($p < 0.0001$)	EQ. # 4
Ln DW = 0.3840 + 0.3870 SD - 0.0041 CR ± 1.42 t= 1.162 t = 3.519 t = 0.342 $p < 0.283$ $p < 0.010$ $p < 0.743$ R^2 = 0.951; Adjusted R^2 = 0.937; F = 67.56 ($p < 0.0001$)	EQ. # 5
Ln DW = 1.291 + 1.040 BA + 0.006066 CR ± 0.5266 t = 5.82 t = 1.973 t = 0.378 $p < 0.001$ $p < 0.089$ $p < 0.716$ R^2 = 0.912; Adjusted R^2 = 0.887; F = 36.430 ($p < 0.0001$)	EQ. # 6
Ln DW = 0.868 – 0.256 H + 0.319 SD + 0.394 BA ± 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^2 = 0.962; Adjusted R^2 = 0.943; F = 50.53 ($p < 0.0001$)	EQ. # 7
Ln DW = 0.536 – 0.286 H + 0.498 SD + 0.0074 CR ± 0.4053 t = -0.1.38 t = -0.801 t = 2.790 t = -0.570 p < 0. 217 $p < 0.454$ $p < 0.032$ $p < 0.589$ R^2 = 0.956 Adjusted R^2 = 0.933; F = 42.95 ($p < 0.0001$)	EQ. # 8
Ln DW = 0.504 + 0.326 SD + 0.632 BA + 0.0161 CR ± 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^2 = 0.967 Adjusted R^2 = 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^2) ± 0.2921 (t = 2.560) ($p < 0.051$) F = 63.65 ($p < 0.0001$), R^2 = 0.982; Adjusted R^2 = 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) = $1.1668.\text{Height}^{3.0505} \pm 0.57398$ 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) = $1.5852.e^{\mathbf{0.3512\ (Stem\ diameter)}} \pm 0.37233$ 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) = $0.7738.\text{Stem Diameter}^{1.8587} \pm 0.46511$ 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) = $27.7928.\text{Basal Area}^{0.9961} \pm 0.48027$ 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) = $-1.9301 + 0.7275\,(\text{Crown}) + 0.0046\,(\mathbf{Crown})^2 \pm 9.6268$ 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) = $-8.9229 + 1.2435\,\text{Crown} \pm 10.6518$ 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 (D2.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 (D2.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.

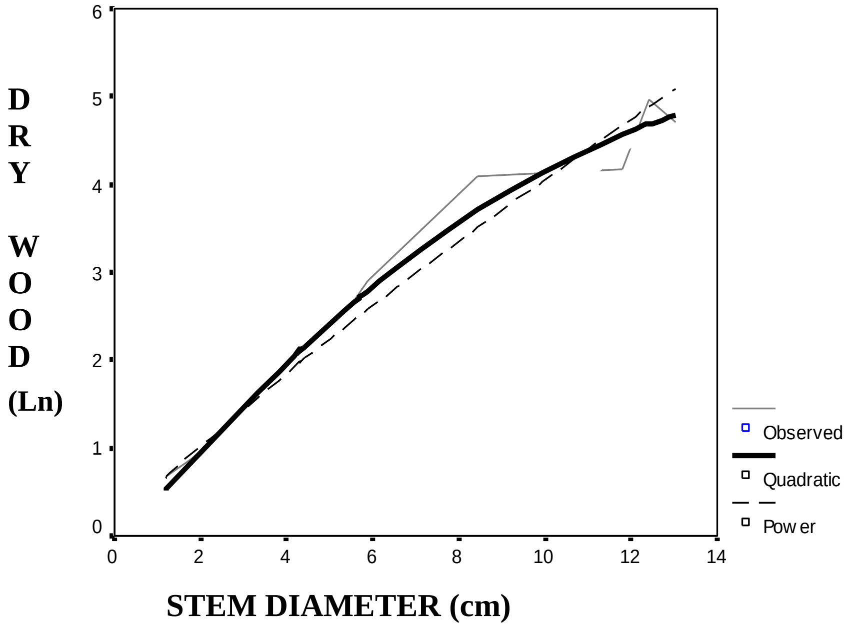


Quadratic Curve:
R = 0.956
$R^2 = 0.915$
Adjusted $R^2 = 0.890$
F = 37.4597 ($p < 0.0002$)
a = -3.366757 ($p < 0.0358$)
b = 3.76205 ($p < 0.0077$)
c = - 0.44536 ($p < 0.0332$)
SE = 0.51995

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*.

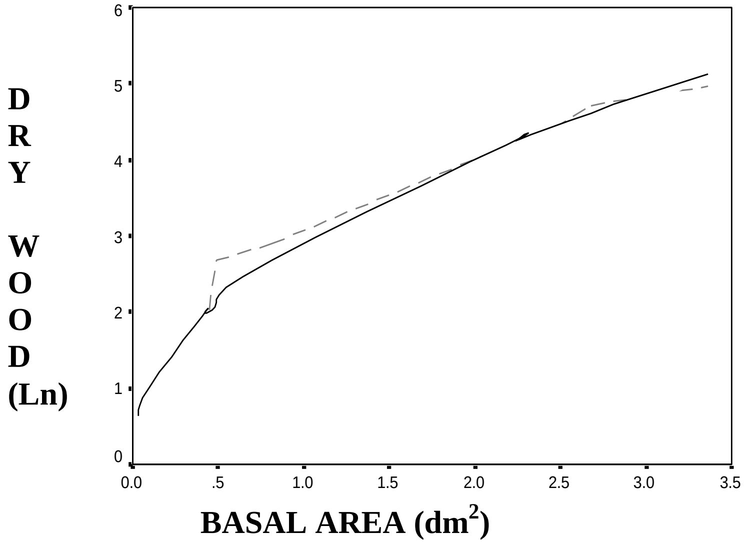
FUEL WOOD – Log $_e$ Transformed (Ln DW)	
Dry Fuel wood (kg) = -3.36676 + 3.76205 (Height) - 0.44536 $(\text{Height})^2$ ± 0.51995 t = -2.592 t = 3.700 t = -2.645 $p < 0.0358$ $p < 0.0077$ $p < 0.0332$ $R^2 = 0.915$; Adjusted $R^2 = 0.890$; F = 37.46 ($P < 0.0001$)	Quadratic Curve
Dry Fuel wood (kg)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



Quadratic Curve:
R = 0.986
R^2 = 0.9730
Adjusted R^2 = 0.966
F = 127.95 (p, 0.00001)
a = - 0.1879 ($p< 0.5709$)
b = 0.6085 ($p< 0.0070$)
c = -0.0174 ($p< 0.0420$)
SE = 0.29024

Power Curve
R = 0.991
R^2 = 0.981
Adjusted R^2 = 0.978
F = 405.56 ($p< 0.00001$)
a = 0.566843 ($p< 0.00001$)
b = 0.854925 ($p< 0.0001$)
SE = 0.10319

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

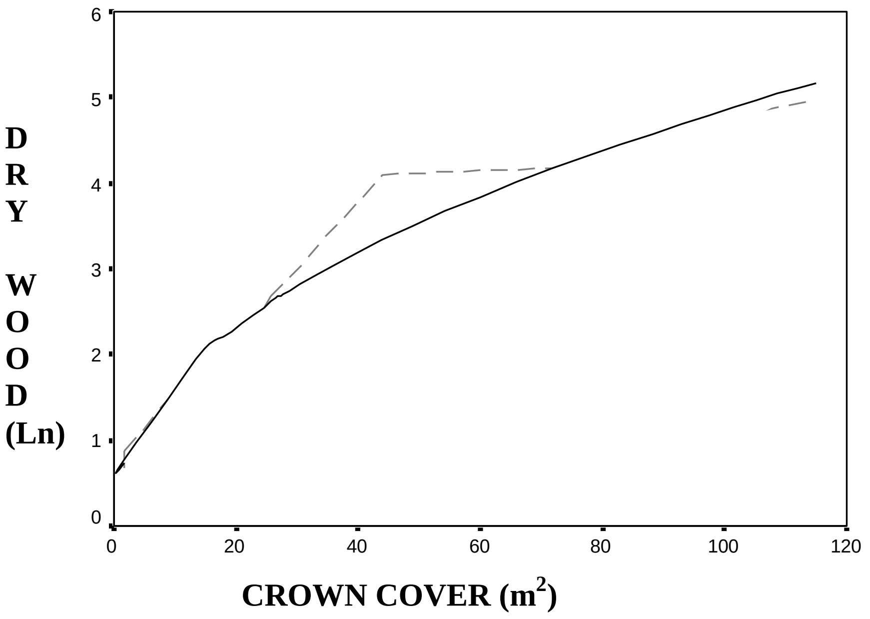


Power Curve:
R = 0.995
R^2 = 0.986
Adjusted R^2 = 0.969
F = 286.599 ($p< 0.0001$)
a = 2.94244 ($p < 0.0001$)
b = 0.45756 ($p < 0.0001$)
SE = 0.12228

Fig.3. Relationship between $\log_e$ dry wood (Kg per plant) and plant Basal area (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*, P*alaquinum* and *Shorea of Dipterocap* forests in east Kalimantan, Indonesia with a log-log model: log e (Total aboveground biomass) = c + a log e (DBH) (Basuki *et. al*. , 2009). The diameter of the longest stem in several species was reported to 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 *Jetropha 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); Pokorny and Tamášková (2007) in young Norway spruce; Achten *et al.* (2010) in *Jetropha curcas* seedlings).



Power Curve:
R = 0.985
R^2 = 0.970
Adjusted R^2 = 0.966
F = 257.47 ($p < 0.0001$)
a = 0.593135 ($p < 0.0001$)
b = 0.456330 ($p < 0.0001$)
SE = 0.12879

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

Sood and Bhatia (1993) presented equations top 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 n D^2H ($r^2 = 0.990$) [Sood & Bhatia, 1993]
Total weight (kg) = 0.1806 + 0.3383 n D^2 H ($r^2 = 0.990$) [Sood & Bhatia, 1993]

Single stemmed plants:

Stem weight (kg) = -0.0287 + 0.2284 n D^2H ($r^2 = 0.970$) [Sood & Bhatia, 1993]
Total weight (kg) = 0.0851 + 0.4705 n 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 $^{0.854925}$ ± 0.10319; R^2 = 0.981, F = 405.56 ($p < 0.0001$)
Ln Dry fire wood = 2.94244. Basal Area $^{0.457560}$ ± 0.12228; R^2 = 0.0.969, F = 286.599 ($p < 0.0001$)
Ln Dry fire wood = 0.593135. Crown Cover $^{0.456330}$ ± 0.12879; $\mathbf{R^2}$ = 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. $[n (D^2)H]^{0.350406}$ ± 0.14566 ; R^2= 0.961; F = 199.54 ($p < 0.0001$)
Ln DW = 2.049506. $[BA.H]^{0.352233}$ ± 0.14446; R^2= 0.962; F = 203.02 ($p < 0.0001$)

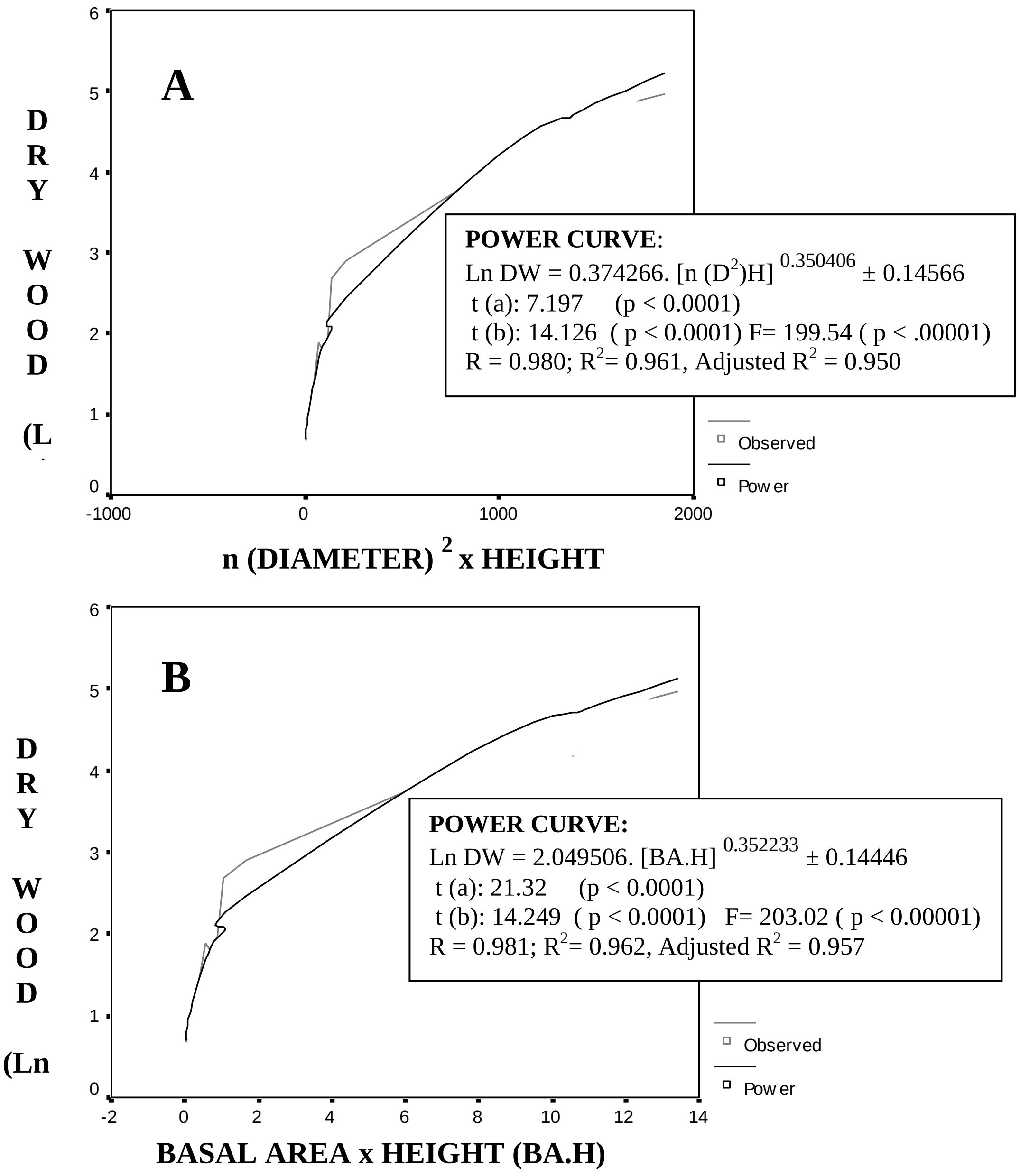


Fig.5. Relationship between dry firewood component (Ln DW) and multiplicative morphometric parameters in *P. juliflora*. Solid lines represent the fitted power curve.

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).

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