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Development of Volumetric Equation and Volume Table for *Casuarina* Species

R.P. Gunaga, L.K. Behera, S.K. Sinha, A.A. Mehta, N.S. Thakur, Y.A. Garde[1], J.B. Bhusara and R.L. Sondarva

College of Forestry, [1]NM College of Agriculture,Navsari Agricultural University, Navsari-396 450, India
E-mail: rpgunaga@nau.in

Abstract: *Casuarina* is one of the multipurpose tree species grown in different parts of the country. In the present study, 1108 casuarina trees were selected in 12 different diameter classes from D_1 (10 to 45 cm) to D_2 (45 to 70 cm). The whole data set was divided into two *viz.,* 10 to 45 cm and 45 to 70 cm to obtain precision equation. The calculated volume and HD^2 Index was used in regression equation. The volumetric equation (V_1) = 0.00005 x HD^2 + 0.0196 can be used to assess the volume of standing *Casuarina* trees having 10 to 45 cm DBH; whereas, for higher diameter classes, *i.e.,* trees having 45 to 70 cm DBH, equation V_2 = 0.00003 x HD^2 + 0.6874 can be used. For farmers point of view, volume table was developed using these two formulae for easy understanding and quick estimation. Further, foresters, wood merchants, wood industrial persons can also utilize these volumetric equations as well as volume table for estimating tree volume.

Keywords: *Casuarina* species, Growth, Volume, Regression equation, Volume table

Casuarina equisetifolia L. (Family Casuarinaceae) is widely planted throughout the tropics, especially to provide timber whilst growing on poor sandy soils near the coast and thus also providing shelter and protection for the soil. The tree fixes atmospheric nitrogen and is able to grow vigorously on barren, polluted sites and thrive in deep sandy soils. It is therefore often planted for reclaiming and improving the land (Nicodemus 2009). The wood is used for house posts, rafters, electric poles, tool handles, oars, wagon wheels and mine props. The wood is used to produce paper pulp using neutral sulphate and semi-chemical processes, and as a raw material for rayon fibres. Calorific value of the wood is about 5,000 kcal/kg and wood ignite readily even when it green, and ashes retain heat for longer periods; moreover, it produces high quality charcoal (Warrier et al 2014). It is estimated that about 500,000 ha are planted with Casuarina in the coastal states of Andhra Pradesh, Orissa, Tamil Nadu and the Union Territory of Puducherry (Nicodemus 2009). Therefore, it is one of the commercial multipurpose tree species suitable for growing in different land use systems including agroforestry, avenue tree, green belts (Nicodemus 2009, Gurumurthi and Subramanian 1998).

Casuarina equisetifolia and *C. junghuhniana* are commercial exotic tree species introduced to India and is grown in different ecological conditions (Amanulla et al 2001, Warrier et al 2014). In the beginning, species was introduced mainly to the coastal belt of different places. Even, old casuarina plantations are still maintained near the sea-coasts in different parts. Due to its pulpwood quality, genetic evaluation has been carried out in different parts of the country. At present, fast growing genotypes/clones and hybrids of *Casuarina equisetifolia x C. junghuhniana* are also planted in different parts of the country and farmers are gaining more yield and higher economic returns from this crop (Amanulla et al 2001, Nicodemus 2009). It is remarkably well suited for boundary planting and shows promise as an agroforestry species for arid and semi-arid areas. Due to its fast-growing nature and local demand for pole and pulpwood, Gujarat farmers are growing this plant in their farmlands. Further, local industries *viz.,* paper industries (for pulp wood) and construction industries (for pole) are procuring raw materials from the farm field. The present study focused towards development of volumetric equation and constructing volume table for this species. This information is helpful for farmers, wood merchants and foresters and industrial staff to quickly asses the volume of standing trees.

MATERIAL AND METHODS

The present study was carried out in different parts of south Gujarat (Agro-ecological zone, *i.e.,* Heavy rainfall zone AES-III), India. In order to develop volumetric equation and volume table, Casuarina trees belonged to different diameter classes *viz.,* D1: 10-15 cm, D2: 15-20 cm, D3: 20-25 cm, D4: 25-30 cm, D5: 30-35 cm, D6: 35-40 cm, D7: 40-45 cm, D8: 45-50 cm, D9: 50-55 cm, D10: 55-60 cm, D11: 60-65 cm and D12: 65-70 cm, were considered and various biometric parameters such as tree height (m), DBH (cm), Mid- diameter (cm), clear bole height (m) and crown height (m) were recorded. Further, using these data base, Form Quotient and

Volume (m^3) of standing trees were estimated (Gunaga et al 2021). Trees located in the conventional plantation, coastal belt, avenue/road-side plantation, agroforestry landscape were used. After compiling all the database and arrangement, data were subjected to statistical analysis and volumetric equation was developed using regression equation following standard method.

RESULTS AND DISCUSSION

In the present study, about 1300 trees belonged to different diameter classes from D1: 10-15 cm to D12: 65-70 cm were selected in different parts of south Gujarat including trees established in and around the NAU campus, and coastal belts. After processing the data, some of the out-layer trees were removed from the data base and total 1108 trees of 12 different diameter classes were used for assessment (Table 1). The quotient [FQ=DBH/MD] and volume [$V=\pi D^2/4 \times H \times FQ$] were estimated using selected 1108 trees. The overall mean clear bole height and crown length recorded in different diameter classes (Fig. 1). The data were subjected to regression equation as per standard statistical procedure and volumetric equation were developed (Table 2). The overall growth showed that diameter increased with increase in the height and the overall tapering was 0.6 (FQ) among sampled trees. For estimation of volumetric equation, index of HD^2 (Height, H x Diameter^2, D^2) was calculated using individual tree height and respective diameter. Then, this data was used along with estimated volume using regression equation with linear model (Fig. 2). The data of volume and HD^2 Index of all the trees belonged to 12 diameter classes were used to fit volumetric equation using regression model and the following equation was developed.

$V = 0.00004 \times HD^2 + 0.1446$ ($R^2 = 0.932$) ------------ Type-1

Where, V is volume (m^3), H is tree height (m), D is DBH (cm) and 0.1446 is constant value

There was a huge difference at lower diameter classes by comparing original calculated volume with equation type-1. Therefore, to reduce the error, data were split into two large data sets. The first set of data from diameter classes D1 to D7 were used for estimation of separate volume and the second set of data belonged to diameter classes- D8 to D12 were used for estimation of volume. Regression equations developed using first data set (D1 to D7 *i.e.,* 10 to 45 cm; Fig. 2a) and second data set (D8 to D12 *i.e.,* 45 to 70 cm; Fig. 2b) are given as Type-2 and Type-3, respectively and volumetric equations are given below:

$V_1 = 0.00005 \times HD^2 + 0.0196$ ($R^2 = 0.919$) ------------ Type-2

where 0.0196 is constant value

$V_2 = 0.00003 \times HD^2 + 0.6874$ ($R^2 = 0.712$)------------ Type-3

where 0.6874 is constant value

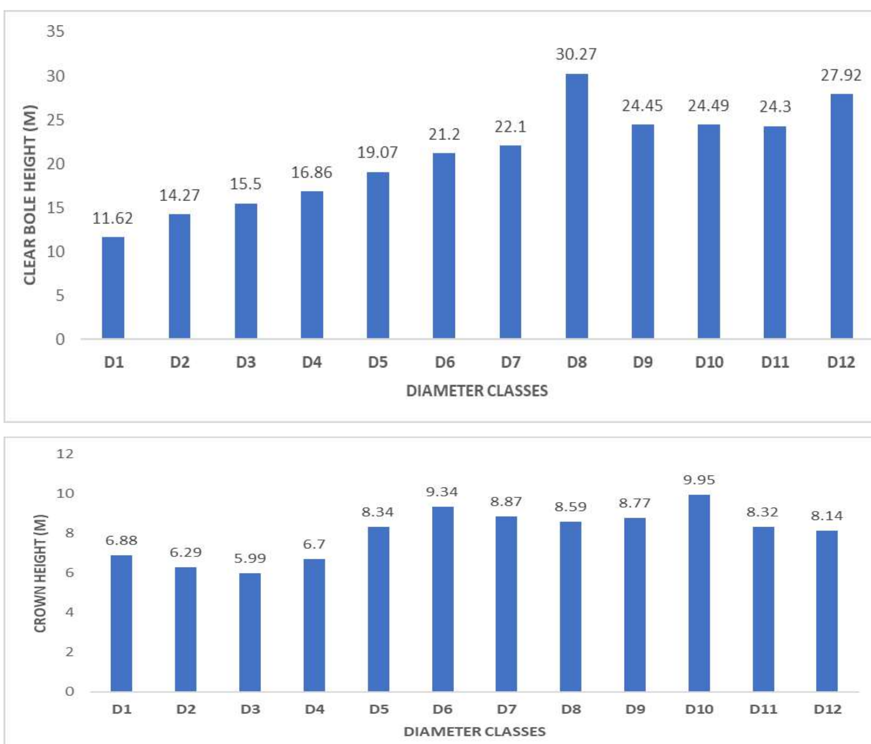

Fig. 1. Average clear bole height and crown height of *Casuarina* trees across different dimeter classes (N=1108)

Estimated values using Type-1, Type-2 and Type-3 volumetric equations were validated with actual volume [$V=\pi D^2/4 \times H \times FQ$] calculated using field data. Result showed that, among three volumetric equations, Type 2 and Type 3 showed better comparison than Type 1. Therefore, Type-2, volumetric equation estimated using $V_1 = 0.00005 \times HD^2 + 0.0196$ can be used for estimating volume of standing *Casuarina* trees belonged to 10 to 45 cm DBH. Furthermore, for *Casuarina* trees having 45 to 70 cm DBH, volumetric equation estimated using $V_2 = 0.00003 \times HD^2 + 0.6874$ can be used. Furthermore, by using these formulae, volume table was constructed with different diameter and height ranges

Table 1. Biometric parameters of standing *Casuarina* trees across different diameter classes

Diameter classes		Sample size (N)	DBH (cm)	Mid-dia. (cm)	Height (m)	FQ	Volume (m^3)
D1: 10 to 15 cm	Min	173	10.25	5.40	8.40	0.09	0.01
	Max		15.00	14.90	27.30	1.05	0.39
	Mean		12.68	9.13	16.54	0.71	0.16
D2: 15 to 20 cm	Min	132	15.10	8.20	10.50	0.51	0.14
	Max		20.00	17.30	29.20	0.94	0.63
	Mean		17.69	12.25	20.39	0.69	0.35
D3: 20 to 25 cm	Min	169	20.05	10.30	13.70	0.47	0.28
	Max		25.00	20.80	30.80	0.95	1.18
	Mean		22.75	14.29	21.81	0.63	0.56
D4: 25 to 30 cm	Min	180	25.05	12.60	15.20	0.46	0.41
	Max		29.95	22.10	33.10	0.82	1.50
	Mean		27.44	16.21	23.74	0.59	0.84
D5: 30 to 35 cm	Min	144	30.10	13.10	17.20	0.42	0.64
	Max		34.95	28.50	40.50	0.88	2.93
	Mean		32.48	18.72	26.54	0.58	1.29
D6: 35 to 40 cm	Min	129	35.05	14.80	19.70	0.40	0.94
	Max		40.00	37.50	41.50	1.00	4.56
	Mean		37.53	22.03	29.49	0.59	1.95
D7: 40 to 45 cm	Min	73	40.10	15.80	18.30	0.37	0.97
	Max		45.00	36.60	41.30	0.85	4.10
	Mean		42.49	23.52	30.42	0.55	2.42
D8: 45 to 50 cm	Min	40	45.05	19.50	26.20	0.40	2.16
	Max		49.85	33.40	45.50	0.74	5.54
	Mean		47.35	25.31	33.71	0.53	3.20
D9: 50 to 55 cm	Min	27	50.60	20.60	26.30	0.39	2.23
	Max		54.95	36.70	43.30	0.67	6.80
	Mean		52.98	27.54	32.56	0.52	3.76
D10: 55 to 60 cm	Min	21	55.40	20.50	27.10	0.35	2.80
	Max		59.95	38.10	45.10	0.66	7.11
	Mean		57.63	28.40	34.33	0.49	4.45
D11: 60 to 65 cm	Min	11	60.30	20.70	27.40	0.34	2.88
	Max		64.75	35.40	43.30	0.56	7.65
	Mean		62.23	27.17	33.93	0.44	4.58
D12: 65 to 70 cm	Min	9	65.95	23.70	31.10	0.36	4.30
	Max		69.50	31.30	41.70	0.45	7.11
	Mean		67.79	27.97	36.66	0.41	5.48
Total		1108					

DBH=Diameter at breast height; FQ= Form Quotient

Fig. 2a

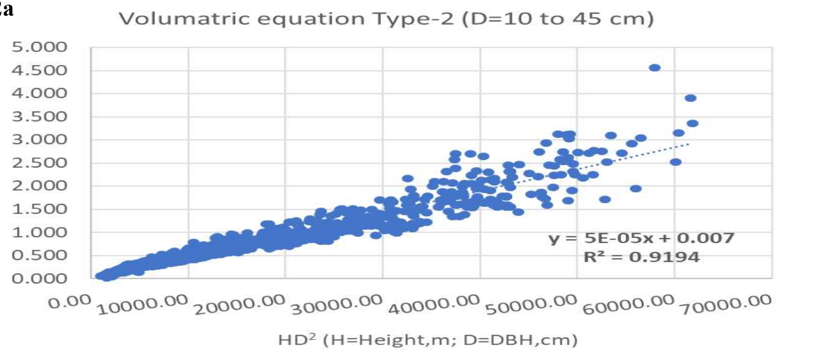

Fig. 2b

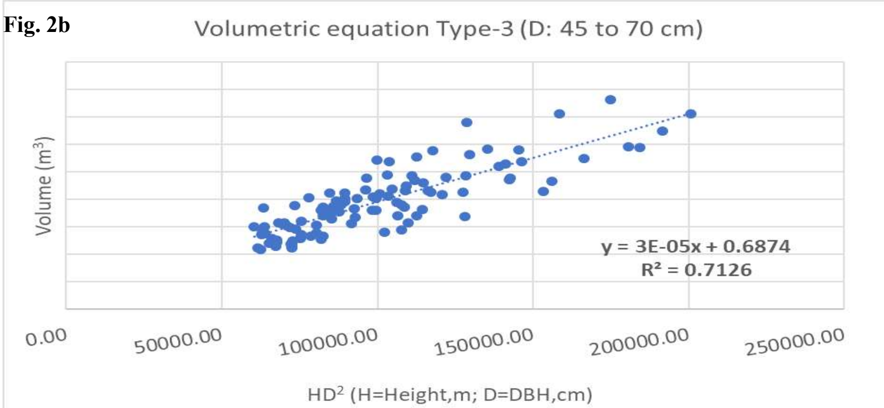

Fig. 2. Regression equations developed using HD^2 values for assesment of volume of standing Casuarina trees (2a- Trees having 10-45 cm DBH; 2b- Trees having 45-75 cm DBH)

Table 2. Details of volumetric model estimated using HD^2 and regression statistical parameters in *Casuarina* sp

Formula type model form	Sample size (N)	Regression constant (a)	Regression coefficient (b)	Multiple R	R^2	Adjusted R^2	SE (±)	F value	Sign. level
Type-2 $Y = a + b\ HD^2$	1000	0.0196	0.00005	0.962	0.925	0.925	0.216	12339.91	<0.001
Type-3 $Y = a + b\ HD^2$	108	0.6874	0.00003	0.844	0.712	0.709	0.646	262.80	<0.001

Table 3. Local volume table developed for Saru (*C. equisetifolia*) trees

DBH (cm) (Dia. range and mid value)	Mid height/ Mid diameter	Height in m (Height range and mid value)											
		8-11	11-14	14-17	17-20	20-23	23-26	26-32	32-35	35-38	38-41	41-44	44-47
		9.5 m	12.5 m	15.5 m	18.5 m	21.5 m	24.5 m	27.5 m	33.5 m	36.5 m	39.5 m	42.5 m	45.5 m
Volume for trees having diameter (DBH) of 10 cm to 45 cm													
10-15	12.5 cm	0.094	0.117	0.141	0.164	0.188	0.211	0.234					
15-20	17.5 cm	0.165	0.211	0.257	0.303	0.349	0.395	0.441					
20-25	22.5 cm		0.336	0.412	0.488	0.564	0.640	0.716	0.868				
25-30	27.5 cm			0.606	0.719	0.833	0.946	1.059	1.286				
30-35	32.5 cm				0.997	1.155	1.314	1.472	1.789	1.947	2.106	2.264	2.423
35-40	37.5 cm				1.320	1.531	1.742	1.953	2.375	2.586	2.797	3.008	3.219
40-45	42.5 cm				1.690	1.961	2.232	2.503	3.045	3.316	3.587	3.858	4.129
Volume for trees having diameter (DBH) of 45 -70 cm													
45-50	47.5 cm						2.346	2.549	2.955	3.158	3.361	3.564	3.767
50-55	52.5 cm						2.713	2.961	3.457	3.705	3.954	4.202	4.450
55-60	57.5 cm							3.415	4.010	4.308	4.605	4.903	5.200
60-65	62.5 cm							3.910	4.613	4.965	5.316	5.668	6.019
65-70	67.5 cm								5.266	5.676	6.087	6.497	6.907

(Table 3). Efforts were also made to develop volumetric and biomass equation among different tree species including *Casuarina* (Segura and Kanninen 2005, Tewari and Singh 2006, Warrier et al 2014, Thakur et al 2021). Yield table for stem wood of *Casuarina equisetifolia* (kg $tree^{-1}$) was worked out using volumetric equation, where HD^2 values are used at the time development of regression equation (Warrier et al 2014). In fact, data on predicted volume can also be used for assessment of tree biomass and yield table across different diameter classes (Dash et al 1999, Vidyasagaran and Paramathma 2014).

CONCLUSION

The regression analysis revealed that standing Casuarina trees can be estimated using following equations for different diameter classes *viz.,* $V_1 = 0.00005 \times HD^2 + 0.0196$ for trees having 10 to 45 cm DBH, and $V_2 = 0.00003 \times HD^2 + 0.6874$ for trees having 45 to 70 cm DBH. Therefore, farmers, foresters, wood merchants, wood industrial persons can utilize these volumetric equations for quick estimating volume of standing *Casuarina* trees.

AUTHORS CONTRIBUTION

Dr. A.A. Mehta and Dr. N.S. Thakur (Co-PI of this technical Programme) helped in technical aspects, Dr. Y.A. Garde, as Statistician helped in analyzing the data; J.B. Bhusara and R.L. Sondarva are SRFs and helped in field data collection

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