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Wood specific gravity of trees in hot semi-arid zone of India: diversity among species and relationship between stem and branches

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Wood specific gravity (WSG) is an important parameter in allometric equations for accurate estimation of C-sequestration and other functional properties of a tree. However, WSG of many tree species especially of arid and semiarid regions are poorly reported. Furthermore, identifying indirect methods for determination of stem WSG from branches may be rapid and relatively easy. Present study determined WSG of stem and branches of 21 tree species of hot semi-arid region of western India. Three individual trees from each species were randomly selected and sampled for determination of WSG of stem, primary and secondary branch. WSG varied significantly among the species ($F=42.83$, $p<0.001$) and sampling locations (stem and branches) ($F=29.43$, $p<0.001$). In stem (at DBH), it ranged from 0.42±0.04 to 0.74±0.03 among the species while within an individual tree it varied in order of stem> primary branch>secondary branch in most of the species. WSG of stem, and branches showed linear relationship and branches were found good predictor of stem WSG ($R^2> 0.83$).

Keywords: Wood specific gravity, tree biomass, arid region, branch

Increasing level of greenhouse gases (GHG) especially CO_2 is a major cause of global warming and climate change[1]. Tree plantation provides a potential mitigation option for arresting climate change by absorbing and converting CO_2 in to biomass through photosynthesis. However, direct method of estimating C-sequestration potential of a tree species is destructive, requiring harvesting of trees for determination of biomass and carbon. Cutting of tree in many countries is environmental issue and legally stopped especially in area with scarce vegetation like semi-arid and arid zones. Allometric equations and models provide better option for non-destructive indirect methods of tree biomass determination. These allometric equations have been reported more accurate when WSG is included into the equation[2]. The wood carbon content is also highly correlated with WSG[3]. Thus, estimation of tree biomass and C-content depends critically on reliable information about WSG of trees. Research is being carried out to quantify potential of tree based C-sequestration in arid and semi-arid regions[4]. However, data on WSG of tree species found and grown in arid and semi-arid environment is scarce leading to choice for destructive methods of estimation. WSG of tree varies with species and climatic condition as well[2,5,6]. The documentation of WSG of hot-semi arid zone of India is required for enhancing accuracy of allometric equation for better prediction of above ground biomass without harvesting of tree. Furthermore, variation in WSG has also been reported within the main stem and branches of a tree[7,8,9]. Determination of WSG of branches and developing relationship may be useful for avoiding tedious process of wood core sampling and tree harvesting. With this background, present study was undertaken to determine WSG of prominent tree species of hot semi-arid region and to develop relationship between WSG of stem and branches for indirect estimation of stem WSG.

Study was conducted at ICAR-Central Arid Zone Research Institute, Regional Research Station, Pali-Marwar under hot semi-arid zone of Rajasthan, India. The research station was spread over 4-5205 Áh4a9 ôl aEn -d7a 3n(Ád21 5ß7Á634 Á2N1Í67)mô above m2ea1n s7ea level. Most of land (>80%) was under rangeland management with large diversity of planted and naturally grown trees and shrub species. The region receives about 460 mm average annual rainfall with annual maximum mean temperature 42°C and minimum 7°C. The soil was shallow in depth (30-45 cm) with sandy clay loam to sandy loam texture, 1.35-1.5 Mg m^{-3} bulk density, 7.7-8.4 pH and 0.15-0.55 dSm^{-1} electrical conductivity. Wood samples were collected from three locations (main stem, primary branch and secondary branch) during July, 2016 from randomly selected three individual trees (with clear bole and similar diameter at breast height) of

21 tree species (>20 years old) at t h e s t a t ‑ 2 5 Á 4 0 2 5 Á 4 7 3 Á 1 .7 6 ÁN) 7 ô The wood cores from main stem was obtained at breast height (1.37 m above ground) while, in branches from basal portion (10 cm away from joint) by incremental borer and wood cutter respectively. The fresh weight, diameter and volume of the sampled wood core with bark were recorded on the day of sampling by digital calliper, electronic balance and water displacement method respectively[10].The wood cores were then dried in hot air oven at 100±2°C till constant weight was obtained followed by recording of dry weight, diameter and volume of wood samples[11]. The WSG of stem and branches had been reported as mean of three sampled tree of a species. Following equation was used for determination of WSG

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Where: Wd = Oven dry weight of wood sample and Vf = weight of water displaced by fresh wood sample or volume of fresh wood sample

Two-way analysis of variance (ANOVA) with species and location of wood sampling (DBH, primary branch and secondary branch) as factors was used to evaluate the effect of these on variation in WSG followed by Tukey HSD test at 95% confidence level to compare difference among the species and sampling locations.

Analysis of variance showed significant effect of species ($F= 42.83$, $p<0.001$) and sampling location (F 29.43, $p< 0.001$) on WSG indicating WSG depends on species as well as location within individual tree (Table 1 and Figure 1)[12]. Stem WSG varied greatly among the species, ranging from 0.42±0.04 to 0.74±0.03 (Table 2). Out of 21 species from seven families, most of species (12 species) had moderately heavy stem wood (WSG 0.66 - 0.75) (Figure 2). *Acacia nilotica var. cupressiformis (0.74±0.023)* followed by *Hardwickia binata (0.73±0.04)* and *Tamarindus indica (0.73±0.01)* showed highest WSG while *Cordia myxa L. (0.42±0.04)* followed by *Ailanthus excelsa Roxb. (0.43±0.04)* had lowest. The coefficient of variation (CV) for stem WSG within species ranged from 1.6% to 9.8% (Table 2). The low CV might be due to small sample size and less variability within the selected individuals because; individuals with similar DBH were selected for sampling within each species. Similar variation within species has been well reported[12, 13, 14].

The WSG of stem was higher than both primary and secondary branch and this relationship was fairly consistent across species in this study (Figure 1). The WSG of primary branch was also higher than WSG of secondary branch, except in *Acacia nilotica var. cupressiformis, Balanites roxburghii, Tamarindus indica,* where it was lower or equal to WSG of secondary branch (Figure 1). This type of variation has been reported in many tree species. Along the main stem of a tree, WSG varies from the base to the top of the stem[8,] and stem WSG are generally higher than branch WSG[7, 13, 15], however, WSG has also reported to decreases from the stump to half of the total height of the tree, and may increase afterwards towards the top[16].

The scattered plot of stem WSG with primary and secondary branch showed linear relationship, indicating use of linear regression for determination of numerical relationship between them (Figure 3). The WSG of primary and secondary branch was good predictor of stem WSG with high value of regression coefficient (R^2>0.83) and other statistical parameters (Table 3). Similar linear relationship has also been reported by many workers[7,15]. Thus, stem WSG can be indirectly estimated using primary/secondary branch sections avoiding tedious process of core sampling or cutting whole tree. However, this regression equation varied among the species. Taking all species in consideration, following common equations were developed for mixed population

$$WSGs = 0.875 + 0.117 * WSGpb$$

$$WSG = 0.805 + 0.173 * WSGsb$$

Where: WSGs = wood specific gravity of stem; WSGpb = wood specific gravity of primary branch; WSGsb = wood specific gravity of primary branch

This study was undertaken to provide data on stem WSG of hot semi-arid zone tree species and its variation within tree, species and between species. WSG varied significantly among species, within tree and species; however, extent of variation was low due to small sample size and uniformity in sampling. This study provided WSG of 21 tree species of hot-semiarid region of India and may be used for given species grown under similar climatic condition. Significantly high linear regression coefficient between WSG of stem and branches was found, indicating, branch WSG can be good predictor of stem SWG. However, accuracy of equations will be area specific and need to be validated.

Acknowledgements

This work was supported by project ñ National Innovations on Climate Resilient Agriculture (NICRA), of the Indian Council of Agricultural Research (ICAR), New Delhi.

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Tables

Table 1. Results of analysis of variance (ANOVA) for the effects of species and sampling location (stem and branches) on wood specific gravity

Source	Sum of Squares	Degree of freedom	Mean Square	F	p
Species	1.771	20	0.089	42.828	<0.001
Sampling location (Stem, primary and secondary branch)	0.122	2	0.061	29.433	<0.001
Species * Sampling location	0.044	40	0.001	0.528	0.989
Error	0.261	126	0.002		
R Squared = 0.881 (Adjusted R Squared = 0.823)					

Table 2. Tree species and their mean wood specific gravity, wood moisture content and wood volume shrinkage of stem

Tree	Family	Stem WSG		
		Mean	SD	CV (%)
Acacia nilotica susp nilotica (L.) Del.	Fabaceae-Mimosoideae	0.71	0.02	2.2
Acacia nilotica var. cupressiformis	Fabaceae-Mimosoideae	0.74	0.03	3.6
Acacia tortilis (Forssk) Hayne	Fabaceae-Mimosoideae	0.69	0.03	4.4
Acacia senegal (L.) Wild	Fabaceae-Mimosoideae	0.70	0.06	9.2
Albizia lebbeck (Benth.)	Fabaceae-Mimosoideae	0.58	0.04	7.5
Ailanthus excelsa Roxb.	Simaroubaceae	0.43	0.04	9.5
Azadirachta indica	Meliaceae	0.63	0.04	5.5
Balanites roxburghii Planch.	Zygophyllaceae	0.58	0.03	4.4
Bauhinia racemosa Lam.	Fabaceae-Caesalpinoideae	0.66	0.04	7.0
Capparis decidua (Forssk.) Edgew.	Capparidacea	0.68	0.03	5.1
Cassia fistula L.	Fabaceae-Caesalpinoideae	0.65	0.03	4.6
Colophospermum mopane	Fabaceae-Caesalpinoideae	0.69	0.05	7.9
Cordia myxa L.	Boraginaceae	0.42	0.04	9.8
Hardwickia binata Roxb.	Fabaceae-Caesalpinoideae	0.72	0.04	5.0
Pongamia pinnata (L.) Pierre	Fabaceae-Papilionoideae	0.55	0.04	7.6
Prosopis cineraria (L.) Druce	Fabaceae-Mimosoideae	0.73	0.05	6.9
Prosopis juliflora (Sw.) DC.	Fabaceae-Mimosoideae	0.71	0.03	4.2
Tamarindus indica (L.)	Fabaceae-Caesalpinoideae	0.73	0.01	1.6
Tecomella undulata D. Don	Bignoniaceae	0.68	0.04	6.2
Ziziphus mauritiana Lam.	Rhamnaceae	0.50	0.03	6.0
Ziziphus nummularia (Burm. F.).	Rhamnaceae	0.61	0.04	5.7

Where: SD stands for standard deviation and CV for coefficient of variation

Table 3. Statistical parameters for determination of stem wood specific gravity from primary and secondary branch wood specific gravity

Model	R	R^2	F	Coefficients		t		Equation
				a	b	a	b	
Primary branch	0.937[a]	0.88	442.554	0.117	0.875	4.67	21.04	WSGs = b + a (WSGpb)
Secondary branch	0.911[a]	0.83	296.899	0.173	0.805	6.28	17.23	WSGs = b + a (WSGsb)

Where: WSGs = WSG of stem; WSGpb = WSG of primary branch and WSGsb = WSG of secondary branch

Figure legends

Figure 1. Frequency distribution of tree species within different wood specific gravity classes.

Figure 2. Wood specific gravity of tree species. Error bars indicate standard deviation while wood specific gravity of species with common letters were insignificantly diffe
HSD, $P<0.05$).

Figure 3. Relationship between WSG of stem and branches (a) WSG of stem vs WSG of primary branch and (b) WSG of stem vs WSG of secondary branch.

Figures

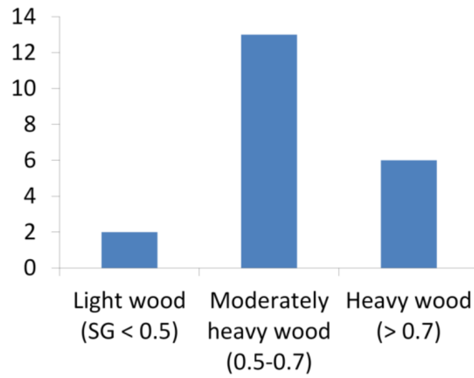

Figure 1

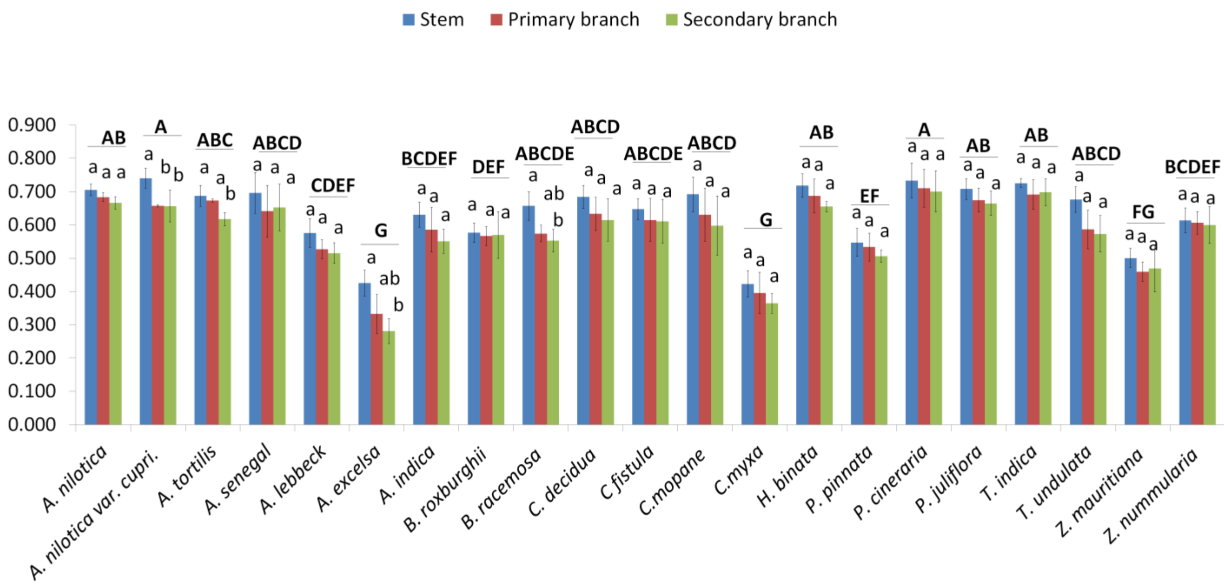
Stem
Primary branch
Secondary branch
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
AB
A
ABC
ABCD
CDEF
G
BCDEF
DEF
ABCDE
ABCD
ABCDE
ABCD
G
AB
EF
A
AB
AB
ABCD
FG
BCDEF
A. nilotica
A. nilotica var. cupri.
A. tortilis
A. senegal
A. lebbeck
A. excelsa
A. indica
B. roxburghii
B. racemosa
C. decidua
C.fistula
C.mopane
C.myxa
H. binata
P. pinnata
P. cineraria
P. juliflora
T. indica
T. undulata
Z. mauritiana
Z. nummularia

Figure 2

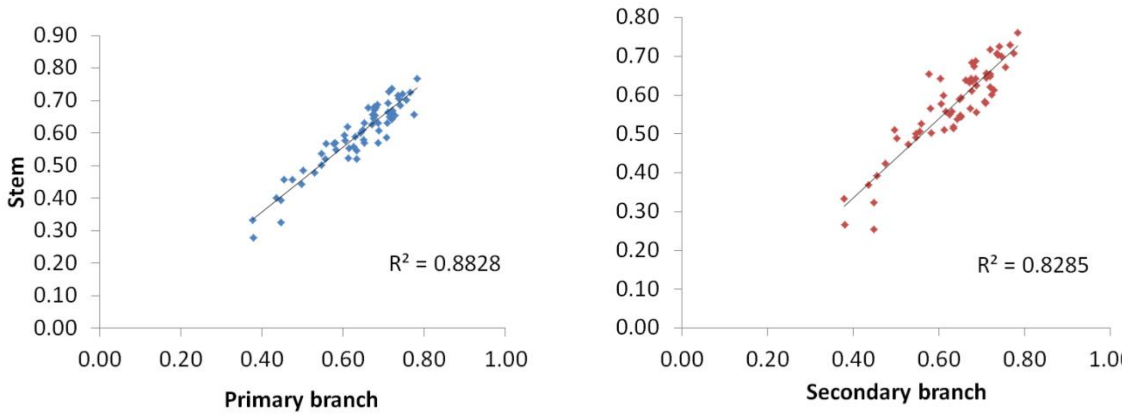
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Stem
R² = 0.8828
0.00 0.20 0.40 0.60 0.80 1.00
Primary branch
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
R² = 0.8285
0.00 0.20 0.40 0.60 0.80 1.00
Secondary branch

Figure 3

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