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Research Article

A comparative assessment of Non-destructive and destructive methods for precise volume estimation of mango (*Mangifera indica*) trees

Alka Kushwaha*
Department of Environmental Sciences, Integral University, Kursi Road, Lucknow-226026 (Uttar Pradesh), India
Ashok Kumar
Division of Crop Production, ICAR- Central Institute for Subtropical Horticulture, Rehmankhera, Lucknow-227101 (Uttar Pradesh), India
Rahila Rahman Khan
Department of Environmental Sciences, Integral University, Kursi Road, Lucknow-226026 (Uttar Pradesh), India

*Corresponding author. Email: akka0444@gmail.com

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Abstract
Terrestrial carbon sequestration is a natural process towards carbon mitigation in which perennial trees play a vital role. Total biomass of the tree can be measured by a destructive and Non-destructive method. Since tree felling is ban in India, Non-destructive measurements by allometric equations have been widely used for the estimation of tree biomass, which is derived from the destructive method. The present study focused on estimating mango (*Mangifera indica*) wood logs volume both by destructive and Non-destructive methods in ICAR-Central Institute of Subtropical Horticulture, Lucknow. In Non-destructive method, all required physical parameters were recorded from different positions and further calculated by T_2: log formula = $\pi h (r_1^2+r_2^2+r_1 r_2)/3$; T_3: cylindrical shape formula = $\pi r^2 h$ with mean value and T_4: cylindrical shape formula = $\pi r^2 h$ with maximum value. The calculated volume of mango wood logs was compared with the obtained volume by T_1:Water displacement method. ANOVA was used to compare volume generated from several methods. The results showed that average volume obtained by T_2 and T_3 methods was found less than the T_1 method, which was 13.69 % and 12.95 %, respectively. The volume obtained by T_4 was found close to the T_1. The study minimized the error while estimating the biomass of mango trees with the essential parameter, the wood volume. Calculating the volume of major branches in the mango tree will make it easier to calculate accurate AGB by a Non-destructive method. The estimated AGB will be helpful to calculate the amount of sequestered carbon and contribution toward mitigating atmospheric carbon dioxide by mango cultivated areas.

Keywords: Destructive methods, Non-destructive methods, Physical measurements, Tree volume, Wood density

INTRODUCTION

Global forest plays a vital role in carbon storage which helps in mitigating climate change. The world forest accumulates the atmospheric carbon into their biomass and organic matter in soil (Vashum and Jayakumar, 2012). It stores atmospheric carbon in to the tree biomass during the process of photosynthesis. Some reports showed that tropical forest has stored up 50 to 55 % of carbon in terrestrial biomass (Di Porcia *et al.,* 2019; Jones *et al*., 2019; Lewis *et al.,* 2015, Aryal *et al.* 2014; Ngo *et al.* 2013;). The total carbon stock in biomass of world' forest is 289 Gt recorded in 2010 (FAO, 2010) which includes above- below ground biomass of a tree. The quantity of world's forest biomass or plantation determines the potential of carbon which helps in conserving carbon pools and biomass production (Chauhan *et al.,* 2019; Panwar *et al.,* 2017; Chauhan *et al.,* 2015; Brown *et al*., 1999).

In India, Lucknow, the capital of Uttar Pradesh, globally famous for their endemic mango varieties like *Dashahari, Chaunsa, Langra, Lucknawi Safeda*. Among the states of India, Uttar Pradesh is the second largest mango producing state after the Andhra Pradesh, which covers 2649.30 km^2(DoACans FW, 2017). The Lucknow, Sitapur, Hardoi, Barabanki and Unnao are main districts of Urrar Pradesh for mango cultivation in which Mal, BakshikaTalab, Kakori and Malihabad are the predominant growing areas of mango. The largest 14belts of Dashehari mangoare abundant in Malihabad of Uttar Pradesh which covers 300 km^2(Paul, 2014), which stored a lot of carbon in their entire biomass but the amount of sequestrated carbon has not been properly quantified yet which can be found by the total biomass of the tree. Biomass of a tree is estimated by the Direct and Indirect method. In the Direct method, the entire tree is harvested and the weight of each part is taken, which is also known as Destructive method.

Allometric equations (Brown, 1997) have been widely used for the estimation of tree biomass which is derived from the destructive method which being easily used on a large area (Chave *et al*., 2005; Malhi *et al*., 2006; Djomo and Chimi, 2017; Kebede and Soromessa, 2018; Altanzagas *et al.,* 2019; Wirabuana*et al.,* 2020). On the other hand, the Indirect method, derived from the Direct method, also known as Non-destructive method. In Non-destructive, measurements of tree height, DBH (diameter at breast height), the volume of branches and wood density are the essential parameters (Brown, 1997). However, the huge error can be caused due to improper measurements while estimating biomass of a tree and inaccurate biomass did not account for actual carbon stock in the tree (Clark and Kellner, 2012; Ahmed *et al*., 2013; Molto *et al*., 2013; Shi and Liu, 2017; RouMéchainéj *et al*., 2017). To quantify the total amount of sequestrated carbon, measurement of the whole tree is required for which the volume and wood density are the essential parameters. Generally, tree trunk or branches are treated as paraboloid, cylinder, conoid or neiloid while calculating volume. So the volume of the tree can be obtained on the basis of formulas of these shapes, but only by changing the position of top and bottom diameter which provides variation in the volume of branches and the volume of the tree. The present study was conducted to determine the volume of wood logs by various methods and to have their comparative assessment.

MATERIALS AND METHODS

Study area

The experiment was conducted at ICAR-Central Institute for Subtropical Horticulture, Rehmankhera, PO-Kakori, Lucknow- 226 101 (Uttar Pradesh) situated at 26 ^{0} 45’ to 27 ^{0} 10’ North latitude and 80 ^{0} 30’ to 80 ^{0} 55’ East longitude. It falls under the humid and warm sub-tropical climatic region with alluvial soil. Due to its climatic condition, Kakori, Malihabad, Mall, Baksikatalab and nearby districts such as; Lucknow, Hardoi, Sitapur, Unnaoare favourable for mango cultivation (Fig. 1).

Field measurements

Nine grafted mango trees with same age groups (40 years old) were selected for this experiment. According to The Indian Forest Act (1927), tree felling is ban in Indiaor illegal even form personal property for any purpose. Therefore, nine primary branches were harvested with legal permission from the Department of Forest,

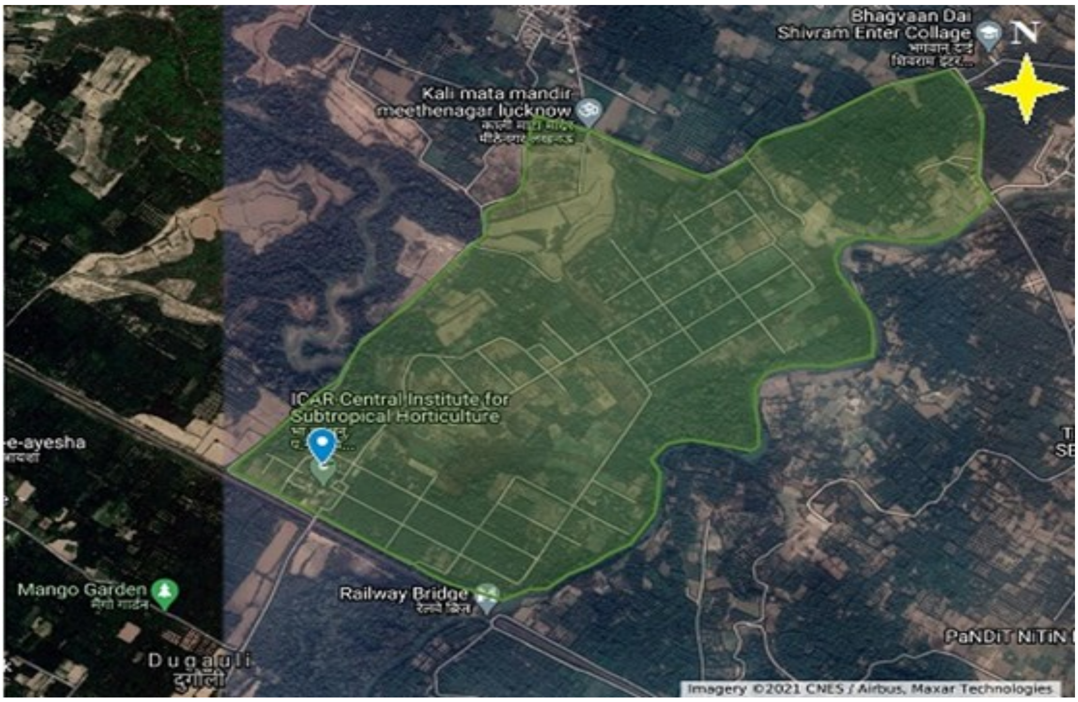

Fig. 1. *Google map imagery of ICAR- Central Institute for Subtropical Horticulture, Lucknow (Uttar Pradesh) , India, Jan 2021.*

Fig. 2. *Showing the pieces of Mango wood logs collected from ICAR-Central Institute for Subtropical Horticulture, Lucknow (Uttar Pradesh).*

Government of Uttar Pradesh for each selected trees. All the harvested branches were further cut into the lower, middle and upper part. Total of 27 logs was collected and properly labelled with numeric series (Fig. 2).The volume of each wood logs was observed by both destructive and Non-destructive method. Further, a comparative study was done. By this experiment, it will be easier to identify which method will provide the accurate volume of major branches in the Non-destructive method.

Volume of wood logs by Destructive method

Destructive method was considered as Treatment-1 (T-1). In this method, volume of wood logs was obtained by Water displacement method with the help of cylindrical flask(ASTM, 2017). Under this process, a wood sample was immersed in a beaker filled with water. The amount of water released from the beaker when the wood submerged, was the volume of that wood. This volume of wood logs was considered as standard value by this method, because Water displacement method is considered as an accurate method for volume estimation.

Volume of wood logs by Non-destructive method

In Non-destructive method, volumes were calculated by various formulas on the basis of branch's shape which were named as Treatment-2, 3 and 4 (T-2, T-3 and T-4). In Non-destructive method, diameter and length of are the essential parameters for the estimation of wood log volume (Blozan. W., 2006).Therefore, maximum and average lengths were taken by geometric scale. Diameters were recorded form bottom middle and top with a tree caliper. Maximum and minimum diameterswere also recorded (Fig. 3).Obtained values werefurther calculated by the following formulas:

Volume of woodlog = $\pi h\{r_1^2 + r_2^2 + (r_1\, r_2)\}$(T-2) …Eq.1

Where, π = 3.14, r_1 = top radius, r_2 = bottom radius, h = height (Wikipedia contributors, 2020; Hussain., 2019).

Volume of cylindrical shape = $\pi r^2 h$(T-3) ….Eq.2

Where, π = 3.14, r = radius (mean value), h = height (mean value) (Saral *et al.,* 2017)

Volume of cylindrical shape = $\pi r^2 h$ (T-4) ….Eq.3

Where, π = 3.14, r = radius (max. value), h = height (max. value)

Statistical analysis

For statistical analysis purpose, One-way ANOVA and MS excel were used. Histographic presentation and frequency distribution was derived from MS excel. Required graphs were plotted from MS excel.

RESULTS

Physical observations for Non-destructive methods

Physical parameters; diameter and length were recorded for the estimation of mango wood log volume. Histographic distribution showed a maximum frequency level of bottom diameter as 10.47 cm, 8.89 cm of top diameter and 10.47 of maximum diameter. Diameters of the wood log were ranging between 7.2 to 11.8 cm and their lengths were 6.2 to 15 cm. Mean diameters varying between 7.23 to 11.20 cm and average lengths of log varied from 6.2 to 14.65 cm (Fig.4).

Treatment-1

In T-1 (destructive method), fresh weight of logs (with 3 replications) was taken before the volume was record-

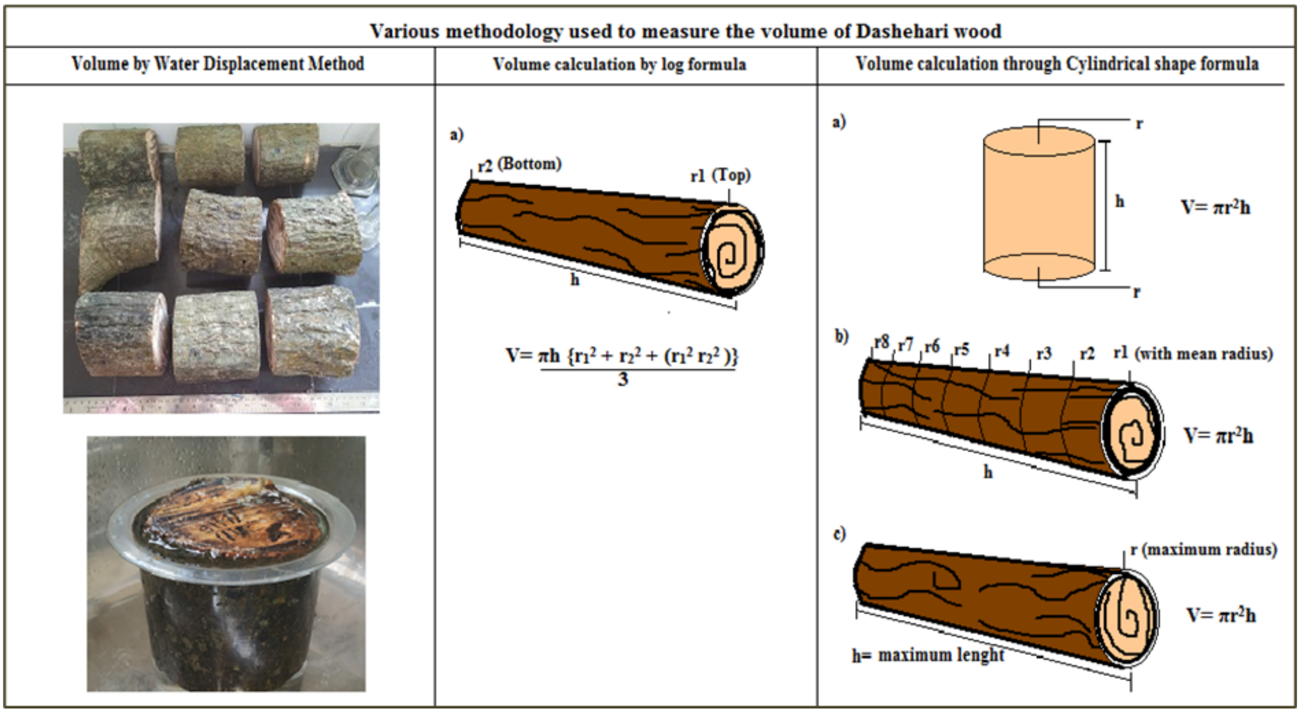

Fig. 3. *Methods, followed in this experiment for the estimation of wood volume*.

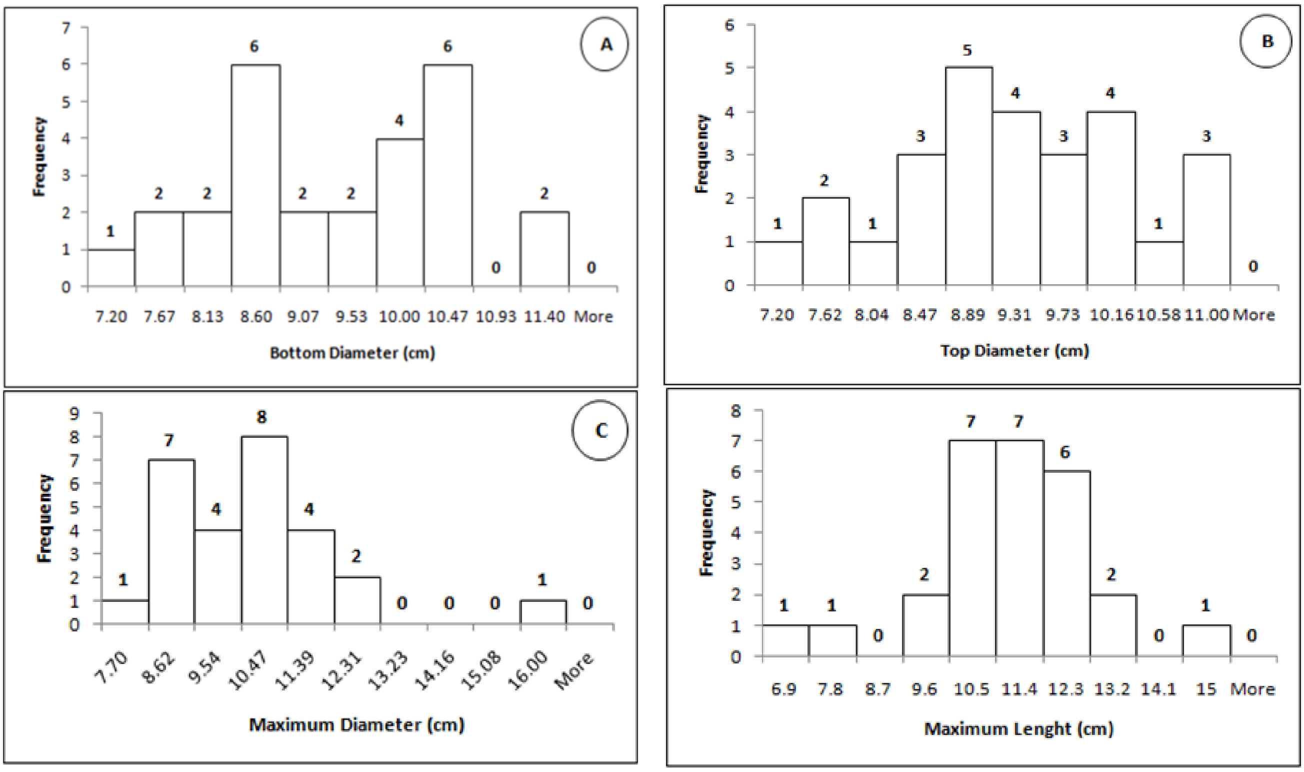

Fig. 4. *Histographic distribution of essential parameters for the estimation of mango wood logs:* ***A****, Bottom diameter (cm);* ***B****, Top diameter (cm);* ***C****, Maximum diameter (cm);* ***D****, Maximum length (cm).*

ed by Water displacement method. Weight of logs ranged between 580 to 1367.5 grams and volumes were between 465 to 1430 cm^3 (Fig. 6). In mango trees, the fresh weight of all branches was found less than the volume of their branches (Fig.5). Most of the wood logs were found floating on the upper surface of the water (Fig.3), but some samples were found drowning in the beaker. This type of pattern was only found in the bottom part of the primary branches. Maximum volume was found in 1^{st} branch and the minimum was in 9^{th} branch.

Treatment-2

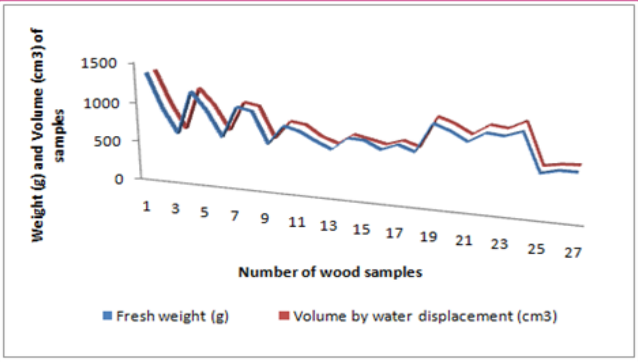

Fig. 5. *Fresh weight and volume of the Mango woods.*

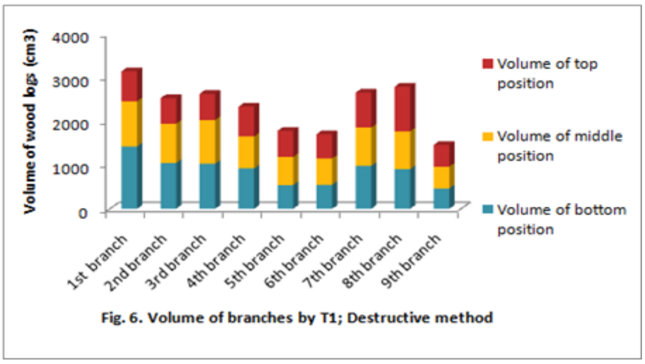

Fig. 6. *Volume of mango wood logs as measured by T1 method.*

In T-2 (Non-destructive method), volume of wood logs was calculated with wood log formula $\pi h\{r_1^2 + r_2^2 + (r_1 r_2)\}/3$.For this formula, average height/length (h) was considered and radius was taken from top and bottom which were named as r_1 and r_2 respectively. The average length of wood logs was ranging from 6.2 to 11.4 cm. The radius of the top part (r_1)was obtained between 7.4 to 10.9 cm and bottom part (r_2) was between 7.4 to 11 cm (Fig.6). Calculated volumes of wood logs wereranging from 429.79 to 915.75 cm3. Maximum volume was found in 1st branch and minimum volume was found in 9th branch (Fig. 7).

Treatment-3

In T-3 (Non-destructive method), the volume of wood logs was calculated with the cylindrical shape formula = $\pi r^2 h$ in which mean values of the radius (radius from the bottom, middle and top positions) and the average length of each log. The average length of wood logs ranged from 6.2 to 11.4 cm, and the mean radius (r) was ranging from7.1 to 10.91 cm. Calculated volumes of wood logs were found between 427.86 to 944.21 cm3 (Fig. 8). Maximum and minimum volume was found same as T-2.

Treatment-4

In T-4 (Non-destructive method), the volume of wood logs was calculated with the cylindrical shape formula= $\pi r^2 h$ in which maximum length and maximum radius were considered. Maximum radius was found somewhere else between the logs instead of top or bottom position. Therefore, in T-4 radius and length were noted at the maximum position for the estimation of woods volume. So, the maximum length was varying from 10.5 to 11.67 cm and maximum radius was varying from 7.8 to 11.7 cm. The volume of wood logs were calculated between 501.65 to 1080.41 cm3 (fig. 9). Minimum volumes of wood logs were found the same as the treatments T-1, T-2 and T-3, but maximum volume was not similar. Maximum volume was found in 3rd branch due to its irregular shape and size (fig. 10).

DISCUSSION

Volumes of wood logs obtained by T-1 were considered as standard values. Most of the wood logs were found floating, but some were drowned in the beaker while measuring volume by the Water Displacement method. The bottom part of each primary branch was only found submerged in water, which showed that the wood density of drowned logs was higher than the other logs. Value of wood density varies within the tree and decreases with increasing height (king *et al*., 2006; Gupta *et al.,*2017; Kushwaha *et al.,* 2019). The volume of wood logs was increased with their fresh weight which showed inverse nature. Volume obtained by T-2 and T-3 was found less than the T-1, which was 13.69 % and 12.95 %, respectively. The volume of wood logs by T-2

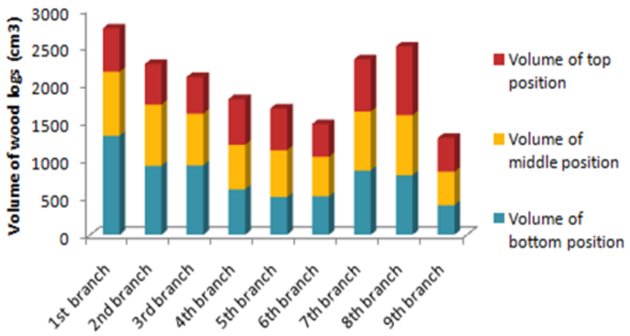

Fig. 7. *Volume of branches by T2;* $\pi h\{r_1^2+r_2^2+(r_1r_2)\}/3$.

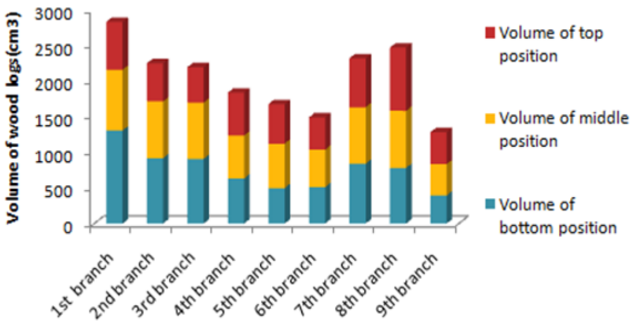

Fig. 8. *Volume of branches by T3;* $\pi r^2 h$ *(mean radius & length).*

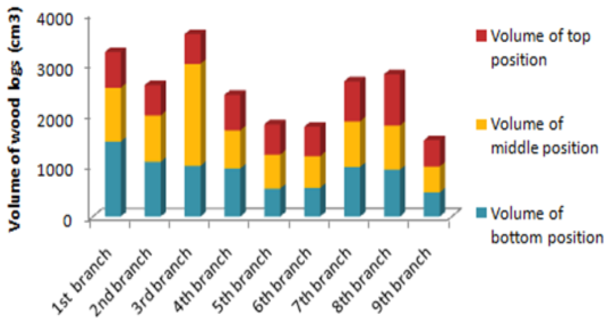

Fig. 8. *Volume of branches by T4; $\pi r^2 h$ (maximum radius & length).*

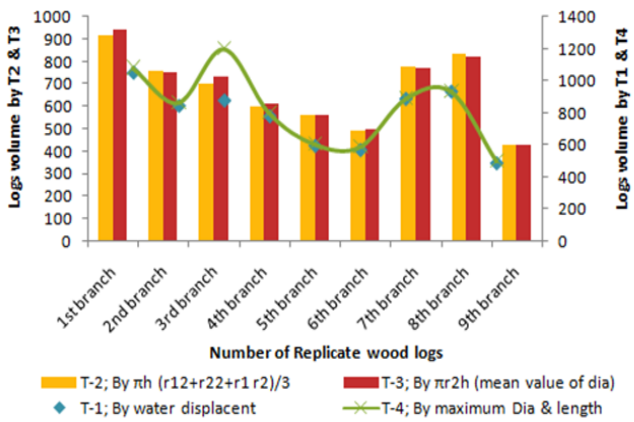

Fig. 11. *Comparative analysis of T1, T2, T3 and T4.*

and T-3 were found almost similar to each other which represents that the average radius (r) and top and bottom radius (r_1 and r_2) of any mango branch will give approximately same volume, but,considering mean radius or top and bottom radiuswill cause major error in while calculating the volume of the mango tree.

Although wood logs were uniform, there was variation in physical measurements after cutting primary branches into small pieces. In most of the samples, the maximum diameter was not found at the bottom, top or middle position. So, the radius was recorded at the position where the maximum. The volume of wood logs by T-4 was found to be higher than all treatments but close to the T-1. Although the volume of wood logs was found similar by T-1 and T-4, the irregular shape and size of the 3rd branch were found higher (Fig.11). So, the average volume of wood logs calculated by T-4 was 5.79 % higher than T-1.

Fig. 10. *Shape of R3 wood log in 3rd branch.*

ANOVA for estimation of wood logs volume using four different methods is given in Table 1. Due to the variation in diameter within the wood logs, an insignificant variance was found in the average volume of wood logs. The level of wood log volumes while estimating by various methods had an insignificant impact on the result, $F(3, 32) = 1.46$, $p = 0.24$ ($p > 0.05$). Therefore, instead of considering mean radius or r_1 and r_2 of the radius at the top and bottom part, the radius at the maximum point will provide better result while estimating the volume of mango tree branches by Non-destructive method. Most of the earlier reports had considered the volume of the whole tree through DBH and tree height instead of the volume of all separate branches of that particular tree while estimating the potential of carbon sequestration through above-ground biomass (AGB) (Saral. et al., 2017; ChavanandRasal., 2010; 2011; 2012; Suryawanshi *et al.,* 2014; Salunkha. *et al.,* 2016) which can cause a huge error in the mango tree. These above findings will reduce the error percentage while estimating the volume of standing tree by Non-destructive method. So, instead of taking diameter at the top and bottom position, diameter at the maximum position will give accurate volume in mango wood logs. Further, the volume of major branches will be used to develop allometric equations based on precise data while estimating above ground biomass and the amount of sequestrated carbon through mango tree.

Conclusion

The present study concluded that among four comparative assessments for précising volume estimation of

Table .1. ANOVA for estimation of wood logs volume using four different methods.

		SUMMARY		
Groups	Count	Sum	Average	Variance
T-1; By water displacement	9	7031.32	781.26	35678.37
T-2; By $\pi h\,(r_1^2+r_2^2+r_1\,r_2)/3$	9	6068.71	674.30	26766.39
T-3; By πr2h (mean value of dia)	9	6120.11	680.01	27861.29
T-4; By maximum Dia and length	9	7463.36	829.26	53817.63

mango (*M. Indica*) branches, the volume by $\pi r^2 h$ with the maximum value of radius and length was found more efficient than the log formula = $\pi h\ (r_1^2+r_2^2+r_1\ r_2)/3$ and cylindrical shape formula = $\pi r^2 h$ with mean radius and length. Cylindrical shape formula with a maximum value of radius and log length was effective measurement compared to other formulas for reducing error while estimating the volume of the wood log by Non-destructive method. The study will be an effective and environmental approach for estimating above-ground biomass of standing mango trees. Further, this can be used to account for total sequestrated carbon through biomass of mango trees.

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Conflict of interest

The authors declare that they have no conflict of interest.

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