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# Nondestructive Estimation of Pomegranate Plant Biomass by Using Allometric Equation

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**Abstract:** The current method available for nondestructive estimation of tree biomass using diameter at breast height (DBH) or other parameters is not applicable to pomegranate bushes, which have multiple stems emerging from the ground level. Therefore, pomegranate bushes in commercial orchards require an independent allometric equation for the nondestructive estimation of plant biomass. Using destructive sampling and parameters other than DBH, a pomegranate-specific allometric equation was developed. The selected allometric parameters were significantly related to the age of the trees. The root-to-shoot ratio (0.231) was also different from the 0.26 reported for forest trees. The biomass expansion factor (BEF) has by and large attained stability beyond 8 years of orchard age. The developed equations generally fit the data well, and in most cases, the product stem girth (SG) x number of stems (NS) explained more than half of the observed variation in biomass. Though there was a good agreement between the observed and predicted biomass using both multiple linear regression (MLR) and the power model, the MLR overestimated the biomass. Hence, based on $R^2$ values and the estimated biomass, it is suggested to use the power model to predict the pomegranate bush biomass.

**Key words:** Allometric equation, biomass expansion factor, nondestructive method, pomegranate bush, tree biomass



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Pomegranate is a shrub that naturally tends to develop multiple stems and has a bushy appearance. It is one of the most popular fruit crops in India and both area and production is recording an annual growth of above 20% t. The production is growing at above 20% every year (Ganeshamurthy, 2023; Kahramanoglu, 2019). Due to favorable climate India is the only country producing pomegranate throughout the year. Due to these advantages India has emerged as a leader in pomegranate cultivation along with China, Iran, and other Asian nations and has an edge over other countries as it can supply pomegranate throughout the year. India cultivates 2.80 lakh ha of pomegranate and produces 3.186 mt of fresh fruits (Ganeshamurthy, 2023).

Expansion of area under pomegranate involves land use changes (LUC), and such acts are an important source of GHG emissions related to production (Rupa, 2023; Ganeshamurthy, *et al.*, 2019; Hertel *et al.*, 2010). Such LUCs attract the attention of environmentalists since the carbon cycle of these areas may change abruptly. Thus, new crops may entail a net sequestration of carbon in the biosphere or liberation of carbon in the form of $CO_2$, depending on what previous land use they are substituting (Ganeshamurthy *et al.*, 2019; Rowe *et al.*, 2016). Apart from India, this is of special importance in many regions of the world where there are rapid LUCs. Pomegranate being a perennial plant, replacement of agricultural crops with pomegranate has an advantage in terms of carbon sequestration.

The lack of a sound methodology for nondestructive estimation of pomegranate tree biomass posed a challenge in estimating biogenic carbon and determining the relevance of LUCs in pomegranate areas in terms of GHG emissions. Based on this background, the main objective of this study is to pave the way for the estimation of carbon sequestration by pomegranate orchards by developing a method for the nondestructive estimation of tree biomass and computing the carbon sequestration by the crop. Results derived from this study are expected to be of utility for stakeholders in the emerging Indian pomegranate sector, as well as in other parts of the world.

## Materials and Methods

The study involved destructive sampling of over 224 pomegranate trees (cv. Bhagwa) ranging in age from 3 to 20 years. Because bearing begins after two years, the first two years of trees were not sampled. Finding orchards beyond 10 years was difficult, as most farmers are uprooting the orchards after ten years owing to the loss of trees as a result of bacterial blight, wilt diseases and stem borer attacks. As a result, trees were sampled at various ages ranging from 3 to 10, 12, 15, and 20 years. The uprooting of trees was done in farmer's fields in Shidlaghatta and Kushtagi areas in the state of Karnataka during 2020 to 2022. The trees were completely uprooted using a JCB make excavator. Before uprooting the tree, the height and number of stems of each plant and their girth at the base were recorded. Different parts of the trees, like leaves, stems, branches, and roots, were separated; roots were washed and cleaned off the adhering soil, drained, and their weight were recorded. This information was used to generate data on biomass distribution.

The total above- and below-ground biomass (BGB) of the felled trees was then computed. Different statistical models were used to estimate tree biomass, like the Multiple Linear Regression (MLR) model and power model. These two models are a class of linear and nonlinear regression models, and as the derivatives of Y with respect to unknown parameters are functions of either of them, a suitable estimation procedure was followed for parameter estimation (Seber and Wild, 1989). SAS codes were developed to fit these regression models. Based on the best fit, the multiple linear and power models were used for the estimation of tree biomass. The MLR model is represented by the following equation:

$$\text{MLR} : Y = a + b X_1 + c X_2.$$

where Y is the Above Ground Biomass (AGB) of tree; $X_1$, $X_2$ are observations on mean Stem Girth (SG) × NS (No. of Stems) and girth of a single stem; a, b and c are the coefficients.

The power model is represented by the following equation:

$$Y_t = a X_t^{\,b} + \varepsilon_t$$

where $Y_t$ is the $t^{th}$ trees AGB, $X_t$ the $t^{th}$ trees observations on mean Stem Girth (SG) × NS (No. of Stems) and "ε" represents the random variability or unexplained fluctuations in biomass corresponding to difference between observed and expected tree AGB of $t^{th}$ tree.

### *Root:shoot ratio*

The data generated from tree felling was used to calculate the mean root-to-shoot ratio in pomegranates by dividing the dry root weight by the dry shoot weight.

### *Biomass expansion factor (BEF)*

The BEF of different tree age groups was estimated following the method described by Ganeshamurthy (personal observation) as the ratio of the biomass to the volume, resulting in a dimensional variable and expressed in Mg $m^{-3}$.

## Results and Discussion

### *Component biomass distribution*

The tree biomass distribution pattern showed that major aboveground biomass is

*Table 1. Component dry weight (kg/plant) of harvested pomegranate trees of different age*

| Tree age (years) | Main stem | Secondary branches | Foliage | AGB dry weight | Roots | Total tree biomass |
|---|---|---|---|---|---|---|
| 3 | 5.86 | 2.26 | 1.16 | 12.06 | 2.77 | 14.83 |
| 4 | 13.26 | 5.10 | 2.62 | 27.28 | 6.27 | 33.55 |
| 5 | 20.37 | 7.84 | 4.02 | 41.92 | 9.64 | 51.56 |
| 6 | 26.70 | 10.27 | 5.28 | 54.94 | 12.64 | 67.58 |
| 7 | 33.01 | 12.70 | 6.53 | 67.93 | 15.62 | 83.55 |
| 8 | 41.51 | 15.97 | 8.21 | 85.42 | 19.65 | 105.07 |
| 9 | 45.79 | 17.62 | 9.05 | 94.21 | 21.67 | 115.88 |
| 10 | 52.77 | 20.30 | 10.43 | 108.58 | 24.97 | 133.55 |
| 12 | 65.63 | 25.25 | 12.98 | 135.05 | 31.06 | 166.11 |
| 15 | 69.81 | 26.86 | 13.80 | 143.64 | 33.04 | 176.68 |
| 20 | 76.87 | 29.58 | 15.20 | 158.18 | 36.38 | 194.56 |

accumulated in the stem wood, with dry weight on average representing 48.6% of the total bush biomass (Table 1). The secondary branches and twigs constituted about 18.7% and the foliage accounted for 9.6%. All put together, the AGB accounted for 76.9% and the remaining 23.1% is accounted for by the roots, which included all small, medium, and large roots.

### *Relationship between tree age and allometric parameters*

The age-wise mean and standard deviations of the biometric parameter SG x NS for the eleven age groups examined are presented (Table 2). With tree age as an independent variable, the changes in SG x NS with time were predicted by applying the logarithmic regression model: Y = a ln(X) – b. The results of the best predictive growth models are presented in Figure 1.

### *Biomass Expansion Factor (BEF)*

The BEF of different tree age groups was estimated as the ratio of the biomass to the volume, resulting in a dimensional variable and expressed in Mg $m^{-3}$. The BEF of pomegranate varied with the age of the trees (Table 3). The BEF ranged from 0.306 to 1.117 Mg $m^{-3}$at the end of the third year, with a mean of 0.717 Mg $m^{-3}$. This increased to 0.530-1.172 Mg $m^{-3}$on average with a mean of 0.819 Mg $m^{-3}$. Gradually, with age, the data indicated a decreasing trend and attained a steady state. At the end of the 8$^{th}$ year, the BEF ranged from 0.211-0.540 with a mean of 0.316 Mg $m^{-3}$. Beyond this, there was some fluctuation in the trend, but it was by and large stabilized.

### *Relationship between AGB and BGB*

The best estimates of BGB are obtained by destructive methods (Ganeshamurthy *et*

*Table 2. Biometric parameters of the different age trees examined in pomegranate*

| Tree age | No of trees | Plant height (m) | | | No of stems | | | SG (cm) | | | SG x NS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Range | Mean | SD | Range | Mean | SD | Range | Mean | SD | |
| 3 | 21 | 1.54- 1.92 | 1.64 | 0.102 | 2-5 | 3.48 | 0.63 | 2.73-3.15 | 2.8 | 0.112 | 9.74 |
| 4 | 18 | 1.82-2.15 | 1.92 | 0.086 | 3-5 | 3.73 | 0.46 | 4.06-4.91 | 4.3 | 0.228 | 16.04 |
| 5 | 26 | 2.08-2.32 | 2.28 | 0.064 | 2-5 | 3.46 | 0.83 | 5.0-6.28 | 5.06 | 0.330 | 17.51 |
| 6 | 24 | 2.29-2.73 | 2.56 | 0.115 | 2-5 | 3.51 | 0.59 | 4.98-5.30 | 5.18 | 0.814 | 18.18 |
| 7 | 21 | 2.41-2.92 | 2.73 | 0.132 | 3-6 | 3.38 | 0.77 | 5.52-6.31 | 5.85 | 0.191 | 19.77 |
| 8 | 19 | 2.50-2.99 | 2.89 | 0.126 | 3-6 | 3.29 | 0.81 | 6.29-6.89 | 6.75 | 0.162 | 22.21 |
| 9 | 22 | 2.76-3.08 | 2.85 | 0.097 | 3-5 | 3.44 | 0.58 | 701-7.59 | 7.32 | 0.155 | 25.18 |
| 10 | 26 | 2.87-3.18 | 2.96 | 0.083 | 2-5 | 3.16 | 0.83 | 7.95-8.96 | 8.51 | 0.251 | 26.89 |
| 12 | 15 | 3.04-3.49 | 3.21 | 0.122 | 1-4 | 3.04 | 0.70 | 8.88-9.62 | 9.36 | 0.283 | 28.45 |
| 15 | 18 | 3.18-3.56 | 3.20 | 0.106 | 2-4 | 3.22 | 0.49 | 9.11-9.83 | 9.45 | 0.709 | 30.43 |
| 20 | 14 | 3.08-3.47 | 3.25 | 0.127 | 2-3 | 3.18 | 0.37 | 9.65-10.54 | 10.22 | 0.917 | 32.50 |

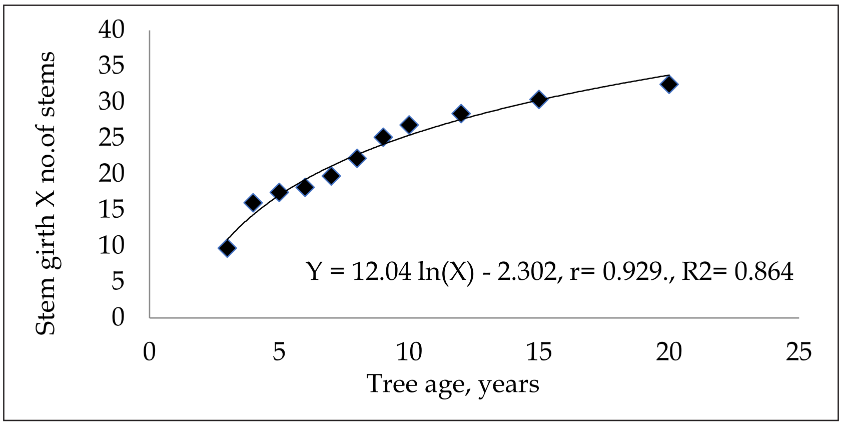


*Fig. 1. Relationship between tree age and mean stem girth.*

*al.*, 2016). Through excavation, it was found that the root is 0.231 times that of AGB. This conversion factor of 0.231 obtained in this study was used to calculate the BGB (Table 2). The majority of the root biomass (80.5%) accumulated in the first 0.75 m from the tree stumps in the sample trees.

*Table 3. Biomass expansion factor of pomegranate*

| Age, years | BEF (Mg m$^{-3}$) | | |
|---|---|---|---|
| | Range | Mean | SD |
| 3 | 0.306-1.117 | 0.717 | 0.506 |
| 4 | 0.530-1.172 | 0.819 | 0.545 |
| 5 | 0.368-0.922 | 0.569 | 0.568 |
| 6 | 0.464-0.812 | 0.449 | 0.413 |
| 7 | 0.235-0.796 | 0.326 | 0.389 |
| 8 | 0.211-0.540 | 0.316 | 0.312 |
| 9 | 0.232-0.558 | 0.307 | 0.254 |
| 10 | 0.218-0.503 | 0.310 | 0.236 |
| 12 | 0.242-0.416 | 0.316 | 0.251 |
| 15 | 0.253-0.481 | 0.321 | 0.267 |
| 20 | 0.218-0.574 | 0.320 | 0.243 |

*Biomass estimation*

A preliminary scatter plot was used to examine the data set. In this study, two types of models were used: multiple linear regression model ($Y_i$= a+b$X_1$+c$X_2$) and power model (Yi = a(X)$^b$) were used to estimate the tree biomass, where Y = the biomass of the tree and "a", "b" and "c" are constants. The predicted green biomass obtained by these two models is presented in Figures. 2 and 3. Both the equations were statistically significant (p ≤ 0.05) for both parameters a and b. The "a" and "c" constant in MLR showed non-significant effect on Y revealing that girth of a single stem did not show significant effect on AGB.

The MLR and Power models are presented below:

MLR: $Y = -116.48 + 8.17\ X_1 + 18.48\ X_2$; $R^2 = 0.971$

Power model: $Y = 0.215\ X^{1.998}$; $R^2 = 0.979$

Both the MLR model and the power model fit well for estimating above-ground green

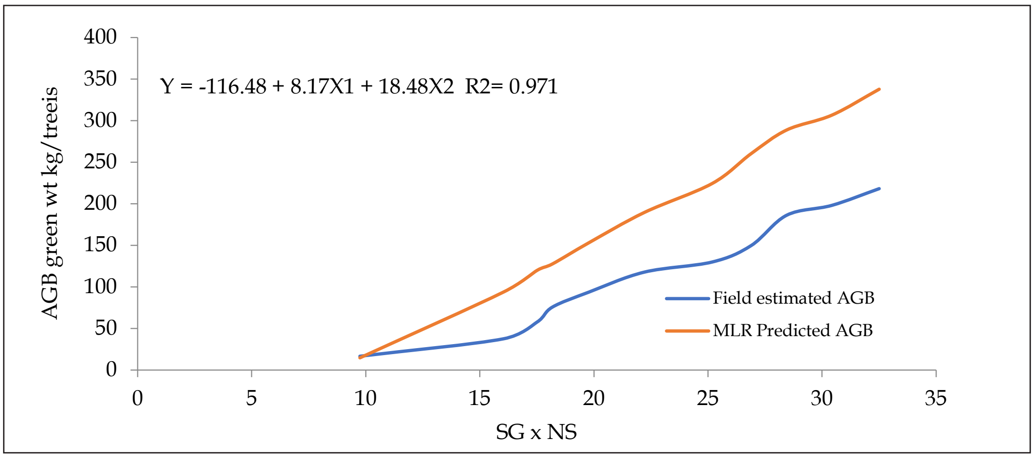


*Fig. 2. Relationship between observed and predicted AGB using MLR.*

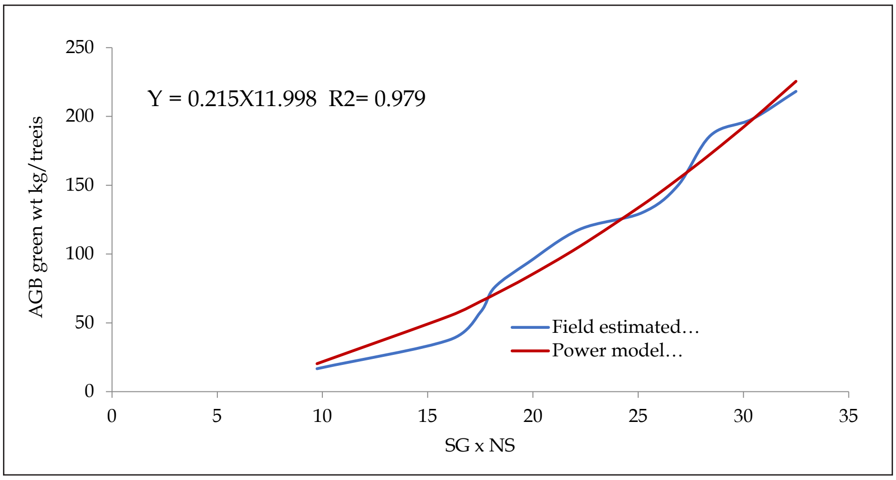


*Fig. 3. Relationship between observed and predicted AGB using Power model.*

biomass of pomegranate orchard trees based on $R^2$ values. The power model estimated the tree biomass well, whereas the MLR model overestimated the tree biomass even though it was statistically significant.

The absence of a reliable method for nondestructive estimation of tree biomass in orchard plants is responsible for the poor data base on carbon sequestration by fruit orchards (Ganeshamurthy *et al.,* 2016, 2023). The authors have earlier developed allometric equations for nondestructive estimation of tree biomass in orchard mango, guava, and sapota (Ganeshamurthy *et al.,* 2016 and personal observation). In this study, the equation developed for pomegranate orchards is reported.

The pomegranate, unlike other fruit trees, is a bushy plant with multiple stems emerging from the ground. Hence, in this crop, the ratio of primary branch girth to the number of primary branches could not be used. Instead product of stem girth [SG] and number of stems [NS] were used. In pomegranate orchards, the stem and primary branches accounted for a major portion of the above-ground biomass. Therefore, these two were combined and shown as main stem biomass. The stem contributed 48.6% of the total biomass. The secondary branches accounted for 18.7%, whereas the foliage accounted for 9.6% of the total bush biomass. Rowe *et al.* (2016) reported similar distributions in pomegranate orchards in Peru. With the age of the bushes, the biomass distribution changed. At the age of three years, the stem accounted for 5.86 kg $tree^{-1}$, secondary branches 2.26 kg $tree^{-1}$, and foliage 1.16 kg $tree^{-1}$ out of the total bush biomass of 14.83 kg $tree^{-1}$ and showed an increasing trend with age. It reached 76.87 kg $tree^{-1}$, secondary branches 29.50 kg $tree^{-1}$, and foliage 15.20 kg $tree^{-1}$ out of a total bush biomass of 194.56 kg $tree^{-1}$ after 20 years. But by and large, the proportional distribution remained similar.

### *Relationship between tree age and allometric parameters*

With tree age as an independent variable, the changes in SG and NS with time were predicted by applying several equations to select an appropriate growth model. Peper *et al*. (2001) proposed logarithmic and nonlinear exponential equations for predicting time-scale changes. Therefore, we first tested this, as this equation showed good prediction in other environments. The logarithmic regression model was therefore applied to predict SG X NS from age:

$$Y = a \ln(X) - b$$

where Y represents the dependent variable (the product of the mean stem girth and the number of stems) of a tree, X represents the age of the tree while "a" and "b" are constants.

The results of the best predictive growth models are presented in Fig. 1. Using this equation, we could predict the relationship between tree age and the identified tree allometric parameter SG x NS. This showed that the allometric parameter was significantly related to the age of the trees (r = 0.930).

### *Biomass expansion factor*

The biomass expansion factor is commonly used in selviculture to directly estimate the merchantable biomass (t $ha^{-1}$). This helps in trade to know the dry weight of the merchantable volume of the growing stock and to estimate the size of the non-merchantable components. In the case of a bushy plant like pomegranate, the merchantable biomass is not relevant as it is not marketable as wood. Our purpose in calculating BEF is different from that of silviculture. Here, this was needed as a complement to growth models that do not include biomass predictions but to reduce the uncertainty associated with the use of BEFs for biomass estimation. It was reported by Ganeshamurthy *et al.* (2016) that initially the BEF is very high, followed by a decreasing phase, and finally a steady phase. In this study, we began with the third year, which marks the start of fruit bearing. At the third year, the BEF ranged from 0.306 to 1.117 Mg $m^{-3}$, with a mean of 0.717 Mg $m^{-3}$ (Table 3). Gradually, with age, the data indicated an increasing trend until the $4^{th}$ year and later attained a steady state from the $8^{th}$ year on. The BEF ranged from 0.218 to 0.574 Mg $m^{-3}$ at the end of the twentieth year, with a mean of 0.320 Mg $m^{-3}$.This is because as the tree grew, the canopy volume varied with the extent of pruning. In pomegranate trees, unlike other fruit trees, pruning is a general practice both to maintain the canopy at a manageable level and to induce juvenility. Defoliation with chemicals to induce flowering is also common in pomegranates. The BEF, by and large, attained stability beyond 8 years. Such similar observations in other species were made by several authors (Ganeshamurthy *et al.*, 2016; 2023; Tobin *et al.*, 2007). Unlike forest trees and bushes, pomegranate trees are subjected to various canopy management practices, leading to fluctuations in BEF values. As a result, in the case of commercially cultivated crops such as pomegranate, the BEF is unreliable data. Nevertheless, these reports support the findings concerning resource allocation during the growth process.

*Relationship between AGB and BGB*

The best estimates of BGB are obtained by destructive methods (Ganeshamurthy *et al.*, 2016; 2023). BGB is estimated for several purposes. But in this study, the purpose was for carbon storage estimation. A conversion factor of 0.29 was generally observed in exploratory studies on several fruit trees, including mango, sapota, and guava (Ganeshamurthy *et al.*, 2016; 2023). In this study, we discovered a conversion factor of 0.231 and discovered that the majority of the root biomass (80.5%) accumulated in the first 0.75 m from the bush stumps. The error associated with the chosen excavation area in the drip circle of the trees was considered to be relatively small, as the measurements made in this study suggest that root biomass stock would appear to reduce exponentially with the distance from the stump. IPCC GPG (Sanesi *et al.*, 2013) reported the mean default value of R as 0.32 with a range of 0.24-0.50 for trees with aboveground biomass stocks of 50-150 tons (dry weight) $ha^{-1}$. In this case, no information is available for bushy plants like pomegranate. Our measured values fell within the range reported for pomegranate in Peru by Rowe *et al.* (2016).

*Biomass estimation*

Allometric equations were developed for mango, guava, and sapota orchard trees by Ganeshamurthy *et al.* (2016, 2023). With this experience, two types of models have emerged: the power model ($yi = a(X)^b$) and a multiple linear regression model ($Y_i= a+bX_1+cX_2$) were used in pomegranates, where y = biomass of trees and "a" and "b" and "c" are scaling factors. Because the results indicated that both the MLR and power models were suitable, a comparison with these two models was made and is shown in Fig. 2 and 3. Both equations were statistically significant ($p > 0.05$) for both parameters, "a" and "b." Based on the $R^2$ values, both the MLR model and the power model fit equally well for the estimation of the above-ground biomass of pomegranate bushes. While the power model estimated the biomass fairly well, the MLR model overestimated the biomass. This is because the $X_2$ parameter (girth of a single stem) was not significantly related. As a result, the power model is well suited for estimating pomegranate bush biomass. Published information shows that most equations relate tree biomass to diameter or diameter coupled with height. A review of equations developed for 65 species by Zianis and Mencuccini (2004) showed that in most cases, tree diameter is the most commonly used single metric for tree allometry. These equations mostly deal with forest species and address selviculture issues, specifically the timber part. Very few have addressed mono-cropped tropical fruit crops such as pomegranate from the perspective of C sequestration (CS). However, their application to a plant that is managed as a bush with multiple stems, such as pomegranate, is problematic for two reasons: first, the origin of multiple stems from the base; and second, the DBH, a very common parameter used in published allometric equations of either mango or related species, is not possible to measure in a bushy plant like pomegranate. Hence, the equation developed specifically for pomegranate bushes in this study will be of immense use in working out the biomass of pomegranate orchards and the CS of pomegranates.

## Conclusion

Estimating the biomass of pomegranate bushes under commercial intensive management practices necessitates the use of an independent allometric equation. The equations were hence developed using parameters other than DBH. The root-to-shoot ratio also differed from those reported for forest trees and bushes. The BEF, by and large, attained stability beyond 8 years. The equations developed using SG x NS fitted the data well and were statistically significant. There was a good agreement between the observed and predicted biomass using the power model equation, whereas the MLR overestimated the biomass. Hence, a power model exclusively developed for pomegranate bushes predicts the bush biomass well and can be used for estimating the carbon sequestration potential of pomegranate bushes.

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