RESEARCH ARTICLE

Root:Shoot Ratio Predicts Total Tree Carbon Stock in Terrestrial Ecosystems: A Meta-Analysis

Vijay P. Gautam,[1]* Swati Mishra,[1] Om Shiwani[1]

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Abstract

Our study aims to determine the root:shoot (R/S) ratio in the terrestrial biome because it is an important predictor of global terrestrial carbon (C) stocks. Forests act as C sinks of the terrestrial ecosystem where the carbon pools of the terrestrial ecosystem are represented by tree biomass, (aboveground and belowground biomass), litters, woody debris and, soil organic matter. Among these C pools, the aboveground biomass harbors the major proportion of the terrestrial C pools. But industrialization, deforestation, and burning of fossil fuels have increased the carbon concentration in the atmosphere and disrupted the global carbon cycle. So, there are plenty of methods available for the estimation of terrestrial carbon, except for the root carbon. However, root: shoot ratio is a basic method for calculation of the root biomass from shoot biomass. Hence, we collected the reliable data on root: shoot ratio from published literatures using which we have developed an allometric equation ($Y = -0.324+0.236X$), where Y represents root biomass and X represents shoot biomass and thus the R/S value obtained was 0.236. Using this allometric equation we can harmlessly estimate the belowground biomass in no time. But this default value (0.236) varies with vegetation type, mean annual precipitation and temperature, tree size and age so using this value in the assessment of biomass and carbon would result into unreliable estimation. So, we also performed an in-situ sampling at the campus of Banaras Hindu University, Varanasi, India to measure the aboveground and belowground biomass using the allometric equation mentioned above and also found the potential tree species with greater aboveground and belowground biomass which can be more useful in sequestration of increased carbon dioxide concentration in the atmosphere.

Keywords: Aboveground biomass, Global carbon stocks, Root biomass, Root:shoot ratio.

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Introduction

Carbon prevails in the earth's atmosphere primarily in the gaseous form i.e. carbon dioxide. Earth's atmosphere contains about 0.04% carbon dioxide. It plays an important role in supporting life on earth, as plants make their food via carbon sequestration. Various plant products are being consumed by different animals and when these plants die or burnt, the carbon (C) stored in them is released back into the atmosphere. Thus, the C cycle is maintained and controlled by a balance between biological and inorganic processes. Since 1957 the CO_2 concentration in the atmosphere is continuously being measured and recorded (Keeling *et al*., 1989). The concentration of CO_2 was about 280ppm during the pre-industrial time and approximately 390ppm in the present-day (Website: www.research.noaa.gov, accessed on 28th April 2012).

Human activities like industrialization, deforestation, and burning of fossil fuels have increased the carbon-dioxide concentration in the atmosphere which has disrupted the global carbon cycle. CO_2 is a major greenhouse gas and potent enough to impact the global climate pattern (Brown, 1993). About 60% of the observed global climate change is due to this increasing CO_2 concentration in the atmosphere (Grace, 2004). But nature has provided us with natural C "sinks" like the oceans and the terrestrial ecosystem. The most important C sinks of the terrestrial ecosystem are the forest ecosystem. Aboveground (AGB) and belowground biomass (BGB) are important components of terrestrial ecosystem carbon stocks. Aboveground biomass (AGB) distribution in terrestrial ecosystems is reasonably well understood, whereas knowledge of BGB and its distribution is quite limited (McNaughton *et al*., 1998). Studies done in several ecosystems have quantified the aboveground carbon stored in different wood components, while the root biomass estimation which contributes a substantial amount to the total carbon budget is still difficult, challenging, and expensive. The root: shoot (R/S) ratio is an important parameter for estimating the root biomass from the shoot biomass, which would be useful in refining the reliable total carbon stock prediction of the terrestrial biosphere.

Allometric regression equations are widely used for estimating tree biomass in forests. Most estimates of tropical forest biomass focus only on aboveground biomass (Chave *et al*., 2005; Fayolle *et al*., 2013; Kenzo *et al*., 2009). IPCC (2006) has provided the R/S ratio value of 0.24 to be used for all moist, dry, and secondary forests. However, R/S ratio values can vary substantially depending on species and growth conditions of the trees (Poorter *et al*., 2012). Brown (1997) reported an 8-fold variation in R/S ratio value ranging from 0.04 to 0.33 (average 0.12) in the low land moist tropical forest. Hence, there is an urgent need to use allometric models that can accurately estimate root

[1]Department of Botany, Institute of Science, Banaras Hindu University, Varanasi 221005, India

***Corresponding author:** Vijay Pr. Gautam, Department of Botany, Institute of Science, Banaras Hindu University, Varanasi 221005, India, Mobile: +91-7007337446, Email: vijayp.gautam17@bhu.ac.in

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biomass (Lima *et al*., 2012; Kenzo *et al*., 2009). Till date several allometric models for both above and belowground biomass from southeast Asian tropical secondary and Dipterocarp forests have been reported (Basuki *et al*., 2009; Kenzo *et al*., 2009; Niiyama *et al*., 2010). Plausible root: shoot (R/S) ratios are required for a wide array of vegetation types to boost the accuracy of root biomass estimation (Mokany, 2006). But unfortunately, such studies are lacking from the dry tropical forest of India which is facing an unprecedented rate of biotic forcing, industrial activities including the use of chemical fertilizers, land use conversation, and fragmentation. So here, we have collected data of root: shoot ratio from previous studies and thus generated an allometric equation using which we calculated the AGB and BGB.

Methodology

Measurement of Aboveground Biomass

There are two types of methods, destructive and non-destructive for the measurement of aboveground biomass. In India where tree felling is banned, destructive sampling is not at all possible. On the other hand, non-destructive sampling does not require the harvesting of trees.

There are three important things for measurement of AGB- stem DBH (diameter at breast height), H (total tree height), and WD (wood density) (Lima *et al.,* 2012).

Non- destructive methods used to estimate AGB and BGB include different biomass equations (linear and nonlinear-transformed) comprising of DBH, H, and WD. Baker *et al*., (2004) used only the diameter at breast height in the biomass equation but this equation faced a significant problem for the comparisons of regional-scale tree biomass estimates. Besides, AGB can be estimated by in situ sampling or remote sensing (Ravindranath, 2008; GTOS, 2009; Vashum and Jayakumar, 2012). Chave *et al.,* (2005) proposed the equation to estimate AGB, where AGB= $\rho D^2 H$….kg/tree (ρ = Wood density; D= Diameter at breast height; H= Height of tree).

Tree Height Measurement

A clinometer is an instrument used to calculate the tree height, but it is highly expensive. However, it is possible to achieve very good results using a smartphone, sticks, and protector. This particular formula can be used to calculate tree height through smartphone:

Tree height = tan angle of elevation X distance of tree + height of eye aboveground.

On the other hand, several authors have published species-specific allometric equations (Navar, 2009; Cai *et al*., 2013).
The value of wood density (ρ) is expressed in g cm^{-3}. Wood density (ρ) varies extensively between tropical forest tree species due to the prevailing structural, environmental, and compositional gradients. Baker *et al*., (2004) included ρ in the biomass equation based on tree diameter and thus represented the regional differences in the estimation of the tropical forest aboveground biomass. Nelson *et al*., (1999) reduced the error in biomass estimation by incorporation of ρ.

Belowground Biomass

Fine roots of less than 2mm diameter are sometimes excluded because they cannot be distinguished empirically from soil organic matter or litter (IPCC, 2006). The belowground component of the tree cannot be easily recognized by remote observations while in situ measurements are time-intensive (GTOS, 2009). However, BGB contributes up to 40% of the total biomass (Brown, 2002). But still, no practical standardized field techniques exist for resolving it (Magalhaes, 2016). BGB can be calculated indirectly using root-shoot ratios (R/S) (Mokany *et al*.,2006; Magalhaes and Seifert, 2015).

Literature Survey

We did an extensive literature survey to obtain below and aboveground biomass in forest ecosystems. All data were critically reviewed using these criteria: (1) Did the methodology sufficiently indicate that all root biomass was quantified? (2) Were biomass densities reported on an oven-dry weight basis? (3) Did the studies adhere to standard methods leading to comparable estimates? Based on the reliable data collected we have generated an allometric regression equation for estimating AGB & BGB where if we have an average value of AGB & BGB, then we can easily calculate the root: shoot ratio value.

Biomass is expressed in tonnes of dry matter (t dm). For converting volume in m^3 to biomass in t dm, the given volume is multiplied to standard conversion and expansion factors available for different forest types. During volume estimation expansion factors include small branches of vegetation, which remains undetected. Conversion and expansion factors (default value is 0.95) used here are those prescribed in the IPCC guidelines for preparing national greenhouse gas inventories (IPCC, 1995). The volume given for each reported forest stratum is multiplied by 0.95 to obtain the total biomass of that stratum. This biomass is then converted into carbon content by multiplying it with a factor 0.50 (Razakamanarivo *et al*., 2011). The IPCC, (2006) recommended an R/S value of 0.24 to be used for all tropical moist, dry, and secondary forests, based on (Cairns *et al*.,1997). However, R/S values can vary substantially based on species type and growth conditions

(Poorter *et al*., 2012). Brown (1997) reported that R/S values in lowland moist tropical forest exhibit an 8-fold variation ranging from 0.04 to 0.33. The R/S value obtained in our study conducted at the campus of Banaras Hindu University, Varanasi, India was 0.236, quite close to the IPCC proposed value i.e. 0.24. In our study, we took into consideration 14 replicates of each trees species found in the campus and measured the aboveground and belowground biomass using the android mobile application.

Although biomass estimation can be done with the help of allometric equations that are non-destructive, less time consuming and less expensive because these equations use only the indicator parameters obtained from the forest inventories. Yet there are allometric equations for biomass estimation but they must be validated and for the validation cutting and weighing of the tree, parts are required (Vashum and Jayakumar, 2012).

Biomass Estimation by Remote Sensing and GIS Method

Measurement of field data is the most conventional and accurate method for estimating forest biomass. However, this method is expensive, time-consuming, and destructive (which may not be very practical for forest ecosystems with threatened or rare or protected species). Besides, it is applicable for only a small sample of trees. Therefore, remote sensing technology is a better solution for biomass estimation challenges. Remote sensing is a process of acquiring data from a distance of an object, area, or phenomenon by analyzing the data through instruments without being in contact with the object or area which is/are being examined. Remote sensing technology provides an inclusive view of the coverage area of interest, thereby capturing the spatial variability in the attributes of interest. Remote sensing technology can monitor natural resources on a continental, as well as on a global scale. Forest's carbon stocks can be easily evaluated using remote sensing technology. Previous studies estimated the forest biomass using the data obtained from the field through remote sensing (Nelson *et al*., 1988).

So, by use of remote sensing we can easily calculate aboveground biomass. If we take into consideration the aboveground and belowground biomass reported in the studies done till date we found that aboveground biomass is strongly correlated with belowground biomass (Fig. 1.)

Thus, we succeeded in obtaining an allometric equation for both aboveground biomass and belowground biomass which would help in the computation of missing data on biomass (either above or below ground) and total carbon.

Results

The result obtained in our case study when compared to the data in previously published literatures (Table 1), was found consistent

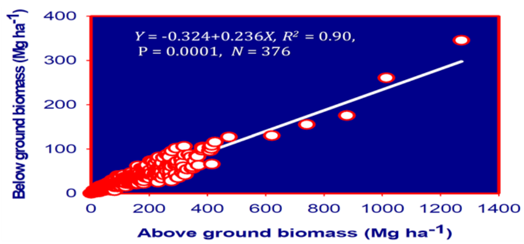

Figure 1: The graph shows the relationship between the above and belowground biomass.

Regression equation: $Y = a + bX$

where, b = The slope of the regression line.

a = The intercept point of the regression line and the Y-axis.

N = Number of values or elements.

Y = Below ground biomass. (Mg ha^{-1})

X = Above ground biomass .(Mg ha^{-1})

Here, $Y = -0.324+ 0.236X$ (equation based on data collected from published literature available on www.sciencedirect.com from year 2002 to 2017)

$R^2= 0.90$

$P = 0.0001$, $N = 376$

Table 1: Underlined values are derived values and values which are without underline are obtained from previous studies. Y = -0.324 + 0.236X, based on this regression equation, we have estimated root: shoot ratio, total biomass, the total mean, total carbon stock (by multiplying it with a factor 0.50 (Razakamanarivo *et al*., 2011) (where Y = belowground biomass, X = aboveground biomass)

Forest type and Location	*AGB (Mg ha^{-1})*	*BGB (Mg ha^{-1})*	*Root: shoot ratio*	*Total biomass (AGB+BGB)*	*C Stocks (Mg ha^{-1})*	*References*
Indian forests	254.26	67.34	0.264	321.6	160.8	(Chhabra *et al*., 2002)
Peat swamp forest, Jambi	215.8	50.604	0.236	265.434	132.71	(Krisnawati *et al*., 2007)
Temperate and boreal forests, Northeast China	165.91	38.86	0.234	204.77	102.385	(Wang *et al*., 2008)
Darugiri Garo hills of Meghalaya, northeast India	256.66	56.32	0.212	312.98	156.49	(Upadhayay *et al*., 2015)
Moist Central African Forest	168.6	39.54	0.234	208.14	104.07	(Ekoungoulou *et al*., 2015)
Teak Plantations of Southern Western Ghats, India	428.6	94.292	0.22	522.89	261.445	(Sandeep *et al*., 2015)
Tropical forests, Vietnam	61.15	12.25	0.20	73.4	36.7	(Kralicek *et al*., 2017)
Tropical forest, Thailand	120	27.6	0.236	147.6	60	(Ogawa *et al*., 1965)
Tropical forest, Sri Lanka	154.0	36.02	0.236	190.02	77.0	(Brown and Lugo *et al*.,1982)
South and Southeast Asia tropical land-use change	35.0	7.936	0.236	42.936	17.5	(Hall and Uhlig, 1991)
The vegetation of Southeast Asia, including India, Cambodia, Malaysia, and Indonesian forests	34	7.7	0.236	41.7	17.0	(Flint and Richards, 1994)
Indian forests	126.0	29.41	0.236	155.41	63	(Ravindranath *et al*.,1997)
Tropical forest, Thailand	76	17.612	0.236	93.612	38.0	(Boonpragob *et al*., 1998)
Indian forests	67.4	15.582	0.236	82.982	41.45	(Haripiya *et al*., 2000)
Tropical dry deciduous forest ,Mexico	226	53.012	0.236	279.012	113.0	(Cairns *et al*., 2003)
Tropical evergreen forest, Colombia	224	52.54	0.236	276.54	112.0	(Sierra *et al*., 2007)
Tropical forests, India	324.0	76.14	0.236	400.14	162.0	(Baishya *et al*., 2009)
Kolli forests, Eastern ghats (India)	372.0	87.466	0.236	459.466	186.0	(Mohanraj *et al*., 2011)
Tropical dry deciduous forest, India	174	40.74	0.236	214.74	87.0	(Chaturvedi *et al*., 2011)
Tropical forest of Cachar, Assam India	32.48	7.341	0.236	39.821	16.24	(Borah *et al*., 2013)
Mean	175.810	40.914	0.233	216.65865	91.2205	

Table 2: The average value of DBH, height and wood density of eight species each having 14 replicate collected from Banaras Hindu university from some selected sites (IIT-BHU latitude: 25.2623°N, IIT-BHU longitude : 82.9893°E; Botany department BHU latitude:25.2623°N, Botany Department BHU longitude: 82.9815°E; Broacha crossroad BHU latitude: 25.2677°N, Broacha crossroad BHU longitude: 82.9919°E)

Species name	*Wood density (g/ cm³)*	*DBH (cm)*	*Height (m)*
Tectona grandis	0.50	67.07	13.55
Terminalia arjuna	0.68	101.64	25.53
Madhuca longifolia	0.74	115.21	15.93
Tamarindus indica	0.75	249	15.23
Grevillea robusta	0.74	128.92	19.45
Eucalyptus tereticornis	0.64	119.28	21
Pinusrox burghii	0.48	67.85	10.23
Anthocephalus cadamba	0.36	107.18	13.05

Table 3: According to (Chave *et al.*, 2005) AGB = ρD2H kg/tree. Using this equation (Y = -0.324 + 0.236X) we calculated the aboveground biomass. Also, on the basis of this regression equation, we estimated the root: shoot ratio (R/S), total biomass,total mean, total carbon stock (by multiplying it with a factor 0.50 (Razakamanarivo *et al.*, 2011) where Y = belowground biomass, X = aboveground biomass) of these eight species each with 14 replicates.

Species name	*AGB (Mg ha⁻¹)*	*BGB (Mg ha⁻¹)*	*Root: Shoot*	*Total biomass (Mg ha⁻¹)*	*C Stocks (MgC ha⁻¹)*
Tectona grandis	30.36	6.84	0.225	37.2	18.6
Terminalia arjuna	179.34	42.00	0.234	221.34	110.67
Madhuca longifolia	156.46	36.60	0.233	193.06	96.53
Tamarindus indica	708.206	166.81	0.235	875.01	437.50
Grevillea robusta	239.21	56.12	0.234	295.33	147.66
Eucalyptus tereticornis	191.22	44.80	0.234	236.02	118.01
Pinusrox burghii	22.53	4.99	0.221	27.52	13.76
Anthocephalus cadamba	53.76	12.36	0.229	66.12	33.06
Mean	197.63	46.31	0.234	243.95	121.97

in the terms of R/S value obtained on conducting a survey at Banaras Hindu University campus, Varanasi (Table 2 and 3).

In our study we found that *Tamarindus indica* had the highest aboveground and belowground biomass and thus it exhibited highest total biomass and C stock while *Pinusroxburghii* had the minimum aboveground and belowground biomass and therefore it exhibited the lowest biomass and C stock.

Conclusion

Forests are the largest carbon pool of the terrestrial ecosystem on the earth. Forest plays an important role in the global carbon cycle because they act as carbon sinks of the terrestrial ecosystem. The carbon stored in the forest trees is mostly referred to as the biomass of the tree or forest. The carbon pools of the terrestrial ecosystem involve biomass, namely the shoot biomass, root biomass, litter, woody debris. Among all the carbon pools, the aboveground biomass constitutes the major portion of the carbon pool. Root: shoot ratio has become a basic method for calculating root biomass from the more easily measured shoot biomass and thus it has been proved useful in the reliable prediction of total carbon stock of the terrestrial biosphere. But, such types of studies are lacking from dry tropical forests of India which are facing an unprecedented rate of biotic forcing, industrial activities, use of chemical fertilizers, land-use conversion, and fragmentation. Our study also focused on the 1) Estimation of aboveground biomass using allometric equations 2) Estimation of root biomass through root: shoot ratio.

In our study, we found that *Tamarindus indica* is the potential tree species for afforestation and reforestation to enhance the carbon density of the area. Also, our finding is consistent with previous studies which state that medium sized trees (as *Tamarindus indica*) play vital role in carbon storage in dry tropical forests of India (Brown *et al.,* 1997; Borah *et al.,* 2013). Ultimately, this meta-analysis would prove useful in sustainable management and conservation of dry tropical forests of India. Additionally, our data would also contribute to the national carbon inventory of India.

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