Eco. Env. & Cons. 29 (2) : 2023; pp. (921-927)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i02.063

Allometric equations for evaluating above-ground biomass and carbon storage capability of Indian bamboos: Review approach

Neha Devi[1], Ajay Thakur[2] and Hukum Singh[2]

[1]Forest Ecology and Climate Change Division, Forest Research Institute, New forest Post Office, Dehradun 248 006, Uttarakhand, India
[2] Genetics and Tree Improvement Division, Forest Research Institute, New forest Post Office, Dehradun 248 006, Uttarakhand, India

(Received 28 November, 2022; Accepted 2 February, 2023)

ABSTRACT

Above ground biomass is the core component of forests and it is known as indirect indicators of carbon storage capacity. The allometric equations help to estimate biomass without felling of trees and are primarily a non-destructive approach to estimate biomass and carbon. Biomass estimation of Bamboo forests can provide information about culm and clumpmaturity, primary productivity, carbon storage and cycling in the forest ecosystem. For accurate and non-destructive assessment of carbon storage and biomass energy values, it is essential to employ the appropriate tree biomass allometric equations. For estimating bamboo biomass, the allometric scaling principles have not been thoroughly investigated. Bamboos are monocotyledonous, hence using models created to estimate dicotyledonous plants' biomass is likely to result in inaccurate results. Height (H) is a key indicator of forest production and demographics.As a result, H-D models are frequently employed to forecast the heights that are lacking from diameter field measurements. Compared to woody dicots, information on H-D correlations for woody monocots, such as bamboos, is sometimes limited. Allometric equations are site and species-specific and thus the selection of equation is important to have a reliable estimate of biomass and carbon. Therefore, for bamboos, the development of age-specific and species-specific equations are strongly recommended for accurate biomass estimation. The present reviews various bamboo species allometric equations developed in several studies to assess above ground biomass and carbon storage potential in the bamboos of India.

Key words: *Bamboo biomass, Carbon storage, Forests, Allometric equations, Bamboo carbon*

Introduction

Globally, this fast-growing grass plant covers approx. 30 million hectares (INBAR, 2019a), and bamboos has proved to its capability to mitigate with the number of global challenges, including climate change, rural poverty, deforestation, land degradation, urban development, unsustainable resource use. (Gray *et al*., 2016; INBAR, 2019a, 2019b; Ingram *et al*., 2017; Nath *et al*., 2015; Odour, 2012; Terefe and Yu, 2019). Bamboos are one of the most important forest species of tropics and subtropics (Signar *et al*., 2017). Bamboo is becoming one of the important bio-resource lately because of its short harvest time (3-5 years). It has been observed that bamboos can capture significant amount of atmospheric carbon and consequently help in mitigating climate change, in a similar way that forests do in relatively short time (Wang *et al*., 2013; Zhang *et al.,* 2014; Zhou *et al*., 2011; Nath *et al*., 2015a; Yen, 2015).

Worldwide there are about 1662 species of bamboo comprising approximately 121 genera, 14% of the species found beyond their native ranges (Canavan *et al*., 2017).Eighty per cent of the total area covered by bamboo is located in Asia and roughly half of this in India (Lobovikov *et al*., 2007). Total of 136 bamboo species, 125 indigenous and 11 exotic species of bamboo, belonging to 23 genera, distributed in 7, 71,821 km2 area naturally and/or under cultivation (FSI, 2013). About 70% of species of bamboos in India are reported from the two-biodiversity hot-spots i.e. North-east India and the Western Ghats.For accurate and non-destructive assessment of carbon storage and biomass energy values, it is essential to employ the appropriate tree biomass allometric equations. For estimating bamboo biomass, the allometric scaling principles have not been thoroughly investigated. Bamboos are monocotyledonous, hence using models created to estimate dicotyledonous plants' biomass is likely to result in inaccurate results. Height (H) is a key indicator of forest production and demographics (Kempes *et al*., 2011). As a result, H and diameter (D) are frequently used as the two fundamental input variables in growth and biomass projection systems. However, obtaining data on H is comparatively more time- and labor-intensive (Huang *et al*., 2000). As a result, H-D models are frequently employed to forecast the heights that are lacking from diameter field measurements. Information on H-D relationships for woody monocots, such as bamboos, is often scarce in comparison to woody dicots. Asymptotic height (Hmax), which is the average maximum height attained by a cohort of mature trees, has frequently been employed as an essential indicator of species size in woody dicots, because H growth is frequently thought to be asymptotic (Thomas, 1996). However, most data do not show the asymptotic horizon of size, and new research has cast doubt on the biological reality of Hmax (Angome *et al*., 2018). Information on H-D relationships and Hmax is essentially nonexistent for woody monocots like bamboos.

However, there aren't any generic biomass estimation models that can be used to many bamboo species (Bontemps and Duplat, 2012). Following the harvest approach, species-specific biomass equations for several of the India min bamboo species have been created (Kumar *et al.,* 2005; Nath *et al*., 2009 and Singnar *et al*., 2017). The relationships between diameter and height have been found to vary across environmental conditions, reducing importance of species type in determining accuracy of equation (Banin *et al.,* 2012; Fayolle *et al*., 2013). Additionally, only a small amount of biomass production and terrestrial carbon capture from bamboo species is possible under various climatic conditions (Nath *et al*., 2015). Moreover, due to structural habit of being uneven aged, the challenging part in biomass estimation is to quantify the differently aged culms distributed in a clump and makes it a complicated process.

Materials and Methods

The methodology system utilized in this review included two stages: first stage dealt with compilation of all available biomass allometric equations for bamboos in India and second stage dealt with validation of the equations. Articles published on India's bamboo biomass assessment studies were accessed from Web of Science and Google Scholar. A blend of keywords including "tree biomass assessment, "Bamboo biomass""biomass stock assessment", "bamboobiomass carbon storage,""allometric biomass equations for bamboos", "bamboo biomass stock,""bamboo species biomass assessment model", were utilized to look through distributed articles.An aggregate of 150-200 distributed articles were short-listed for basic screening. The articles were selected by following these criteria: (i) articles should provide the detailed description about the method of data collection and accurate information about the study area, (ii) study dealt with the model development in biomass estimation for Indian bamboo species. The primary emphasis was on extracting information on different biomass pools such as AGB, total biomass (TB), and components like a branch, bole, and roots.

Results and Discussion

Allometric equations for Biomass Estimation

Allometry is a non-destructive approach for forest biomass estimation using measurements that do not require to harvest trees (FAO 2012). It uses allometric equations, conversion factors and other statistical methods to estimate in-situ (Table 2) and/or remotely sensed biomass and extrapolate to larger ground area. These equations calculate biomass based on other factors such as diameter at breast height (dbh), tree height, wood density, etc. Allometry is based on the principle of relating 'size of one structure in an organism to the size or amount of another structure in the same organism,' and extend the results to a larger area with same characteristics (FAO 2012). The allometric equations apply the scaling relationships between tree form and function to derive the tree biomass, total as well as in different components such as branch, needle, bole, root, bark, foliage etc. (West *et al*., 1999).

Development of allometric equations and models

The development of the allometric equations involves destructive sampling, which entails harvesting or selecting sample trees for morphometric measurements, followed by the felling of the tree to determine its age and the dry weight of its many components, including the bole, first order branches, other branches, foliage, cones, root system, etc. The harvested biomass data for the sample trees for total tree as well as each component is then related to morphological measurements such as dbh, height etc. using various statistical equations and models such as regression equations (Chatuvedi and Singh, 1982), non-linear seemingly unrelated regression; logarithmic models (Vorster *et al*., 2020) etc. These developed allometric or volumetric equations along with conversion factors (Figure 1.) can be applied directly in non-destructive studies of biomass estimation.

Due to their rapid development, bamboos growth and wood density greatly vary with age and species.

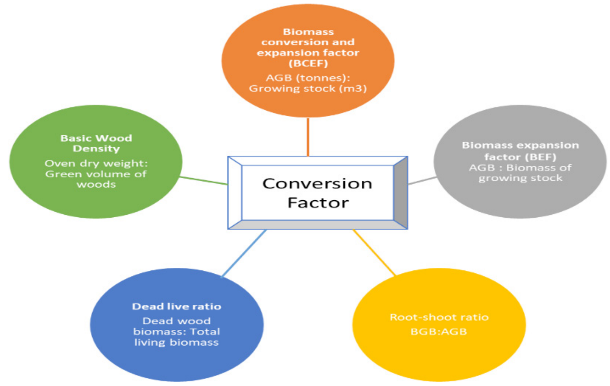

Fig. 1. Various conversion factors used in biomass estimation studies. (Source: FRA 2005, IPCC 2006).

Therefore, it is strongly advised to create age- and species-specific equations for bamboos in order to estimate biomass accurately. In order to create biomass equations for 10 different bamboo species, six investigations were conducted in India (Table 2). However, a variety of variables, including the availability of the independent variables employed, the format of the equations, and the quantity of collected data used in equation formation, have a significant impact on how reliable these equations are for use in the future. For each equation, the variable D is conveniently available. It is typically advised to forecast various plant biomass with greater accuracy than other factors (Lui *et al*., 2017; Bramha *et al*., 2021).

H has commonly been employed as a covariate in volume equations for estimating AGB in bamboos. For the development of age-specific Power-law equations for bamboo culms under 1 to >3 yr of age for different species in India, at least 15 different

Table 1. Various methods for vegetation carbon estimation using inventory-based approach (Source: Modified from Sun and Liu, 2020)

Methods	Basic Formula	Data required	
	Average biomass method	Y= A x y x d	Forest area, average biomass density, carbon content rate
Inventory-based Biomass Estimation	Volume-derived method	Y= A x (a x V + b) x d	Forest area, stand volume, carbon content rate
	Biomass regression equation	Y= A x a x $(D^bH)^c$ x d	Forest area, dbh, tree height, carbon content rate
	Conversion factor continuous method	BEF= a + b/vY = A x V x BEF x d	Stand volume, forest area, carbon content rate

Y= vegetation carbon storage, A= forest area, y= average biomass or average density, V= stand volume, D= diameter at breast height (dbh), H= tree height, d= carbon content rate of forest, BEF= biomass expansion factor, a,b, and c are constants based on forest types or climatic zones bamboo culm biomass data have been used. At least 90 culms were used in the development of the AGB equations for *Pseudostachyum polymorphum, Dendrocalamus strictus, Melocanna baccifera, and Schizostachyum dullooa*. In India, there was only one study that discussed AGB estimation of banana plants (Laskar *et al.*, 2020). There have been reported species-specific formulae for the AGB calculations of 26 woody tree species in India. Model accuracy is substantially impacted by the required minimal dataset for equation development. Consequently, it is advised to have more than 40 retrieved samples for the creation of the AGB model of woody species (Sileshi, 2014). About 60% of research published in India employed less than 40 numbers of harvested biomass data for developing equations, according to the graph of harvested data frequency (Table 2). 13 research in all employed 50 to 160 gathered biomass data to generate AGB equations. According to the AGB equation created (Nath *et al.*, 2019), at least 23 different woody trees were related to the tropical to subtropical bamboo species. The biggest percentage of the tree biomass, which ranged from 30 to 53% of the total tree biomass and 34 to 56% of the AGB (Nath *et al*., 2017; Naik *et al*., 2018; Singh *et al*., 2011; Swamy *et al.*, 2004), came from tree bole (Naik *et al*., 2018; Newaj *et al.*, 2016). Numerous independent variables, including D, (collar diameter), CD, circumference at breast height (CBH), number of branches (NB), and plant height (H), have been extensively used in previous reported studies to estimate bole or stem biomass. For estimating the biomass of bamboo culms and tree boles, respectively, 85 and 6 species-specific equations have been reported from India. The literature also contained three formulae for estimating the biomass of bole in mixed stands. *Dendrocalamus strictus* ranging in age from 1 to 4 years, power-law equations based on D of the

Table 2. Equations and default values used in various biomass and carbon estimation studies for the bamboos in India.

Associated Species	Equations	Age (yr)	Harvested sample size (number)	Sources
Bamboos				
Bambusaarundinacea	$AGB= 15.487 + 134.779D^2H$	1	25	Chandrashekara, 1996
Bambusaarundinacea	$AGB= 13.371 + 145.202D^2H$	2	25	Chandrashekara, 1996
Bambusaarundinacea	$AGB= 16.372 + 148.869D^2H$	3	25	Chandrashekara, 1996
Bambusaarundinacea	$AGB= 14.668 + 120.826D^2H$	>3	25	Chandrashekara, 1996
Bambusacacharensis	$\ln AGB= 2.078+2.140 \ln D$	<1	27	Nath *et al.*, 2009
Bambusacacharensis	$\ln AGB= 2.134+2.268 \ln D$	1	27	Nath *et al.*, 2009
Bambusacacharensis	$\ln AGB= 2.174+2.306 \ln D$	2	27	Nath *et al.*, 2009
Bambusacacharensis	$\ln AGB= 2.184+2.178 \ln D$	3	27	Nath *et al.*, 2009
Bambusa vulgaris	$\ln AGB= 2.281+2.149 \ln D$	<1	20	Nath *et al.*, 2009
Bambusa vulgaris	$\ln AGB=2.386+2.079 \ln D$	1	20	Nath *et al.*, 2009
Bambusa vulgaris	$\ln AGB= 2.554+1.956 \ln D$	2	20	Nath *et al.*, 2009
Bambusa vulgaris	$\ln AGB=2.548 + 1.970 \ln D$	3	20	Nath *et al.*, 2009
Bambusabalcooa	$\ln AGB=2.149 + 2.284 \ln D$	<1	20	Nath *et al.*, 2009
Bambusabalcooa	$\ln AGB =2.199+2.353 \ln D$	1	20	Nath *et al.*, 2009
Bambusabalcooa	$\ln AGB=2.368 + 2.214 \ln D$	2	20	Nath *et al.*, 2009
Bambusabalcooa	$\ln AGB= 2.153+2.477 \ln D$	3	20	Nath *et al.*, 2009
Bambusabambos	$AGB= -3.225.8 + 1730.4D$		9	Kumar *et al.*, 2006
Dendrocalamusstrictus	$AGB=0.1002D^{2.266}$	1 to 4	112	Kaushal *et al.*, 2016
Melocannabaccifera	$\ln AGB= \ln(-1.83) +1.11(\ln D^2)$	1 to 5	180	Singnar *et al.*, 2017
Pseudostachyum polymorphum	$\ln AGB= \ln(-7.76) +0.82 (\ln(D^2H)$	1 to 5	90	Singnar *et al.*, 2017
Schizostachyumdullooa	$\ln AGB= \ln(-4.33) +0.51(\ln(D^2H))$	1 to 4	132	Singnar *et al.*, 2017
Schizostachyumpergracile	$AGB=-2.99+1.83D$	<1	15	Thokchom and Yadava, 2017
Schizostachyumpergracile	$AGB= -3.12+2.12D$	1	15	Thokchom and Yadava, 2018
Schizostachyumpergracile	$AGB = -3.09+1.95D$	2	15	Thokchom and Yadava, 2019
Schizostachyumpergracile	$AGB = -2.92+1.63D$	3	15	Thokchom and Yadava, 2020
Schizostachyumpergracile	$AGB = -2.34+1.51D$	>3	15	Thokchom and Yadava, 2021

112 culms were established. The age-specific equations for 1 to >3-year-old *Bambusa arundinacea* have also been developed using the incorporation of H as a co-variable with D (Sileshi, 2014). The Power-law equations were employed in three investigations to calculate the biomass of mixed woody species in India (Rana *et al*., 1989; Chaturvedi *et al*., 2012; Chaturvedi and Raghubanshi, 2013). However, this research either took into account young or small woody diameter trees or assessed minimal harvest data for the construction of biomass equations.

There are four species-species regression equations for bamboo and 75 species-specific equations for estimating the branch biomass of woody plants, both of which were discovered to be published in India. For bamboos (*Bambusa arundinacea*) that are 1 to >3 years old, age-specific Power-law equations have been developed using H as a co-variable with D. Results from a small number of harvest data were used to generate these findings. After going through multiple validation steps, these equations can be used in subsequent references. There have been reported on five different biomass equations for Indian bamboos. Age-appropriate equations for culms from 1 to 3 years old growth of *Bambusa arundinacea* stands was dependent on the D and H of the culm. based on D of 112 culms of 1–4-year-old stands of *Dendrocalamus strictus,* Kaushal *et al.* have reported this regression equation model (2016).

Biomass estimation of bamboo species helps in quantifying the carbon dioxide which can be sequestered. Its estimation largely depends upon variety of factors (i.e., age of the stand, topography etc). In forestry, it can be generally done by direct method (destructive techniques) and indirect method (biomass equations). Out of this, the indirect method is less time consuming and cost effective. Several workers have selected the indirect method of biomass estimate for bamboo species (Nath *et al.,* 2015; Nfornkah, 2018). The reliability of the usage of the indirect method for biomass and carbon stock estimation can be improved by applying existing knowledge on tree allometry. The accuracy increases with the increase in the development of regional or local biomass equations by representing the varied factors like species-specific culm, culm growth behaviour, different culm ages in each clump, climatic parameters and soil properties etc. The fundamental tenet of allometry is that dependent factors quantitatively relate to independent variables, such as height or DBH, or both, and yield estimations that are generally accurate (Philips *et al*., 2002). Different linear and non-linear models have been developed worldwide for estimating biomass. Both linear and nonlinear models like mono molicular, logistic and allometric etc. are considered better for predicting biomass and depicting height-diameter relationship (Xu *et al*., 2018; Chimmi *et al*., 2018).

Conclusion

Bamboo is a key development resource for offering workable solutions to threats associated with climate change. Understanding the response of bamboo species in the Indian forest ecosystem in terms of carbon stock, carbon budgeting, carbon flux monitoring, and productivity for the mitigation of climate change requires the quantification of bamboo biomass. Since species-specific allometric equations are used, different regions may have different default values. Therefore, in order to reduce estimation bias and uncertainty, the best allometric equation must be chosen (Vorster *et al.,* 2020). The predictive models for bamboo biomass estimation are a crucial component in the current situation, especially by reducing the possible detrimental impact on the effectiveness of forests to act as carbon sinks. Carbon stocks of plant around the world is site are site-specific and dependent on stand composition, age, soil characteristics, and sustainable forest approaches. It is useful to determine the precise accurate carbon stock using an indirect method like allometric equations. Due to biological variety, geographic and environmental variables, and their management approaches, these equations are site- and species-specific. The creation of species-specific allometric equations for bamboo species would aid in the adoption of the IPCC Tier 3 technique (higher order approach is used, which incorporates precise mensuration measurements like species-specific allometric equations) for estimation of carbon stocks.

Acknowledgments

The authors are very thankful to university officials of Forest Research Institute (Deemed to be) University Dehradun India for supporting the field of the study.

Conflict of interest

None

References

Angom, S. D., Sinh, K. S. and Lalramnghinglova, H. 2018. aboveground biomass production of *Melocannabaccifera* and *Bambusatulda* in a sub-tropical bamboo forest in Lengpui, North-East.

Banin, L., Feldpausch, T.R., Phillips, O.L., Baker, T.R., Lloyd, J., Affum-Baffoe, K., Arets, E.J.M.M., Berry, N.J., Bradford, M., Brienen, R.J.W., Davies, S., Drescher, M., Higuchi, N., Hilbert, D.W., Hladik, A., Iida, Y., Salim, K.A., Kassim, A.R., King, D.A., Lopez-Gonzalez, G., Metcalfe, D., Nilus, R., Peh, K.S.-H., Reitsma, J.M., Sonké, B., Taedoumg, H., Tan, S., White, L., Wöll, H. and Lewis, S.L. 2012. What controls tropical forest architecture? Testing environmental, structural and floristic drivers. *Global Ecol. Biogeogr*. 21: 1179–1190

Bontemps, J.-D., Duplat, P.2012. A non-asymptotic sigmoid growth curve for top height growth in forest stands. Forestry 85, 353–368.

Canavan, S., Richardson, D. M., Visser, V., Le Roux, J. J., Vorontsova, M. S. and Wilson, J. R. U. 2017. The global distribution of bamboos: Assessing correlates of introduction and invasion. *Aob Plants*. 9(1): plw078. https://doi.org/10.1093/aobpla/plw078

Chaturvedi, O. and Singh, J. 1987. The structure and function of pine forest in Central Himalaya. I. Dry matter dynamics. *Ann. Bot*. 60 (3): 237–25

Chaturvedi, R., Raghubanshi, A. and Singh, J. 2012. Biomass estimation of dry tropical woody species at juvenile stage. *Sci. World J*. doi:10.1100/2012/790219.

Chaturvedi, R.K. and Raghubanshi, A. 2015. Allometric models for accurate estimation of aboveground biomass of teak in tropical dry forests of India. *For. Sci*. 61 (5): 938–949.

Chimi, C. D., Louis, Z. and Adrien, N. D. 2018. Diversity, structure and biomass (above and below) in a semi-deciduous moist forest of East Region of Cameroon. *Journal of Biodiversity and Environmental Sciences*. 12 (3): 60–72. 2220-6663 (Print) 2222-3045 (Online) http://www. innspub.net.

FAO, 2012. Guidelines on destructive measurement for forest biomass estimation. Rome: Author.

Fayolle, A., Doucet, J.L., Gillet, J.F., Bourland, N. and Lejeune, P. 2013. Tree allometry in Central Africa: Testing the validity of pantropical multi-species allometric equations for estimating biomass and carbon stocks. *Forest Ecology and Management*. 305: 29–37. doi:10.1016/j.foreco.2013.05.036 10.1016/j.foreco.2013.05.036.

FSI, 2015. Indian State of Forest Report 2015. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Dehradun, India.

Gray, C.L., Simmons, B.I., Fayle, T.M., Mann, D.J. and Slade, E.M. 2016. Are riparian forestreserves sources of invertebrate biodiversity spill over and associated ecosystem functions in oilpalm landscapes?. *Biological Conservation*. 194: 176–183. https://doi.org/10.1016/j.biocon.2015.12.017

Huang, S., Price, D. and Titus, S.J. 2000. Development of ecoregion-based heightdiameter models for white spruce in boreal forests. *For. Ecol. Manage*. 129:125–141.

INBAR, 2019a. Bamboo as a source of bioenergy. Facebook/Twitter: @INBAROfficial www.inbar.int.

INBAR, 2019b. Bamboo and climate change. Facebook/Twitter: @INBAROfficial www.inbar.int.

Ingram, V. 2017. Changing governance arrangements: NTFP value chains in the Congo Basin. *International Forest Review*. 19(S1): 18p. https://doi.org/10.1505/146554817822407394International Journal of Applied Earth Observation and Geoinformation, 66, 116–125. https://doi.org/10.1016/j.jag.2017.11.008

Kaushal, R., Subbulakshmi, V., Tomar, J.M.S., Alam, N.M., Jayaparkash,J., Mehta, H. and Chaturvedi, O.P. 2016.Predictive models for biomass and carbon stock estimation in male bamboo (*Dendrocalamus strictus* L.) in Doon valley, India. *Acta Ecologica Sinica*. 36 : 469 –476.

Kempes, C.P., West, G.B., Crowell, K. and Girvan, M. 2011. Predicting maximum treeheights and other traits from allometric scaling and resource limitations. *PLoS One*. 6 (6): e20551.

Laskar, S.Y., Sileshi, G.W., Nath, A.J. and Das, A.K. 2020. Allometric models for above andbelowground biomass of wild Musa stands in tropical semi evergreen forests. *Glob. Ecol. Conserv*. 24: e01208.

Liu, M., Feng, Z., Zhang, Z., Ma, C., Wang, M., Lian, B.L., Sun, R. and Zhang, L. 2017. Development and evaluation of height diameter at breast models for native ChineseMetasequoia. *Plos One*. 12 (8): e0182170.

Lobovikov, M., Lou, Y., Schöne, D. and Widenoja, R. 2009. The poor man's carbon sink. Bamboo in climate change and poverty alleviation. Non-Wood ForestProducts. Working Document (FAO), No. 8, FAO, Rome (Italy), 68 p.

Lobovikov, M., Schoene, D. and Lou, Y.P. 2012. Bamboo in climate change and rural livelihoods. *Mitigation and Adaptation Strategies for Global Change*. 17(3):261–276.

Naik, S.K., Sarkar, P.K., Das, B., Singh, A.K. and Bhatt, B.P. 2018. Predictive models for drybiomass and carbon stock estimation in Litchi chinensis under hot and dry sub-humidclimate. *Arch. Agron. Soil Sci*. 64 (10): 1366–1378.

Nath, A.J., Lal, R. and Das, A.K. 2015. Managing woody bamboos for carbonfarming and carbon trading. *Global Ecol Conserv*. 3: 654"663.

Nath, A.J. and Das, A.K. 2009.Carbon storage and sequestration in bamboo-based smallholder home gardens of Barak Valley, Assam. *Current Science*. 100 (2) : 25.

Nath, A.J., Das, G. and Das, A.K. 2009. Above ground standing biomass and carbon storagein village bamboos in North East India. *Biomass Bioenergy.* 33 (9): 1188–1196.

Nath, A.J., Lal, R. and Das, A.K. 2015a. Managing woody bamboos for carbon farming and carbon trading. *Glob. Ecol. Conserv*. 3: 654–664

Nath, S., Nath, A.J., Sileshi, G.W. and Das, A.K. 2015. Biomass stocks and carbon storage inBarringtonia acutangula floodplain forests in North East India. *Biomass Bioenergy.* 98: 37–42.

Newaj, R., Chavan, S.B., Alam, B. and Dhyani, S.K. 2016. Biomass and carbon storage in treesgrown under different agroforestry systems in semi arid region of central India. *Indian For*. 142 (7): 642–648

Nfornkah, B. N., Zapfack, L., Tchamba, M., Chimi, D. C. and Sonke, B. 2018. A protocol to estimateepiphyte biomass in a forest management unit: Case of Cameroon. *Journal of Sustainable Forestry.* 37(6): 619–631. https://doi.org/10.1080/10549811.2018.1449122

Odour, N. 2012. Sustainable Feedstock Management for Charcoal Production in Kenya, Resources,initiatives and Options: Working Paper. Practical Action Consulting Eastern Africa; 40 pg.

Rana, B., Singh, S. and Singh, R. 1989. Biomass and net primary productivity in CentralHimalayan forests along an altitudinal gradient. *For. Ecol. Manag.* 27 (3-4): 199–218.

Sileshi, G.W. 2014. A critical review of forest biomass estimation models, common mistakes and corrective measures. *For. Ecol. Manag*. 329: 237–254

Singh, V., Tewari, A., Kushwaha, S.P. and Dadhwal, V.K. 2011. Formulating allometric equations for estimating biomass and carbon stock in small diameter trees. *For. Ecol. Manag*. 261 (11) : 1945–1949

Singnar. P., Das M.C., Sileshi, G.W., Brahma, B., Nath, A.J. and Das, A.K. 2017. Allometric scaling, biomass accumulation and carbon stocks in different aged stands of thin-walled bamboos *Schizosta chyumdullooa, Pseudostachyum polymorphism and Melocanna baccifera. For. Ecol. Manage*. 395: 81–91.

Swamy, S., Kushwaha, S. and Puri, S. 2004. Tree growth, biomass, allometry and nutrientdistribution in Gmelina arborea stands grown in red lateritic soils of Central India. *Biomass Bioenergy*. 26 (4): 305–317.

Terefe, R. L. J. and Yu, K. 2019. Role of bamboo forest for mitigation and adaptation to climatechange challenges in China. *Journal of Scientific Research & Reports.* 24(1): 1–7. 2019; Article no.JSRR.44239 2320-0227. https://doi.org/10.9734/jsrr/2019/v24i130145

Thomas, S.C.1996. Asymptotic height as a predictor of growth and allometric characteristics in Malaysian rain forest trees. *Am. J. Bot*. 83: 556–566.

Wang, B., Wei, W.J., Liu, C.J., You, W.Z., Niu, X. and Man, R.Z. 2013. Biomass and carbon stock in Moso bamboo forests in subtropical China: characteristics and implications. *J. Trop. For. Sci*. 25 : 137–148.

West, G.B., Brown, J.H. and Enquist, B.J. 1999. A general model for the structure andallometry of plant vascular systems. *Nature.* 400: 664–667.

Yen, T. M., Ji, Y. J. and and Lee, J. S. 2010. Estimating biomass production and carbon storage for afast-growing makino bamboo (*Phyllostachys makino)* plant based on the diameter distributionmodel. *Forest Ecology and Management*. 260: 339–344. INBAR. https://doi.org/10.1016/j.foreco.2010.04.021

Yen, T.M. 2015. Comparing aboveground structure and aboveground carbon storage of an age series of moso bamboo forests subjected to different management strategies. *J. For. Res*. 20: 1–8

Zhang, H., Zhuang, S., Sun, B., Ji, H., Li, C. and Zhou, S.2014. Estimation of biomass and carbonstorage of Moso bamboo (*Phyllostachys pubescens* Mazel ex Houz.) in Southern China using adiameter- age bivariate distribution model. *International Journal of Forest Resources*. 87: 674–682.

Zhao, Y., Feng, D., Jayaraman, D., Belay, D., Sebrala, H., Ngugi, J. and Kissa, S. 2018. Bamboomapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery.