International Journal of Research in Agriculture and Forestry
Volume 3, Issue 1, January 2016, PP 49-56
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

Investigation of the Desirable Predictor Variable in Accounting Above-Ground Carbon for *Pseudolachnostylis maprouneifolia* Pax. (Kudu-Berry)

Nyatwere Donasian Mganga

Department of Life Sciences, Mkwawa University College of Education (A Constituent College of the University of Dar e Salaam), Private Bag, Iringa, Tanzania

ABSTRACT

Biological interactions that involve the capture of the ever increasing levels of carbon dioxide in forest ecosystems have drawn global attentions to carbon accounting. In the present study the desirable predictor variable in carbon accounting was established in *Pseudolachnostylis maprouneifolia* Pax. Twenty one trees of *P. maprouneifolia* Pax with diameter at breast height (DBH) from 5.7 to 14.7 cm and total height (H) between 300 cm to 672 cm were destructively sampled from Miombo woodland of Ilunde in Tanzania. Regression analysis was carried out by using DBH and H as predictor variables. The best fit allometric models in stems and branches were obtained when both H and DBH were used as predictor variables with coefficient of determination values (R^2) of 0.99 and 0.79 at $P < 0.05$, on the contrary, in leaves and/or twigs the best fit allometric model had R^2 of 0.96 when DBH was the only predictor variable.In *P. maprouneifolia* Pax. measurement of both DBH and H is recommended for reliable carbon inventory in the Central Zambezian Miombo woodlands under the specified tree dimensions.

Keywords: branches, leaves, predictor, *Pseudolachnostylis maprouneifolia*, stem, twigs, variable.

INTRODUCTION

Miombo woodlands like other forest ecosystems are important carbon sinks and reduce emissions of carbon dioxide which accounts for nearly half of the atmospheric warming, through photosynthesis [1, 2]. Main miombo genera (*Brachystegia*, *Julbernadia* and *Isoberlinia*) and miombo associates such as *Pseudolachnostylis maprouneifolia* Pax., *Pterocarpus angolensis* DC. and *Parinari curatellifolia* Planch. ex Benth. comprise 95-98% of the above-ground biomass, while grasses and herbs make up the remaining portion [3]. That is why main efforts on biomass estimation to date have paid attention to the above-ground tree components (foliage and/or leaves, branches and stem) because they account for the greatest fraction of total biomass density. Miombo woodlands have carbon densities ranging between 15 and 100 t C ha^{-1} in woody biomass [4]. *Pseudolachnostylis maprouneifolia* Pax. is among the most abundant miombo associates and efficient in carbon storage [5, 6, 7, 8].

In the tropics much attention has been placed on developing generalised biomass allometric models for carbon accounting [9, 10]. However, the use of generalized equations can lead to a bias in estimating biomass for a particular species [11, 12, 13], hence the need to develop species-specific allometric models. Development of these equations for different forests/vegetation types requires destructive sampling. However, once developed, biomass allometric models are effective in

Address for correspondence:

nyatwere2@yahoo.com

estimating above-ground biomass so is quantification of carbon over large areas of forests without further destruction of vegetation.

So far species-specific allometric models for miombo-defining species include that of *Brachystegia spiciformis* Benth. and *Brachystegia boehmii* Taub. [14, 15]. It is evident that allometric models developed so far to estimate carbon sequestered in biomass for miombo woodland species have targeted only a few species especially for the non-miombo defining species such as *Pseudolachnostylis maprouneifolia* Pax, *Pterocarpus angolensis* DC. and *Parinari curatellifolia* Planch. ex Benth..

In developing allometric models, regression functions are developed from which biomass hence carbon can be predicted using easily measurable variables such as tree height and diameter [16]. It follows that, some equations use DBH as a predictor variable or H as a predictor variable, while others use both DBH and H as predictor variables.

Thus, the objective of this study was to investigate the suitable predictor variable in estimation of carbon using DBH and H as predictor variables and relating them with leaves and/or foliage, branches and stem of *Pseudolachnostylis maprounefolia* Pax.

METHODOLOGY

The Study Area

The study was confined to forested ecosystem of Ilunde which is located between latitudes 5° 00 and 6° 00 S, and longitudes 30° and 31° E in the Western Tanzania (Figure 1).

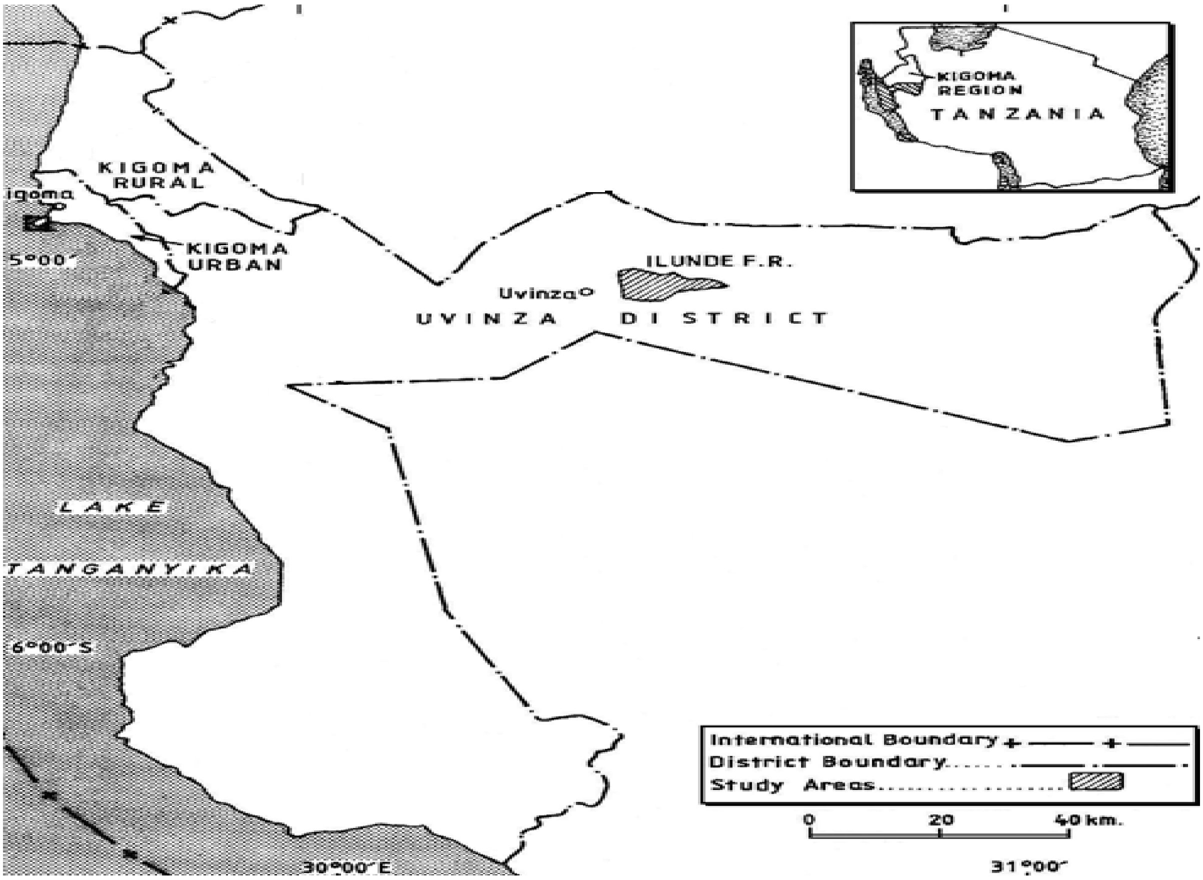

Figure1. *Location of the study area*

The area is characterized by tropical rainy climate and receives modest amount of rainfall varying from 900-1050 mm and experiences one long wet season lasting from November to May and one long dry season [17]. Vegetation typology of the study area was once characterized by pristine forests of miombo woodlands [18]. Ilunde forest has been facing anthropogenic pressure despite of the slogan seen in Figure 2 ('ACHA KUKATA MITI WEWE, ACHA KUCHOMA MOTO WEWE, ACHA KUINGIZA MIFUGO WEWE' meaning DON'T CUT TREES, DON'T START FIRE, DON'T GRAZE IN').

Tree Sampling

A total of 21 trees with DBH and H ranging between 5.7 cm and 14.7 cm, 300cm and 672 cm, respectively were destructively sampled, randomly as recommended by [19] and [20] for development of biomass allometric models. Sampling was restricted to trees with that DBH and H ranges based on sizes of trees that were encountered in the field. The selected trees were measured of their DBH and total heights, then felled at 0.3 m above the ground as recommended by [2].

The felled trees were then divided into stems, branches, leaves and twigs. The stems were cut into sections of 1 to 2 m billets depending on their length (Figure 3), as recommended by [19]. The components were weighed separately in the field for green weight (Figure 4). Wood discs of 2 cm thick were cut from the middle part of different sections of the stem and branches. The samples were weighed immediately to determine the sub-sample green weight and labelled. Sub-samples of twigs and leaves of 50 g were collected from each tree. Prior to transportation, the collected discs and leaves were air-dried to prevent rotting (see Figure 5). All samples were transported to the Botany laboratory of the University of Dar es Salaam for determination of biomass and ultimately carbon.

Figure2. *Slogan on forest conservation*

Figure3. *Billets of P. maprouneifolia Pax.*

Figure4. *Weighing of billet in the field*

Figure5. *In situ air-drying of tree discs*

Sample Treatment

The twigs and leaves were oven dried to constant weight at 70ºC as recommended by [14]. On the other hand, sub-samples from stems and branches were oven dried at 105ºC to constant weight so as to obtain oven-dry weight in accordance with [21]. Biomass ratio was calculated as a ratio between the oven-dry weight and sub-sample green weight.

$$\text{Biomass ratio} = \frac{\text{Sub} - \text{sample oven dry weight}}{\text{Sub} - \text{sample green weight}}$$

Biomass = Biomass ratio x Field green weight (kg tree^{-1}) [19]

Carbon in tree (kg tree^{-1}) = Biomass x 0.5

Tree carbon was estimated as 50% of the biomass [2, 22].

In this study, above-ground carbon (kg) was used as a dependent variable, while DBH (cm) and H (cm) were used as independent variables. The calculated carbon for each tree component was regressed against tree DBH and H to develop above-ground carbon allometric models. Regression equations were developed from data obtained from 21 trees that were destructively sampled using steps outlined in Excel Microsoft Windows version 2007.

Linear regression was performed on the dependent and independent variables. Scatter plots were generated for all variables using the original variables initially, then with all variables transformed. Using raw data and logarithmically transformed data, carbon was first modelled as a linear function for each predictor variable. The equations were obtained through simple and multiple linear regression analysis, after testing for co-linearity between the selected variables. The data were logarithmically transformed so as to equalize the variances over the whole range of carbon values, which is a condition required for linear regression, enabling the use of parametric statistical analyses [23].

Finally, logarithmic units were converted to arithmetic units to obtain the reliable carbon content in accordance with [24]. In the present study, the criteria used to select the best fit models were: highest coefficient of determination (R^2), lowest standard error (SE) of Y estimated values [19]. Besides, overall higher F-value at 95% confidence level was considered for upgrading of the best fit models [25].

The following are the general forms of functions that were fitted to the collected data as recommended by [26]:

1. $Y = a + b\,DBH$ 2. $Y = a + b\,DBH + c\,H$

3. $Ln\,(Y) = a + b\,Ln\,DBH$ 4. $Ln\,(Y) = a + b\,Ln\,DBH + c\,Ln\,(H)$

Where:

Y = Carbon (kg tree^{-1} component)

DBH = Diameter at Breast Height (cm)

H = Total tree height (cm)

a, b and c = regression coefficients

b and c correspond to DBH and H value for multiple ranges

a = Y-intercept which is a constant

RESULT& DISCUSSION

Results

The allometric models for prediction of carbon in the components of *Pseudolachnostylis maprouneifolia* Pax. are shown in Table 1. All six models developed explained well the relationship between tree carbon and the predictor variables (DBH and H) with the coefficient of determination, standard error and F-value ranging from 0.40 to 0.99, 0.05 to 3.37 and 12.88 to 1101.34, respectively.

The best fit allometric models that were developed to estimate stem and branch carbon in *Pseudolachnostylis maprouneifolia* Pax. were obtained when using DBH and H as predictor variables. However, the best fit model in estimation of leaves and twigs carbon used only DBH as a predictor variable. In the studied species, stem explained 99% of the variation in carbon content, while the branches, and leaves and twigs accounted for 79% and 96% of carbon respectively.

Table1. *Allometric Models and their Goodness of Fit for Estimation of Above-ground Carbon of Stem, Branch, and Twigs and Leaves in P. maprouneifolia Pax*

Part	Model	Allometric relationship	R^2	SE	F-value
Stem	1	$Y = -8.351 + 1.676\ DBH + 0.004\ H$	0.97	0.64	427.16
	2*	$Y = -3.547\ DBH^{1.817}\ H^{0.265}$	0.99	0.05	1101.34
	3	$Y = -7.424 + 1.775\ DBH$	0.97	0.71	695.33
	4	$Y = -2.227\ DBH^{1.961}$	0.98	0.07	1082.66
	5	$Y = -4.416 + 0.025\ H$	0.40	3.37	12.88
	6	$Y = -7.250\ H^{1.489}$	0.46	0.38	15.91
Branches	1	$Y = -5.313 + 0.421\ DBH + 0.009\ H$	0.76	1.07	27.86
	2*	$Y = -9.129\ DBH^{1.445} + H^{1.117}$	0.79	0.30	34.15
	3	$Y = -3.000 + 0.669\ DBH$	0.60	1.33	27.98
	4	$Y = -3.561\ DBH^{2.049}$	0.68	0.36	41.76
	5	$Y = -4.324 + 0.015\ H$	0.59	1.33	28.38
	6	$Y = -12.074\ H^{2.091}$	0.57	0.42	25.65
Twigs and/or leaves	1	$Y = -1.557 + 0.285\ DBH + 0.001\ H$	0.95	0.17	183.54
	2	$Y = -5.724\ DBH^{1.879}\ H^{0.312}$	0.97	0.10	258.73
	3	$Y = -1.308 + 0.311\ DBH$	0.93	0.19	296.23
	4*	$Y = -4.169\ DBH^{2.047}$	0.96	0.12	403.99
	5	$Y = -0.889 + 0.004\ H$	0.43	0.59	14.46
	6	$Y = -9.552\ H^{1.578}$	0.45	0.41	15.91

Asterick (*) = best fit model

The best fit allometric model for total above-ground carbon in *P. maprouneifolia* was obtained using both DBH and H as predictor variables (Table 2).

Table 2. *Allometric Models and their Goodness of Fit for Estimation of Total Tree Above-ground Carbon in P. maprouneifolia Pax.*

Model	Allometric relationship	R^2	SE	F-value
1	$Y = -15.221 + 2.382\ DBH + 0.014\ H$	0.95	1.58	175.05
2*	$Y = -4.366\ DBH^{1.746}\ H^{0.489}$	0.97	0.09	349.31
3	$Y = -11.733 + 2.755\ DBH$	0.91	1.99	212.70
4	$Y = -1.926\ DBH^{2.011}$	0.95	0.13	334.79
5	$Y = -9.629 + 0.045\ H$	0.49	4.94	18.70
6	$Y = -7.925\ H^{1.66f6}$	0.52	0.38	20.74

DISCUSSION

The results of this study show the usefulness of total height and diameter at breast height in estimation of total tree, stem and branches carbon in *Pseudolachnostylis maprouneifolia* Pax, with R^2 values of 0.97, 0.99 and 0.79 respectively, all at $P < 0.05$. This implies that both height and diameter at breast height contribute substantially to the stock of carbon in *Pseudolachnostylis maprouneifolia* Pax.

The relationship between total and components (stem and branches) carbon, and the DBH and H obtained in the present study is in agreement to that reported in semi-arid Rangeland of Ethiopia by [27]. The analogy that exists among specific allometric models on the predictor variable(s) regardless of the ecosystems concerned could be answered by allometry.

On the contrary, the best fit allometric model in estimation of leaves and twigs carbon used only DBH as a predictor variable. This suggests a linear relation that exists between leaves and/or twigs and girth of the tree stem. In a study carried out in Hawaiian woody plants, it was reported that allometric models in foliage and wood relied only on DBH [28].

Inclusion of height as a predictor variable in *Pseudolachnostylis maprouneifolia* branch carbon allometric model resulted into large coefficient of determination. It was observed that in *P. maprouneifolia* inclusion of total height improved the model by 1%, 11% and 1% for stem, branches and leaves and/or twigs respectively. Low coefficient of determination in branch carbon and improvement in the fitness of above-ground carbon allometric models by including total height as a predictor variable is in agreement with [29], whereby inclusion of total height as a predictor variable improved the model by 0.5-2%.

CONCLUSION

Estimation of leafy carbon in *P.maprouneifolia* Pax. could be precisely accomplished by measurement of DBH only. However, it would be illogical to exclude stem and branch in carbon inventory. Thus, both diameter at breast height and total height are suitable variables in accounting carbon in *P. maprouneifolia* Pax. There is a need to investigate the power of predictor variables of more plant species in estimation of carbon so as to precisely comply with the emerging carbon credit market mechanism.

REFERENCES

[1] Mwandosya, J. M. 1999. Survival emissions: A Perspective from the South on global climate change negotiation. DUP Ltd. Dar es Salaam.177 pp.

[2] Munishi, P. K. T. and, Shear, T., 2004. Carbon storage of two Afromontane rain forests in the Eastern Arc Mountains of Tanzania. Journal of Tropical Forest Science, 6, 78-93.

[3] Chidumayo, E. N. 1993. Silvicultural Characteristics and Management of Miombo Woodlands. Paper Presented in the Conference on International Symposium on Ecology and Management of Indigenous Forest in Southern Africa, Victoria Falls Zimbabwe, July 27 to 29, 1992.

[4] P. Frost 1996. 'The ecology of miombo woodlands'. In: Campbell B (ed) The miombo in transition: Woodlands and welfare in Africa. CIFOR, Bogor, Indonesia. pp11-57.

[5] Gestão de Recursos Naturais e Biodiversidade (GRNB), 2009; Baseline Carbon Estimation in Dombe, Manica Biofuel Production Area Mozambique Principle Enery, Maputo, Mozambique.

[6] Kalaba, F. 2012. Carbon storage, biodiversity and species composition of Miombo woodlands in recovery trajectory after charcoal production and slash and burn agriculture in Zambia's Copperbelt. Centre for Climate Change Economics and Policy, Working Paper No. 119; Sustainability Research Institute Paper No. 40. pp 1-39.

[7] Kalaba, F. K., Quinn, C. H., Dougill, A. J., and Vinya, R. 2013. Floristic Composition, Species Diversity and Carbon Storage in Charcoal and Agriculture Fallows and Management Implications in Miombo Woodlands of Zambia. Forest Ecology and Management, 304, 99-109.

[8] Ribeiro, N. S., Matos, C. N., Moura, I. R., Washington-Allen, R. A., and Ribeiro, A. I., 2013. Monitoring Vegetation Dynamics and Carbon Stock Density in Miombo Woodlands. Carbon Balance Mnanagement, 8, 11-11.

[9] Brown, S. 1997. A Primer for estimating biomass and biomass changes of Tropical Forest. FAO Forest paper No. 134. Food and Agriculture Organization of the United Nations, Rome. 55 pp.

[10] Chave, J., Andalo, C., Brown, S., Cairns, M., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P.M., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., and Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145, 87 – 99.

[11] Clark, D. A., Brown, S., Kicklighter, D. W., Chambers, J. Q., Thomlinson, J. R., and J. Ni. 2001. Measuring net primary production in forests: Concepts and field methods. Ecological Applications, 11, 356–370.

[12] Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S., and Perez, R. 2004. Error propagation and scaling for tropical forest biomass estimates. Philosophical Transactions of the Royal Society B: Biological Sciences, 359, 409-420.

[13] Pilli, R., Anfodillo, T., and Carrer, M., 2006. Towards a functional and simplified allometry for estimating forest biomass. Forest Ecology and Management**,** 237, 583–593.

[14] Stromgaard, P. 1985. Biomass, growth and burning of woodland in a shifting cultivation area of south central Africa. Forest Ecology and Management, 12, 163-178.

[15] Brown, S. and, Lugo, A. E., 1982. The storage and production of organic matter in tropical forests and their role in global carbon cycle. Biotropica, 14, 161-167.

[16] Stewart, J. L., Dunsdon, A. J., Hellin, J. J., and Hughes, C. E., 1992. Wood biomass estimation of central American dry zone species. Tropical forestry papers: University of Oxford, Oxford Forestry Institute, Department of Plant Sciences, Oxford, 83 pp.

[17] Kigoma Water Masterplan, 1980. Hydrology: Volume 7. NorConsult Consulting Engineers, Norway.

[18] Chepstow-Lusty, A., Winfield, M., Wallis, J., and Collins, A., 2006. The importance of local tree resources around Gombe National Park, western Tanzania: Implications for humans and chimpanzees. Ambio, 35, 124-129.

[19] Malimbwi, R. E., and Mugasha, A. G., 2002. Reconnaissance Timber Inventory for Handeni Hill Forest Reserve in Handeni District, Tanzania. Morogoro: FOCON-SULT.

[20] de Gier, A. 1999. Woody biomass assessment in woodlands and shrublands. Proceedings of a Workshop on Off-forest tree resources of Africa Held at Arusha, Tanzania, 12-16 July 1999.

[21] Ketterings, Q. M., and Bigham, J. M., 2000. Soil Color as an Indicator of Slash-and-Burn Fire Severity and Soil Fertility in Sumatra, Indonesia. Soil Science Society of America Journal, 64, 1826-1833.

[22] Basuki, T. M., van Laake, P. E., Skidmore, A. K., and Hussin, Y. A., 2009. Allometric equations for estimating the above-ground biomass in tropical lowland *Dipterocarp* forest. Forest Ecology and Management**,** 257, 1684-1694.

[23] Zar, J. H. 1974 Biostatistical analysis. Englewood Cliffs, NJ: Prentice-HaIl. Department of Biological Sciences. Northern Illinois University, DeKalb.

[24] Van, T. K., Rayachhetry, M. B., and Center, T. D., 2000. Estimating Above-ground Biomass of *Melaleuca quinquenervia* in Florida, USA. Journal of Aquatic Plant Management, 38, 62-67.

[25] Maraseni, T. N., Cockfield, G., and Apan, A., 2005. Community Based Forest Management Systems in Developing Countries and Eligibility for Clean Development Mechanism. Journal of Forest and Livelihood, 4, 31-42.

[26] Philip, M. S., 1983. Measuring trees and forests: a textbook for students in Africa, Viion of Foretry. University of Dar es Salaam, Tanzania.

[27] Hasen-Yusuf, M., Treydte, A. C., Abule, E. and Sauerbern, J., 2013. Predicting Aboveground Biomass of Woody Encroacher Species in Semi-arid Rangelands, Ethiopia. Journal of Arid Environments, 96, 64-72.

[28] Litton, C. M., and Kauffman, J. B., 2008. Allometric Models for Predicting Aboveground Biomass in Two Widespread Woody Plants in in Hawaii, U.S.A. Biotropica, 40(3), 313-320.

[29] Abbot, P., Lowore, J., and Werren, M., 1997. Models for Estimation of Single Tree Volume in Four Miombo Woodland Types. Forest Ecology and Management, 97, 25-37.