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Allometric relationships and carbon content for biomass-carbon estimation of East African Highland Bananas (*Musa spp*. AAA-EAHB) cv. *Kibuzi, Nakitembe, Enyeru* and *Nakinyika*

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Globally, interests to increase carbon stocks have gained momentum in both woody and non-woody ecosystems. Despite efforts made to generate appropriate methods to estimate these stocks, most equations developed do not cater for intraspecific variabilities across e.g. species, regions or growth stages; especially in the case of bananas. Therefore, there is need to develop more robust equations to improve on the precision of biomass-carbon prediction especially at local scales to facilitate estimation of specific carbon stocks often lost in global assessments. This study aimed at developing cultivar-specific biomass estimation relationships and determining carbon content of EAHB cultivars at two growth stages. Plant data were collected purposively using destructive sampling techniques on farmers' plots for 4 cultivars (*Kibuzi, Nakitembe, Enyeru* and *Nakinyika*) in two agro-ecological zones: the L. Victoria crescent and the South-western farmlands in the districts of Lwengo and Mbarara respectively. Results show that biomass differed across cultivars (P<0.001); hence four equations (*Enyeru, Nakinyika, Kibuzi_Nakitembe* and Generic) were developed following an exponential function, y=Aexp(ax), using diameter at breast height (DBH) as the predictor variable with an R² range of 82-94%. EAHB mean carbon content varied significantly with growth stage (P<0.05) (47.6% for maiden plants before flowering and 48.8% for mature plants with a developed bunch). This study concludes that it is important to develop cultivar-specific equations for biomass-carbon estimation of EAHB cultivars to help assess their contribution to the carbon cycle especially in future studies.

Key words: East African Highland Bananas (EAHB) cultivars, allometric equations, total plant biomass, carbon content, growth stage.

INTRODUCTION

Globally, interests to enhance carbon stocks in the biosphere have gained momentum in both woody and

non-woody ecosystems as a means to address global climate change (Nair et al., 2009; Anthony et al*.,* 2011; Lal, 2011). However, considering the continuous shortage of land available for production of woody ecosystems (Henry et al., 2009), the need to find accommodative alternatives to deal with increasing atmospheric GHGs without compromising food production and economic development has to be addressed, e.g. through use of perennial crops like banana. The approach has since then received attention despite that pre-requisites to actual implementation of such initiatives require accurate verifiable methods developed to estimate biomass, carbon content and carbon stocks especially in agricultural landscapes (Singha et al*.,* 2011; Shem et al*.,* 2013) which remains a big challenge.

Nevertheless, efforts to estimate species biomass in both natural and agricultural ecosystems have been realized especially for crops like coffee, banana, commercial tree species, cocoa, etc., whose allometric equations have been globally developed (Hairiah et al., 2001; IPCC, 2003; Nyombi et al*.,* 2009; ICRAF, 2011). This has mainly been attributed, for example, to the need to explore the role of such species in the global carbon cycle through carbon sequestration monitoring, as well as for their sustainable management (Eamus et al*.,* 2000). In spite the importance of appropriate methods to estimate carbon stocks, these equations do not cater for intraspecific variabilities across e.g. species, regions or growth stage. Hence the need to develop more robust and viable equations to accurately capture the impact of region-specific and species-specific carbon contents and stocks of ecosystem components which are in most cases lost in global assessments (Hutchinson et al*.,* 2007).

Uganda is one of the largest national producers of bananas (*Musa* spp.) in the world; and is recognized as a secondary center of diversity with high levels of different cultivars observed on individual farms (Suzanne and Emile, 1999; Edmeades et al*.,* 2005; FAO, 2009). Over 75% of the cultivars are East African Highland Bananas (EAHB) (Karamura, 1998; Nantale et al., 2008). The perennial crop is an important food security crop cultivated in a wide range of agro-ecological zones and readily available throughout the year (NARO, 2001; Eledu et al*.,* 2004; Wairegi, 2010). Though the potential of bananas to sequester carbon has been reported (e.g. Lascoa et al., 2000; Christina, 2004; Oliver, 2009), there is limited knowledge on how much different cultivars contribute despite their high morphological and physiological differences. This could perhaps be attributed to the lack of cultivar-specific methods to estimate their

biomass. This is because existing equations widely used in carbon studies were developed by Arifin (2001) using bananas grown in Indonesia that perhaps exhibit different morphological traits as compared to EAHB.

Nevertheless, efforts made by Nyombi et al. (2009) to develop such equations for EAHB are worth appreciating though they did not explore the use of Diameter at Breast Height (DBH) to predict plant biomass, a commonly used predictor variable in many carbon related studies (e.g. Amy et al., 2010; Arias et al., 2011 and Adeline et al., 2013 among others). In addition, DBH has been considered as the best explanatory variable for biomass prediction of several species, but also given its ease to measure and high accuracy (Shem et al., 2013). Key variables commonly used for bananas have mainly been the pseudo-stem girth-at-base, its diameter at 100cm, and or plant height (Nyombi et al*.,* 2009; Wairegi et al., 2009); hence the need to explore the use of DBH as a predictor variable for biomass of EAHB cultivars was worth considering in this study.

On the-other-hand, carbon content values are an important element to consider in any carbon related study. Though scarce, information on local carbon content values is more important than generalized ones as recommended by Timothy et al*.* (2005). This is because such data on various species e.g. bananas are essential for accurate assessment of their carbon stocks (Arias et al., 2011). However, the conversion coefficient of biomass to carbon stock of 50% that has been universally accepted and promulgated by scientific bodies, e.g. IPCC (Timothy et al., 2005; West, 2009), is subject to debate given that it perhaps does not cater for intraspecific variabilities across species, different growth stages, or even regions.

But also, other studies have proposed the use of a default carbon content conversion value of 0.46 for trees (Hairiah et al., 2010), lower than one recommended by IPCC. However, a study by Thomas and Malczewski (2007) found out that coniferous trees had a higher carbon content value of 50.9% than other hardwoods in China, while others like (Gifford, 2000) actually noted a 54.1% content for *Pinus radiate* in Australia, all higher than the 50% value. This therefore shows great uncertainties in the use of one carbon content value as opposed to another; hence a great need to estimate species-specific carbon content values to better estimate their carbon stocks. This could also be considered for different growth stages for species like banana with different development stages that exhibit several carbon content potential components. Therefore, this study also determined the actual carbon content value of EAHB to

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minimize over or under estimation of carbon stocks that could perhaps be brought about by the use of general values.

MATERIALS AND METHODS

Study area

Plant biomass-carbon data were obtained in 2013 from two distinct agro-ecological zones; that is, the Lake Victoria Crescent and South-western Grass Farmlands in Kisekka and Nyakayojo sub-counties of Lwengo and Mbarara districts respectively. These were classified as potential banana production areas by Eledu et al. (2004). Mbarara district lies at a high altitude of about 1400 m above sea level (0°20.5'S 30°31'E) and Lwengo at a low altitude range of 1080-1330 m above sea level (00°24'S 31°25'E) (Nantale et al., 2008; Kemigabo and Adamek, 2010). Both areas experience a bimodal mean annual rainfall range of about 1000-1500 mm (Lwengo) and 1000-1200 mm (Mbarara). Their mean annual temperature range lies between 20-25°C. According to the 1998 FAO soil classification, the soil types are acric ferrasols, and dystric regosols and lixic ferrasols for Kisekka and Nyakayojo respectively. However, to minimize variability across zones, all farms selected were comprised of the ferralsol soils given that they are deep in nature and cover about 60% of the potential banana production area for Uganda (Eledu et al., 2004).

Farm site selection

Based on the preliminary findings of the reconnaissance survey conducted in December 2012 and with the aim of minimizing the effect of potential confounding factors, participating farmers were purposively selected following a set of criteria: i) The farm had all the cultivars of interest; ii) The plantation was mature (20 to over 50 years); iii) All farms in a given region existed in a similar soil type classification and relatively same altitude range; iv) The farmer was willing to participate fully in the study. (ii) and (iv) were also considered for the same reason in other studies (e.g. Nantale et al., 2008; Wairegi et al., 2009). In total therefore, 14 farmer plantations (7 in each area) were considered since they were the only ones meeting the criteria; but also considering the availability of resources. Four cultivars (*Kibuzi* and *Nakitembe* existing in both sites, and *Enyeru* and *Nakinyika* being unique to Mbarara and Lwengo respectively) were selected because they had a higher population density than others identified, similar to observations by Wairegi et al. (2009); and their total biomass allometric relationships had not been developed before.

Biomass estimation

In each sampling plot, all individuals belonging to the cultivars of interest were inventoried *in-situ* before destructive sampling (ICRAF, 2011). Estimation of total plant biomass therefore included non-destructive sampling measurements (Height and Diameter) of individual banana stems important for use in the allometric models generated for this study as suggested by Wairegi et al. (2009) and ICRAF (2011). To minimize bias and cater for variability, six individual mats, two for each cultivar, were purposively identified anywhere on the same farm. These were then tagged for excavation for dry weight biomass and oven-dry carbon content determination. Care was taken to ensure that mats selected had at least two individuals at different growth stages; that is, H1 (maiden plant before flowering, at least half or more the height of H2) and H2 (plant at true phonological maturity with a developed bunch). Therefore, a total 84 mats (14 per cultivar per site) were sampled. For every mat, total plant biomass (TPB) of selected plants was obtained and used to develop cultivar specific allometric relationships. In general, allometric relationships for trees are best taken at DBH (1.3m) in reference to Brown et al. (1989). However, a number of studies such as Wairegi et al. (2009) and Nyombi et al. (2009) have developed similar relationships for EAHB bananas considering Girth at base (G^{Base}) and Diameter at 1 m (D^{100cm}); and height. Therefore, in this study, all the three diameter levels and height were considered to find out which one best predicts the relationship for a specific cultivar. Girth at base was calculated as πD.

Individual plants were then carefully dug out from the soil and prepared following procedures detailed in Nyombi et al. (2009). Sub-samples of each part (pseudo-stem, leaves, corm, peduncle and fingers), 250 g each, were weighed, bulked and carried to the Soil Science Laboratory in Kawanda. These were oven dried to constant weight at approximately 70°C for 48 h (Timothy et al., 2005). In total, 1001 sub-samples representing all plant parts for all cultivars were obtained (that is, 420 for H1 class and 581 for H2; each class comprising of 5 and 7 samples per individual respectively). Total plant part dry mass (biomass) was then calculated based on an equation obtained from Timothy et al. (2005); where:

$$DryMass(kgs) = \left[\frac{Subsample\,Dry\,Mass}{Subsample\,Fresh\,Mass}\right] \times Fresh\,Mass\,of\,Whole\,Sample$$

Biomass data was then regressed with all the diameter levels and or plant height as explanatory variables to develop power equations; and one with the best explanatory power was selected and linearized (Nyombi et al., 2009) as below:

$$In(y) = c + aIn(x)$$

Where: y is the total dry plant biomass (Kg) (corm, pseudo-stem, leaves (H1) or corm, pseudo-stem, leaves, peduncle and fingers (H2)); c a constant; a the equation parameter; and x the explanatory variable (diameter, girth or height). The choice to estimate total plant biomass as opposed to several other carbon studies was due to the morphological nature of bananas where the corm remains the true stem of the plant not the pseudo-stem (UNCST, 2007). All data collected by destructive sampling was used for model calibration and validation.

EAHB carbon content determination

Out of all the plant individuals obtained through destructive sampling, six cultivar specific individuals with their sub-samples (corm, upper stem, middle stem, lower stem, leaf, and or fruit and peduncle), originally dried for biomass determination were randomly sampled following a sampling design of (3 cultivars×2 sites×7 (or 5) parts×6 replicates). A total of 432 sub-samples (H2:252 and H1:180) were selected for plant part carbon content determination following procedures laid out in Okalebo et al. (2002) for plant carbon content analysis.

Data analysis

All data were statistically analyzed using GenStat software

Table 1. Regression analysis of biomass across variables variate: In_total_biomass.

Variable	Enyeru				Nakinyika				Kibuzi_Nakitembe				Pooled			
	v.r.	F pr	SE.	R^2	v.r.	F pr	SE.	R^2	v.r.	F pr	SE.	R^2	v.r.	F pr	SE.	R^2
In_G_Base	3.34	0.079	0.501	0.080	3.29	0.081	0.563	0.078	20.50	<.001	0.535	0.151	48.76	<.001	0.533	0.223
In_D_100	81.16	<.001	0.263	0.755	149.82	<.001	0.219	0.851	540.97	<.001	0.237	0.833	760.01	<.001	0.247	0.823
In_DBH	168.20	**<.001**	0.093	**0.933**	214.51	**<.001**	0.187	**0.891**	762.88	**<.001**	0.205	**0.876**	1123.36	**<.001**	0.210	**0.873**
In_H	57.20	<.001	0.299	0.684	192.01	<.001	0.197	0.88	351.15	<.001	0.282	0.764	446.99	<.001	0.303	0.732

G_Base was the girth at base; D_100 the diameter at 100 cm; DBH the diameter at 130 cm and H the height. N for *Enyeru*, *Nakinyika*, *Kibuzi_Nakitembe* and Pooled data were 28, 28, 112 and 168 respectively.

(v.13.3.5165). Descriptive statistics used to explain the distribution of biomass across cultivars were obtained for region specific and pooled data. ANOVA was run to test for any significant differences, if any, in biomass across the factors (cultivar type and growth stage) considering the l.s.d of their means at a 95% confidence level. Prior to equation development, simple linear regressions were run across cultivars for all variables (DBH, Height, Girth at base and Daimeter_100 cm) with biomass as the response to obtain a predictor variable (s) with a better explanatory power to predict biomass. Following results of Anderson-Darling normality test, data used in the generation of the equations were *log* transformed to fit a linear equation because the raw data were not symmetrically distributed; but also to increase on the sensitivity of the statistical tests (Seth, 2008). To develop the allometric relationships, half the data were used for equation calibration and the other half for validation.

One-way ANOVA was also performed to test for any significant differences in carbon content of cultivars as well as growth stages at a 95% confidence level. Mean values of the carbon content for the various plant parts were also determined. However, given that the degree of freedom for growth stage was 1 (very small to base a decision on), the difference in carbon content across growth stages was also tested using a two sample T-test assuming equal variance at a 95% confidence level (details of the analysis not presented in this document).

RESULTS

The average total dry biomass amounts across all cultivars sampled in Mbarara were generally higher (*Kibuzi*, 8.13±4.68; *Nakitembe*, 7.98±3.91 and *Enyeru* 9.15±4.58) than those in Lwengo (*Kibuzi*, 5.69±2.60, *Nakitembe* 5.59±2.98 and *Nakinyika* 4.89±2.45). Therefore, the relatively high average biomass amounts for pooled data (6.89±3.95) could perhaps be explained by the biomass amounts resulting from data obtained from Mbarara. The standard errors across all cultivars were high. The variation could be attributed to the differences in biomass that was obtained from plant individuals growing at different stages (H1 and H2). ANOVA results showed a significant difference in biomass for both factors (cultivar type and growth stage) with P<0.001. However, basing on the l.s.ds of the means, biomass was different for cultivars *Enyeru* and *Nakinyika*, and similar for *Kibuzi* and *Nakitembe*.

Therefore, it was on this basis that three allometric relationships were developed for biomass prediction of the cultivars (that is, *Enyeru, Nakinyika and Kibuzi_Nakitembe*). Also, a generic equation for EAHB was developed to ascertain how best it could predict biomass for other cultivars. Regression results for all cultivars as well as pooled data showed that DBH was highly correlated with a coefficient of determination (R^2) of above 87% compared to others (Table 1). These results were based on all the data for a specific cultivar or set of cultivars. It was therefore on this basis that DBH was selected as a better explanatory variable for biomass prediction of EAHB cultivars.

All equations were highly correlated with DBH (*P*<0.001) with R^2 between 82-94% being higher in cultivar specific equations of *Enyeru* and *Nakinyika* compared to a set of cultivars (that is, *Kibuzi_Nakitembe* and the Generic equation) (Figures 1 and 2, and Table 2).

A generic equation was also developed for use in similar studies in future for EAHB given that its predictions were highly correlated across all cultivars giving an R^2 of 82, 90 and 88% for *Enyeru*, *Nakinyika* and *Kibuzi_Nakitembe*; respectively (details of analysis not presented in this document). These were not significantly different from those predicted by the specific or a combination of cultivars as shown in Figures 1 and 2 above. Therefore, the linear equations that were developed for predicting total plant biomass of specific cultivars were as follows:

Carbon content of EAHB

On average, carbon content of EAHB across parts followed the pattern: fruit>leaf>corm>stem> peduncle for H2; and leaf>corm>stem for H1
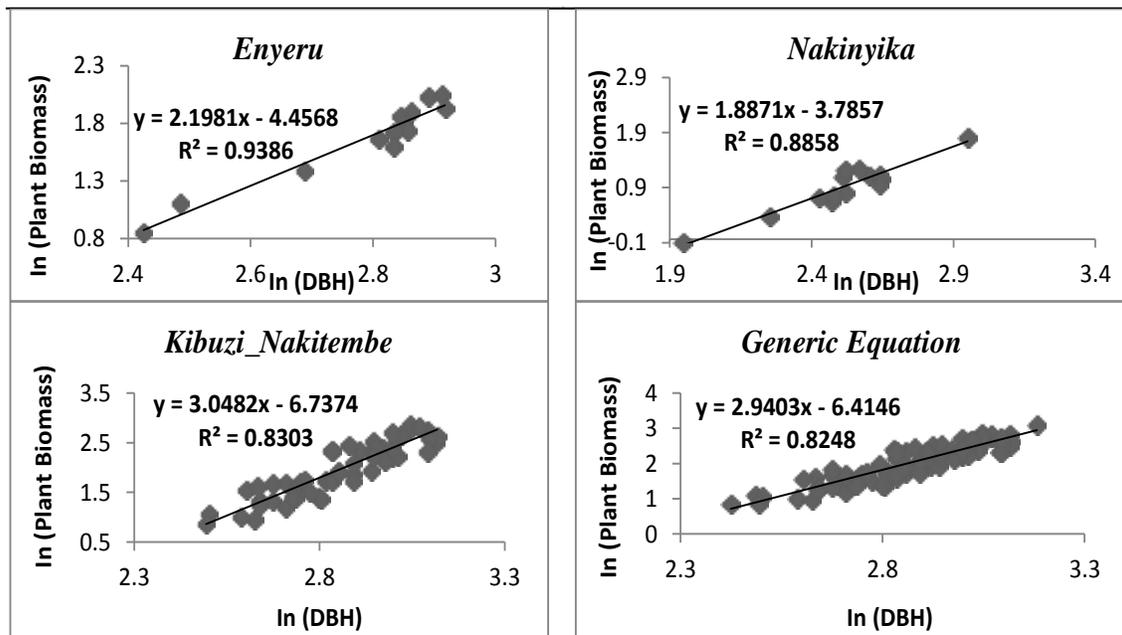
Figure 1. Calibrated allometric relationships for EAHB cultivars.
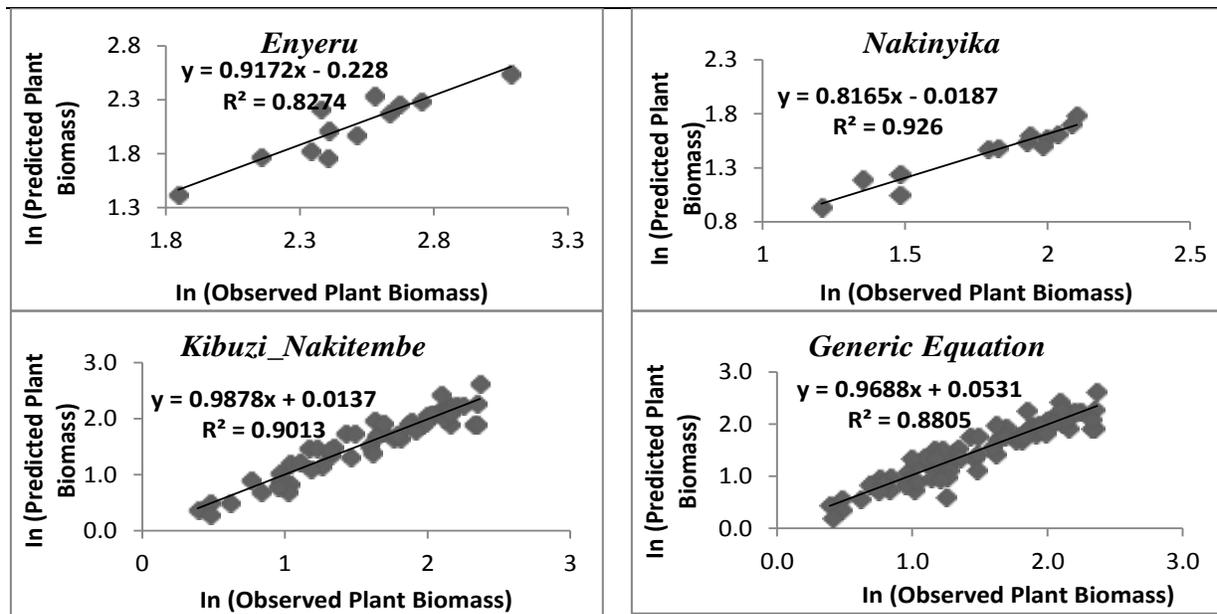

Figure 2. Validated allometric relationships for EAHB cultivars.

(Figure 3). However, in the interest of this study, focus was put on the carbon content of cultivars and or growth stages. Results from One Way ANOVA showed no significant difference in carbon content across cultivars ($P>0.05$) but growth stages ($P<0.05$). The later was also confirmed by the results obtained from the T-test ($P<0.05$). Therefore, 47.6 and 48.8% were the means of the carbon content considered in this study for H1 and H2; respectively as obtained from the T-test. Nevertheless, in studies where these growth stages are

Table 2. Summary of equations developed for total biomass estimation of EAHB cultivars.

Cultivar	n	Model	c	a	S.E (a)	S.E (c)	R^2	R^2 (adj.)	P
Enyeru	14	$In(y)=c+aIn(x)$	-4.457	2.198	0.170	0.473	0.939	0.933	0.000
Nakinyika	14	$In(y)=c+aIn(x)$	-3.786	1.887	0.196	0.493	0.886	0.876	0.000
Kibuzi_Nakitembe	56	$In(y)=c+aIn(x)$	-6.730	3.048	0.189	0.540	0.830	0.827	0.000
Generic	84	$In(y)=c+aIn(x)$	-6.415	2.940	0.151	0.432	0.825	0.823	0.000

a and *c* are regression coefficient constants, *y*, dry plant biomass (Kg), and *x*, the explanatory variable DBH.
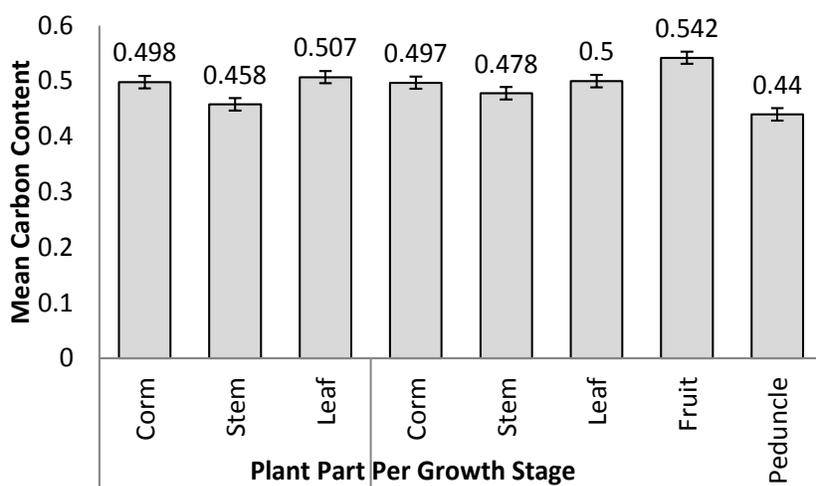
Figure 3. Carbon content means of plant parts.

not considered e.g. at flowering, then the mean value of 48.2% can be used as the carbon content of EAHB.

DISCUSSION

Allometric relationships for biomass estimation of EAHB cultivars

The allometric equations developed in this study were cultivar specific (Figures 1 and 2; and Table 2) though results showed that total dry biomass was significantly different across both cultivars and growth stages. These findings are in line with Nyombi et al. (2009) suggestion on the need to develop growth stage (or cultivar) specific allometrics given that dry biomass of EAHB differs across ontogeny. This was also evident considering the differences in the means of dry biomass across cultivars in the different regions except for cultivars *Kibuzi* and *Nakitembe* whose biomass was not significantly different. Similarities exhibited in biomass obtained from *Kibuzi* and *Nakitembe* cultivars could perhaps be attributed to the fact that *Kibuzi* shows some similar traits as those of the

Nakitembe clone set where *Nakitembe* cultivar belongs (Karamura, 1998). However, in the interest of this study, growth stage specific allometrics were not developed since focus was put on developing cultivar specific equations using data obtained from both stages; hence their applicability to all stages of growth considered in this study.

Linear regressions run on all potential total plant biomass predictor variables (height, girth at base, DBH and diameter at 100 cm) revealed that DBH was the best predictor variable with an R^2 ranging between 87-93% across cultivars (Table 1) similar to observations made for *Eucalyptus* in Kenya (Shem et al., 2013). Results are also in line with the predictor variable used for above ground biomass estimation of bananas developed in Indonesia by Arifin (2001) a widely used allometric relation for bananas in carbon studies (e.g. in Oliver, 2009; Henry et al., 2009; Hariah et al., 2010 among others) though DBH was taken as 135 cm. The variable is also commonly preferred for other perennial crops like trees, coffee, cocoa, etc (Arifin, 2001; Basuki et al., 2009; Amy et al., 2010; Twongyirwe, 2010; Michiel et al., 2011; Sirike, 2012; Mugasha et al., 2013); hence making it a

key variable to consider in such a study.

Girth at base however, emerged the weakest of all variables across cultivars (except *Kibuzi_Nakitembe* whose R^2 was very small) not being significantly related to biomass; results deviating from those obtained by Nyombi et al. (2009). This could perhaps be attributed to the fact that DBH has not been explored before for biomass estimation of EAHB among other factors. Important to note however is that the equations developed in this study (Table 2) cater for intraspecific variabilities that could perhaps be brought about by the type of cultivars used, age, and site conditions (edaphic and climatic variability) as noted by Juan et al. (2010). But also such variabilities could be as a result of increased variance in total dry biomass of individuals due to growth stages that resulted in high standard errors across all cultivars as well as pooled data (Table 2) (Nyombi et al., 2009) including on-farm variations and management among others.

Despite that the 3 parameters (DBH, height and diameter at 100 cm) gave high R^2 values, all could not be included in the model as this would be considered inappropriate; but also to eliminate cases of redundant parameters with high co-linearity in one equation function (Montgomery and Peck, 1992). However, in cases where DBH data is not available (e.g. when a plant is still young), height can be used as an alternative parameter for plant biomass estimation (Nyombi et al., 2009; Mugasha et al., 2013) though it is relatively difficult to measure as well as time consuming compared to DBH.

The fact that biomass quantities were significantly different for region specific cultivars but similar for common ones was proof enough to generate specific equations instead of a generalized one given that the former has the potential to improve the accuracy of prediction (Wairegi, 2010). However, developing such equations for more than 80 EAHB cultivars could be challenging due to limited resources (Karamura, 1998; Gold et al., 2002; Wareigi, 2010). Therefore, in cases where a cultivar specific equation is absent, the generic equation developed in this study could perhaps be applied on cultivars of more or less similar origin after all its prediction gave significantly high R^2 values for all cultivars ranging from 82-90%; not very different from specific ones.

Carbon content of EAHB

In general, the average carbon content of EAHB was found to be 48.2% relatively lower than the recommended value of 50% (Timothy et al., 2005; IPCC, 2006). Results are in line with those obtained for broadleaf tree species whose average C. content was minor than 50% for the whole plant (Arias et al., 2011) and among plant parts as reported in coniferous species in a study by Yen et al.

(2009). Also, the value is very close to the 48% C content value that was used in a study by Shackleton and Scholes (2011) but slightly higher than the 46 and 47.9% values used for the conversion of dry wood biomass to carbon (Hairiah et al., 2010; ICRAF, 2011). All in all, results obtained in this study fall in the range of 46-49% carbon content values recommended for use in the tropics for tree species with DBH >10 cm (IPCC, 2006) considering that all individuals used for carbon content determination in this study had a DBH value >10 cm (Figure 3).

The difference of 1.2% in C content between growth stages could be as a result of one stage (H1) lacking both the fruit and peduncle components present in the other (H2) given that the components common to both show no significant difference across stages (Figure 3). Therefore, to obtain relatively accurate estimates for carbon stocks of cultivars in this study, it was considered prudent enough to use the growth stage specific C. content values, that is, 47.6% (H1) and 48.8% (H2) since they were locally available as recommended by Timothy et al. (2005).

In comparison with say tree components, generally bananas have more C. content in leaves at any stage (50-50.7%) compared to tree species like *V. guatamalensis* (41.0%) but not far from *P. caribeae* (49.6%) as observed in a study by Arias et al. (2011). This could be attributed to the fact that banana as a whole possesses large leaves as compared to any broad leaved tree species. However, comparing stems, EAHB contain less carbon content (45.8-47.8%) than one observed for tree species (e.g. *P. caribeae* with a 50.8% content). This could be explained perhaps by the pseudo-stem nature of banana stems containing high moisture content (Jing et al., 2010) as opposed to wood deposit present in trees. Therefore, considering these results, the 50% carbon content coefficient would be a relatively high estimate for species like EAHB (48.2%) but could be a fair rule of thumb in cases where the specific carbon content is missing (Arias et al., 2011).

Conclusions

Banana biomass can be accurately estimated using an exponential function (y=Aexp(ax)). The values of the constants tend to vary from one cultivar to another. The use of DBH as the best predictor variable for biomass of EAHB cultivars was confirmed as recommended for use in most carbon related studies. Carbon content was significantly different across growth stages ($P<0.05$) and not cultivars ($P>0.05$). The mean carbon content of EAHB is 48.2% slightly higher than the carbon content value (47.6%) of banana plants before flowering and lower than those at maturity with a content value of 48.8%. All the values were found to be lower than the globally

recommended 50% value by IPCC.

RECOMMENDATIONS

Generally, the allometric equations developed for biomass estimation of EAHB cultivars (*Enyeru, Nakinyika, Kibuzi and Nakitembe*) cater for intraspecific variabilities, growth stage, cultivar type and site conditions considering DBH as a key predictor variable as observed in other carbon related studies. Also, the determination of the actual carbon content of these bananas was timely as this was used to relatively estimate the actual plant carbon stock of the cultivars that would perhaps be lost in the use of readily available values. Therefore, more biomass prediction equations should be developed for other banana categories like plantains to ascertain the contribution of the entire banana cropping system to the global carbon cycle given that EAHB cultivars are not grown in isolation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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