

Biomass Conversion and Expansion Factors for Young Norway Spruce (*Picea abies* (L.) Karst.) Trees Planted on Non-Forest Lands in Eastern Carpathians

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Abstract

In this study biomass conversion and expansion factors (BCEFs) were developed for young Norway spruce trees planted on non-forest lands, in order to support quantification of carbon stock changes in biomass pools of afforestation works. Regression models for stem volume and stem wood density were also developed. The data set included 250 trees collected from 25 plantations between 1 and 12 years old, located in the Eastern Carpathians of Romania. The study shows that BCEFs decreased with increasing tree dimensions, following an exponential trend. In all proposed models the highest prediction was reached when both variables considered (i.e. root-collar diameter and height) were used together. However, used separately, height produced a slightly higher prediction compared to root-collar diameter. Stem volume was well predicted by both root-collar diameter and height. Anyway, a significant improvement in prediction resulted when both variables were used together. Stem wood density decreased sharply with the increase of the two tree dimensions used as variables.

Keywords: BCEF, biomass, wood density, stem volume, Norway spruce, non-forest land, afforestation

Introduction

Romania, as a party of Annex I within the United Nations Framework Convention on Climate Change (UNFCCC), must elaborate and regularly submit the National Inventory Report (NIR) that contains the national greenhouse gases (GHG) inventory. By signing the Kyoto Protocol (KP) in 1999 the country committed itself to reduce GHG emissions between 2008 and 2012 by 8% compared to the levels reached in 1989. As a consequence of the ratification of this protocol, it is mandatory to estimate, report and account for removal/emissions from Land Use, Land Use Change and Forestry (LULUCF) activities under Article 3.3. (Afforestation/Reforestation – AR, Deforestation – D) and Article 3.4. (Forest Management – FM, Revegetation – Rv) of the KP. Until 2010, Romania reported no data for category 5.A.2. *Land converted to forest land* within the LULUCF sector, therefore affecting directly the accounting of AR under KP. Moreover, since 2007, when Romania became a member state of the European Union, a report on GHG emissions should also be sent to the EU (according to the Directive on GHG Monitoring Mechanism 280/2004/EC). Therefore, the need to assess carbon stock changes for reporting under this category (i.e. land converted to forest land) and developing biomass functions at national or regional level became an important and urgent need for our country.

In the last decades across Europe, studies on tree allometry were carried out for many species, including Norway spruce. For example, in 1999, Johansson published dry weight equations for Norway spruce trees growing on abandoned farmland in Sweden. In 2006, Snoransson and Einarsson developed functions of volume and above-ground biomass at tree level, for eleven species from Iceland, including Norway spruce as well. In Austria, Eckmullner (2006) made estimations of needles and branches biomass. He showed that dry needle biomass was highly correlated with sapwood area at the base of the live crown, while dried branches biomass showed the best correlation with the diameter at the same location along the stem. In Romania allometric relationships were developed for young Norway spruce trees but only between sapwood area at the base of the live crown and leaf area (Stancioiu and O'Hara 2006). Recently, Pajtik *et al.* (2008) have published allometric equations and biomass expansion factors (BEFs) for young Norway spruce trees (less than 10 years old) from natural regenerations in Slovakia. A meta-analysis based on data collected from 19 authors was published by Wirth *et al.* (2004) who developed generic biomass functions for Norway spruce in Central Europe. In 2007, Muukkonen made a compilation from several published studies and synthesized some generic equations for volume and biomass at European level. A similar analysis, but at stand level, was carried out by Teobaldelli *et al.* (2009). They reported an

extended set of BEFs and developed generic functions for BEF using as independent variables the age of the stand, growing stock and site index.

Biomass conversion and expansion factor (BCEF) is a factor that converts stem volume to stem dry weight (i.e. the conversion factor) and thereafter expands stem biomass to whole tree biomass (i.e. the biomass expansion factor – BEF). Therefore BCEF is a factor that converts stem volume to whole tree biomass (Tobin and Nieuwenhuis 2007). The use of BCEFs and of allometric equations depends on the type of input obtained from the National Forest Inventory (Brown, 2002). In most European countries, the GHG inventories within LULUCF are largely or exclusively based on converting tree volume data from National Forest Inventories to biomass using BCEFs (Teobaldelli *et al.*, 2009). However, BCEF should be locally developed otherwise biased biomass estimates can result (Lethonen, 2005).

In Romania, 30% of the forest and other woodland areas are covered by coniferous species, especially Norway spruce (Abrudan *et al.*, 2009). Norway spruce has also been the main species used for the afforestation of non-forest lands in the last decades, especially in the post-restitution land ownership context (Ioraş and Abrudan, 2006). Therefore, developing BCEFs for this species is an important objective at national level.

The main goal of this paper is to develop BCEFs for young Norway spruce trees planted on non-forest lands in the Eastern Carpathians of Romania. These conversion and expansion factors could be used further to estimate the amount of carbon stored in this type of plantations (i.e. established on non-forest lands). This will help Romania reporting under the category 5.A.2. within the LULUCF sector and also support the implementation of AR projects by estimation of carbon stored in biomass (Abrudan *et al.*, 2003; Blujdea, 2007; Blujdea *et al.*, 2010).

Material and methods

Research sites

The measurements were conducted in 25 Norway spruce plantations established on non-forest lands. These plantations are located in the Eastern Carpathians of Romania (Fig. 1), where the largest range of this tree species at country level occurs (Şofletea *et al.*, 2008). This part of Carpathians covers almost the entire latitude range of the species at national scale. The altitude of the sites ranged between 641 and 1563 m and the age of these 25 plantations ranged between 1 and 12 years. Ten sample trees from each plantation were selected for measurements.



Fig. 1. Location of the research sites

Tree measurements

The height (H) of the sample trees ranged between 0.5 and 5.5 meters. As a result, root-collar diameter (RCD) was used instead of diameter at breast height (i.e. measured at 1.3 meters height above ground-DBH). However, RCD is a good predictor for small trees as they do not suffer from important deformations and thickening of the stem at the base as much as mature trees do.

The two variables, RCD and H were measured for each sample tree in the field. Entire biomass (including roots) was collected and transported to the laboratory where biomass (B) and stem volume (SV) were determined. The volume of the stem was calculated as a sum of the internodes volume, including bark. The individual internodes volume was calculated using length of the internodes and diameter at half distance between nodes:

$$SV = \frac{\pi}{4} \times [(D_1^2 \times L_1) + (D_2^2 \times L_2) + \dots + (D_n^2 \times L_n)] \quad \text{Eq. 1}$$

where D is the diameter of the internodes (at the middle), L is the length of the internodes and n is the number of the internodes.

In order to determine biomass, the tree was separated in the following four categories: needles, branches, stem and roots. All categories were dried at 80°C until constant weight was reached. To ease separating fresh needles from shoots, entire branches were pre-dried for 3 days at the same temperature.

Modeling biomass conversion and expansion factor

BCEF is a factor that transforms stem volume directly to whole tree biomass in two steps. First, it converts stem volume into stem biomass and then expands stem biomass to the whole tree biomass. BCEF can be also calculated separately for tree components (i.e. needles, branches, stem and roots). In this study BCEF for component i (BCEF_i) was calculated as a ratio between biomass of the component i (B_i) and stem volume (SV):

$$BCEF_i = B_i \times SV^{-1} \quad \text{Eq. 2}$$

Although the most important BCEF for practice is the one that expands stem volume to whole tree biomass (BCEF_t), in this paper were also developed BCEF models for: aboveground biomass (BEF_{ab}), belowground biomass (BEF_{bb}), needles (BEF_n), branches (BEF_{br}), and stem (BEF_s).

It is well known that the relative biomass of the canopy and roots decreases during stand development. This is because stem wood is entirely preserved whereas other compartments i.e. foliage, branches and roots turn over and thus a part of them are lost as litter (Lethonen, 2005). Therefore BEF is changing once with the tree dimensions. In order to evaluate the relationship between BEF and tree dimensions (i.e. RCD and H) three models were tested for each type of BCEF (i.e. corresponding to each tree com-

ponent). Equations 03 and 04 are exponential log-transformed based on RCD and H, whereas equation 05 is a power log-transformed double regression:

$$BCEF = e^{(\ln b_0 \times b_1 RCD)} \lambda \quad \text{Eq. 3}$$

$$BCEF = e^{(\ln b_0 \times b_1 H)} \lambda \quad \text{Eq. 4}$$

$$BCEF = e^{(b_0 + b_1 \ln H + b_2 \ln RCD)} \lambda \quad \text{Eq. 5}$$

Modeling stem volume

Stem volume together with BCEF are used to predict biomass. Usually stem volume is calculated based on diameter at breast height (DBH) and a shape factor. However, this shape factor is developed only for mature trees. Additionally, for our small trees only root-collar diameter is a representative variable (i.e. most of them do not reach breast height; the rest are little over this height and the DBH is not representative). In order to get an accurate prediction of volume for young trees, three models were proposed. All these models are log-transformed power equations based on RCD (equation 06), on H (equation 07) and on both variables (equation 08):

$$SV = e^{(b_0 + b_1 \ln RCD)} \lambda \quad \text{Eq. 6}$$

$$SV = e^{(b_0 + b_1 \ln H)} \lambda \quad \text{Eq. 7}$$

$$SV = e^{(b_0 + b_1 \ln RCD + b_2 \ln H)} \lambda \quad \text{Eq. 8}$$

Modeling stem wood density

Stem wood density (SWD) is usually used to convert stem volume into biomass. This is the conversion factor within BCEF. Stem wood density was calculated as a ratio between stem biomass and stem volume. In order to evaluate the relationship between stem wood density and the two tree dimensions (RCD and H) three models (i.e. log-transformed power function) were proposed: i) the first model, (equation 09) is based on RCD, ii) the second one (equation 10) is based on H of the tree and iii) the third model (equation 11) is also a power log-transformed model, but based on both variables mentioned above:

$$SWD = e^{(b_0 + b_1 \ln RCD)} \lambda \quad \text{Eq. 9}$$

$$SWD = e^{(b_0 + b_1 \ln H)} \lambda \quad \text{Eq. 10}$$

$$SWD = e^{(b_0 + b_1 \ln H + b_2 \ln RCD)} \lambda \quad \text{Eq. 11}$$

Correction factor

The logarithm transformation induces a systematic bias into output (Baskerville, 1972). Therefore a correction factor (λ) proposed by Sprugel (1983) and based on standard error of the estimate (SEE) was adopted:

$$\lambda = e^{\left(\frac{SEE^2}{2}\right)} \quad \text{Eq. 12}$$

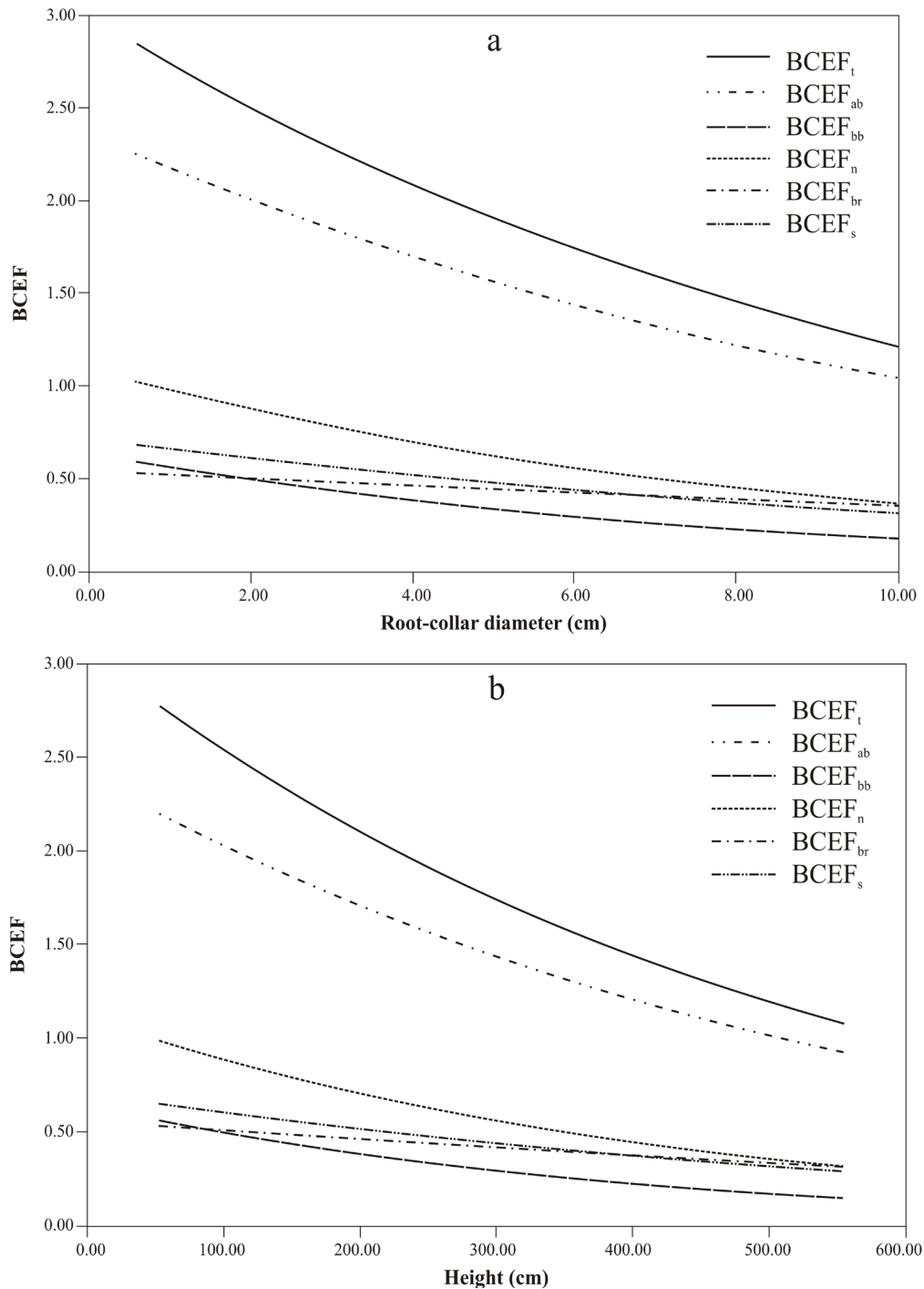


Fig. 2. The variation of BCEFs by root-collar diameter (a) and tree height (b)

Results and discussions

Biomass conversion and expansion factor

The relationship of BCEF with RCD and H is described in Fig. 1 for all types of biomass determined in the study (including total biomass, aboveground and belowground biomass). For both independent variables, the BCEF for needles (BCEF_n) decreases to approximately half in the size range from this study (i.e. at the beginning

of the interval, BCEF_n is approximately 1.0; at the end of the range the BCEF_n is about 0.4). In relative values, this means that at the beginning of the interval, the needle biomass is comparable with stem volume, and at the end it is about 40% of the stem volume. For roots (i.e. belowground biomass) the decrease of BCEF_{bb} is similar. At the beginning of the range the BCEF_{bb} is about 60% of the stem volume while at the end of the range it represents only about 20% (also considering relative values). For BCEF of

Tab. 1. Regression coefficients (b_0 , b_1 and b_2), their standard error (S.E.), coefficient of determination (R^2), F-ratio, standard error of the estimate (SEE) and correction factor (λ) for BCEF estimation proposed models

Equation	BCEF type	b_0 (S.E.)	b_1 (S.E.)	b_2 (S.E.)	R^2	F-ratio	SEE	λ
03	BCEFt	1.101 (0.024)	-0.091 (0.005)	-	0.543	294.3	0.2184	1,0241
	BCEFab	0.861 (0.024)	-0.083 (0.005)	-	0.490	237.9	0.2207	1,0247
	BCEFbb	-0.453 (0.032)	-0.128 (0.007)	-	0.568	325.6	0.2923	1,0436
	BCEFn	0.083 (0.034)	-0.109 (0.007)	-	0.461	212.4	0.3088	1,0488
	BCEFbr	-0.604 (0.034)	-0.043 (0.008)	-	0.112	31.2	0.3137	1,0504
	BCEFs	-0.341 (0.013)	-0.081 (0.003)	-	0.747	731.9	0.1234	1,0076
04	BCEFt	1.119 (0.022)	-0.002 (0.000)	-	0.615	396.7	0.2003	1,0203
	BCEFab	0.879 (0.022)	-0.002 (0.000)	-	0.564	320.9	0.2040	1,0210
	BCEFbb	-0.438 (0.030)	-0.003 (0.000)	-	0.617	399.9	0.2750	1,0385
	BCEFn	0.107 (0.031)	-0.002 (0.000)	-	0.531	280.3	0.2883	1,0424
	BCEFbr	-0.570 (0.033)	-0.001 (0.000)	-	0.171	51.0	0.3032	1,0470
	BCEFs	-0.342 (0.013)	-0.002 (0.000)	-	0.757	773.7	0.1208	1,0073
05	BCEFt	4.567 (0.259)	-0.864 (0.063)	0.494 (0.058)	0.647	226.6	0.1922	1,0186
	BCEFab	4.313 (0.258)	-0.861 (0.063)	0.521 (0.058)	0.618	199.4	0.1915	1,0185
	BCEFbb	3.279 (0.381)	-0.930 (0.093)	0.426 (0.086)	0.597	183.2	0.2826	1,0407
	BCEFn	4.400 (0.378)	-1.077 (0.093)	0.633 (0.085)	0.557	155.6	0.2805	1,0401
	BCEFbr	3.534 (0.353)	-1.036 (0.086)	0.847 (0.080)	0.383	76.7	0.2620	1,0349
	BCEFs	1.477 (0.144)	-0.449 (0.035)	0.123 (0.033)	0.810	527.8	0.1070	1,0057

the other tree elements, the trend is less steep although a constant decrease is recorded as well. The decreasing trend of BCEFs is a result of changing wood density with tree size. BCEFbr shows the lowest decrease rate. It could be noticed that at the end of the size range all aboveground components (needles, branches and stem) converge to approximately the same value of BCEF (i.e. close to 0.4 - 0.5) which means that the biomass of these components is comparable. The decrease trend for BCEFt leads to the conclusion that with increasing tree size the proportion of stem volume increases compared to the proportion of the other tree components.

The statistics of the models are presented in Tab. 1. As mentioned before, equation 03 is based on RCD, equation 04 on H and equation 05 on both variables. Height was a better predictor than RCD for all types of BCEF considered, with no exception. The tree components having the lowest predictive power are the branches. A small but significant improvement for this model was achieved using both variables. The highest predictive power occurred

in the stem BCEF model. All these results are confirmed by a study of Pajtik *et al.* (2008) who developed BCEFs for young trees of Norway spruce from natural regenerations, although the equation type they used was power log-transformed.

Stem volume and wood density

Estimated coefficients of the proposed models for stem volume and density are presented in Tab. 2. The RCD proved to be a better predictor for stem volume estimation than H, although the difference was small. Using both variables together for stem volume estimation, the coefficient of determination improved, about 99.6% of the observed values being explained by this new model. Considering F-ratio to compare the regression accuracy of the models the conclusion is the same as in the case of coefficient of determination.

The stem wood density models had a lower accuracy than those proposed for volume. But in this case H proved to be a better predictor than RCD. Although for the dou-

Tab. 2. Regression coefficients (b_0 , b_1 and b_2), their standard error (S.E.), coefficient of determination (R^2), F-ratio, standard error of the estimate (SEE) and correction factor (λ) for stem volume and wood density estimation models

Equation	D.V.	I.V.	b_0 (S.E.)	b_1 (S.E.)	b_2 (S.E.)	R^2	F-ratio	SEE	λ
06		RCD	2.955 (0.031)	2.627 (0.025)	-	0.979	11376.0	0.2871	1.0421
07	Stem volume	H	-8.497 (0.155)	2.841 (0.031)	-	0.972	8578.5	0.3295	1.0558
08		RCD and H	-2.467 (0.175)	1.450 (0.039)	1.331 (0.043)	0.996	28273.4	0.1299	1.0085
09		RCD	-0.353 (0.015)	-0.274 (0.012)	-	0.686	542.2	0.1374	1.0094
10	Stem density	H	0.967 (0.052)	-0.322 (0.010)	-	0.799	988.8	0.1098	1.0060
11		RCD and H	1.477 (0.144)	-0.449 (0.035)	0.123 (0.033)	0.810	527.8	0.1070	1.0057

D.V. – dependent variable, I.V. – independent variable

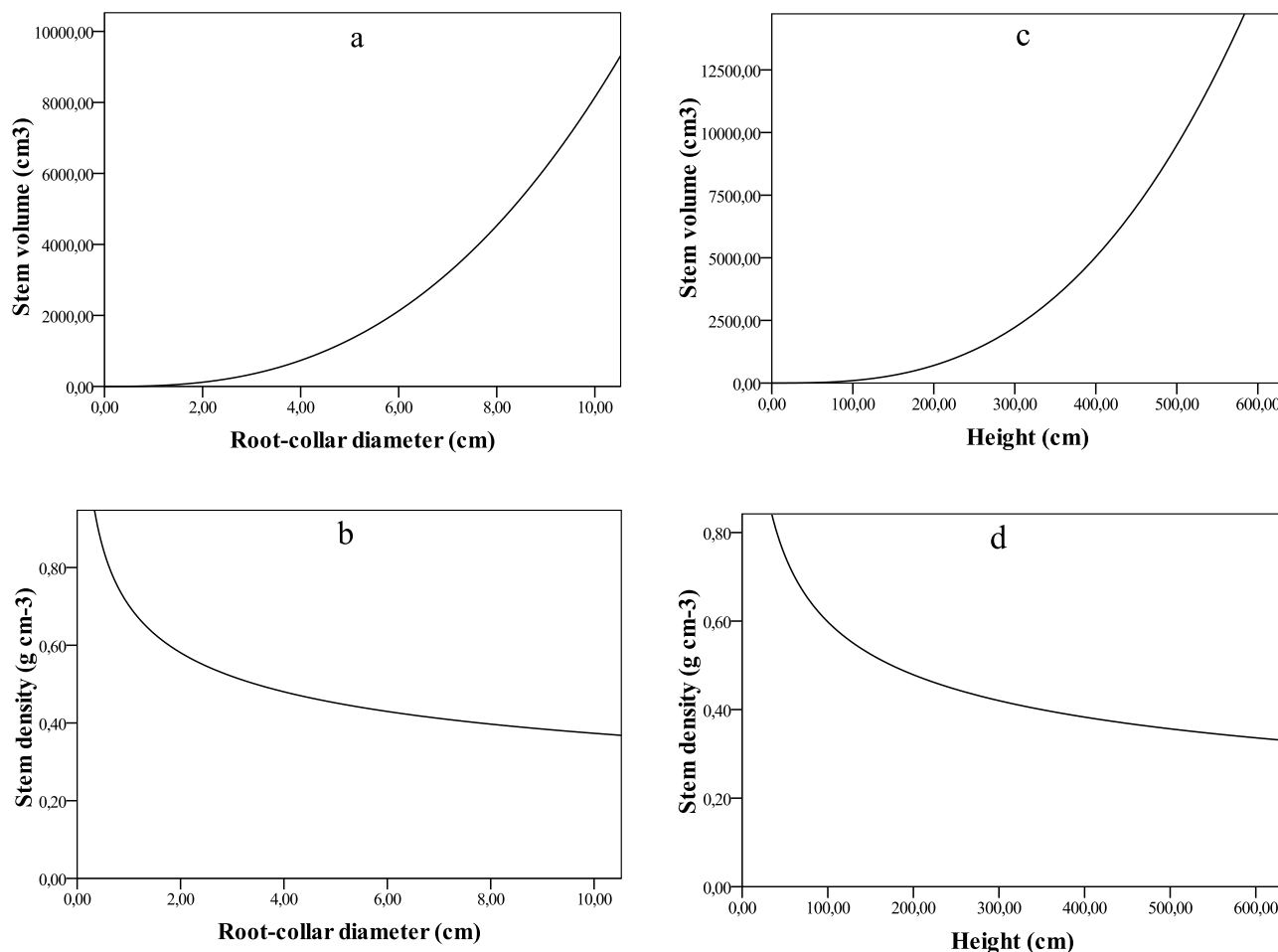


Fig. 3. The variation of stem volume (a, c) and stem density (b, d) with root-collar diameter and height

ble regression the coefficient of determination was higher, the F-ratio decreased by 461, keeping H as the best predictor for stem wood density.

As expected, stem volume increases exponentially with increasing H and RCD (Fig. 3 – a, c). However, wood density showed a sharp decrease with increasing H and RCD (Fig. 3 – b, d). This variable decreased from about 0.75 g cm⁻³ (for trees of 0.5 m in height) to about 0.35 g cm⁻³ (for trees of 5.5 m in height). This high density of small trees can be explained by the difference between earlywood and latewood content. As young trees grow more slowly they invest more in latewood (Van Gelder *et al.*, 2006).

The residuals for all proposed models (i.e. for BCEF, stem volume and stem wood density) have met the assumptions of normality, homoscedasticity and independence.

Conclusions

Although H is not a variable commonly used for prediction of BCEF, in the case of small trees it gives better

precision than RCD does. Moreover, for small trees, H is easier to measure than RCD. Due to the fact that BCEF is dependent on tree size, for accurate estimation of stored biomass appropriate models should be used (i.e. BCEFs developed for a certain tree size range).

In the case of stem volume prediction, both variables offered good results. However, when they were used together the accuracy increased substantially. As a result, the high prediction accuracy for stem volume of this model (i.e. including both H and RCD) helps acquire a higher precision in tree biomass estimation.

The height was a better predictor than RCD for stem wood density. Using both variables together the model did not improve very much (i.e. the power of prediction has not improved substantially). Although small trees have small volume, their higher wood density makes them hold more biomass per volume than mature trees. Therefore at the same wood volume small trees contain more carbon than mature trees do. As a result, using simple biomass expansion factor (BEF) with a constant wood density as

conversion factor might lead to underestimation of biomass in the case of small trees.

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