SILVA FENNICA

Silva Fennica 46(3) research articles

www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

# Individual Biomass and Carbon Equations for *Mimosa scabrella* Benth. (Bracatinga) in Southern Brazil

Anabel Aparecida de Mello, Leif Nutto, Karla Simone Weber, Carlos Eduardo Sanquetta, Jorge Luis Monteiro de Matos and Gero Becker

**Mello, A.A., Nutto, L., Weber, K.S., Sanquetta, C.E., Monteiro de Matos, J.L. & Becker, G.** 2012. Individual biomass and carbon equations for *Mimosa scabrella* Benth. (bracatinga) in southern Brazil. Silva Fennica 46(3): 333–343.

*Mimosa scabrella* Benth. is an important native species of southern Brazil widely used for energy and promising for reforestation carbon offsets. Quantification of biomass and carbon stock is valuable for both purposes. From a forest inventory conducted in southern Brazil, data of *M. scabrella* were analyzed. Thirty sample trees were felled, excavated and weighed in the field and brought to laboratory for biomass and carbon determination. The total aboveground biomass represented 85% of the tree biomass, while roots corresponded to 15%. Correlation matrix of diameter at 1.3 m height ($D$), tree height ($H$) versus total and compartment biomass ($P$) indicated strong association between tree dimensions and biomasses. Five regression models were tested and equations were fitted to data of five biomass compartments and total tree biomass. The best fitting model for total biomass was $P = -0.49361 + 0.034865 \times D^2H$ whereas for the partial biomass of the compartments was $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$. Carbon concentration was statistically significantly different in foliage than in other compartments. Three approaches of calculating carbon stocks were evaluated and compared to actual data: 1) Estimated total biomass × weighted mean carbon concentration; 2) Estimated partial (compartment) biomass × compartment average carbon concentration; and 3) Carbon regression equations. No statistical difference was detected among them. It was concluded that biomass equations fitted in this study were accurate and useful for fuelwood and carbon estimations.

**Keywords** carbon offsets, forest inventory, firewood, modeling, tree compartments
**Addresses** *Mello*: Federal University of Sergipe, Brazil; *Nutto*, *Weber*, *Sanquetta* & *Monteiro de Mato*s: Federal University of Paraná, Brazil; *Becker*: University of Freiburg, Institute of Forest Utilization and Work Science, Germany
**E-mail** lnutto.ufpr@gmail.com
**Received** 9 August 2010 **Revised** 19 January 2011 and 3 May 2012 **Accepted** 27 June 2012
**Available at** http://www.metla.fi/silvafennica/full/sf46/sf463333.pdf

# 1 Introduction

Biomass represents 10.9% of the world´s offer of energy (IEA 2008). In turn, Brazil has a consolidated and growing use of this energy source in its matrix, comprised of 27.3% of biomass, of which 9.6% correspond to wood sources, mainly firewood and charcoal (BEN 2011).

*Mimosa scabrella* Benth. (bracatinga) is key native species in southern Brazil. This $N_2$-fixing legume tree is fast-growing (MacDicken 1994), produce sawntimber, honey, animal forage, besides of providing excellent firewood to use in a wide range of small and medium size factories. It is distributed naturally in southern and southeastern Brazil, within 23°05' and 29°04'S and 48°05' to 53°50'W, where a great number of small-scale farmers use its wood from generation to generation for various purposes. Just in the neighborhood of Curitiba (the Parana State capital), over 60 thousand hectares of bracatinga are cultivated and managed, especially through the traditional family agroforestry (EMBRAPA 1988). The usual rotation for firewood management regime is 4–7 years, with 2200 plants per hectare (Carvalho 1994).

Besides the economic and social importance of *M. scabrella* as energy wood, it is also important for projects that combine forest restoration and carbon sequestration (Urbano 2007). This species is valuable for small-scale reforestation projects and also as a substitute of fossil fuels and electricity. Hence, it has a remarkable potential to the development of projects aiming at $CO_2$ removal and reducing greenhouse gas emissions, such as CDM (Clean Development Mechanism), voluntary carbon offsets as well as carbon neutral initiatives. There is a remarkable interest of farmers in using this species for low carbon agriculture projects supported by the Brazilian government.

The establishment of reforestation and forest management projects with *M. scabrella* for fuelwood purposes requires quantification of biomass. At the same time, carbon offset projects and low carbon plans need suitable techniques for quantification of carbon stocks. However, direct methods imply in tedious and expensive destructive procedures. Regression models are very useful to obtain indirect estimation of biomass and carbon (Somarriba and Kass 2001). The aim of this study was to test regression models and fit equations for using in total and partial biomass and to evaluate different approaches of quantifying carbon stock of individual trees of the species *M. scabrella* in southern Brazil.

# 2 Material and Methods

## 2.1 Study Site

In a circle of 30 km around the União da Vitória municipality, 30 trees of *Mimosa scabrella* were sampled in native forests of the states of Santa Catarina and Paraná (Fig. 1). The region has extensive areas of native forests with pure stands of this species or forests where it occurs in significant volumes alongside other tree taxa. Most of these forests are owned by small farmers that produce firewood or charcoal from the woody parts of *M. scabrella*.

## 2.2 Forest Inventory

Pure and mixed stands of *Mimosa scabrella* were selected according to their age class (3–5 years = 5 sample trees, 5–8 years = 11 sample trees and >8 years = 14 sample trees). The mixed stands with *M. scabrella* are generally older and richly structured native forests whereas the pure stands are younger and established under highly perturbed ecosystems.

The inventory plots were selected randomly using LANDSAT satellite imagery, where pure and mixed stands of *M. scabrella* could be distinguished with good precision. This could be evaluated by several "ground true" activities of the authors, which were involved in the inventory. The sampled trees were taken from forest inventory plots consisting of 70 units of a size of 20 m × 20 m. Tree biomass weighting in the field was carried on trees close to the forest inventory plots.

The data collection for determining the biomass of *M. scabrella* has to consider some particularities of the species. *M. scabrella* is considered a pioneer species. It occurs in native stands as well as in plantation-like homogeneous stands. Some

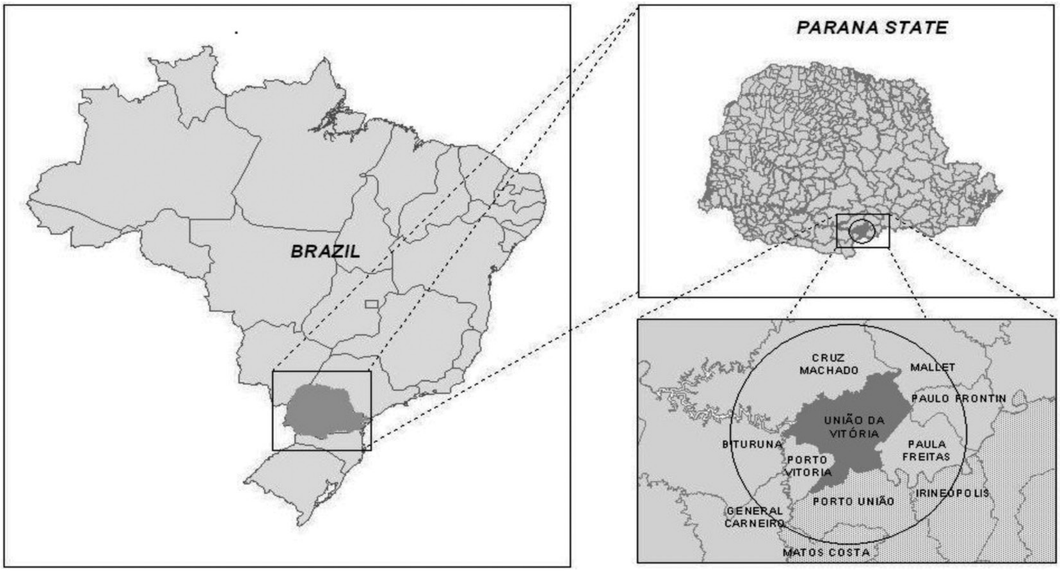


**Fig. 1.** Location of the area where the *Mimosa scabrella* trees were sampled, at a circle of 30 km around the União da Vitória municipality.

provenances of the species tend to have bifurcation, whereas others show straight growth. The 30 sampled trees were selected according to the morphological characteristics of the distinct age classes. The selected trees fulfilled the following characteristics:

- no open grown single trees;
- no bifurcations below 3 m height allowed;
- no excess of dead or broken branches; or
- no dying trees or of unsound appearance.

Of the 70 analyzed inventory units, 30 trees fulfilling these criteria were randomly selected. GPS coordinates were taken for each tree and the diameter at a 1.3 m height and crown diameter were measured. After felling, tree length and crown length were measured. Tree height was difficult to measure at standing trees, because of intensive understory in the mixed stands. In this study, tree length was taken as an estimator for tree height, even both are not always identical. Exact tree age was determined by stem disc analysis. For details on sample trees see Table 1.

**Table 1.** Characteristics of the sample trees used in the study ($D$ = diameter at 1.3 m height, $H$ = tree height).

| Variable | Range | Mean | St. dev. |
|---|---|---|---|
| Age (years) | 2–19 | 9.2 | 4.6 |
| $D$ (cm) | 4.3–23 | 11.2 | 5.6 |
| $H$ (m) | 6.9–19.6 | 12.7 | 3.7 |

## 2.3 Biomass Measurements in the Field

After felling the sample trees were divided into the following biomass compartments: stem, bark, branches (living and dead), foliage, and roots. The fresh masses of the different compartments were measured directly after felling by a simple beam balance. The stemwood was completely measured with bark. Fresh mass of bark was taken directly after the measurement by cutting stem discs of 5 cm thickness at 0.5 m, 50% of tree height and at height of crown base. Bark was removed from the discs and separately analyzed. Branches were defined as thick branches (diameter ≥ 4 cm) and thin branches (diameter < 4 cm). Wood after a bifurcation was always considered as branchwood. To determine the fresh mass of the branches, they were separated into living and dead and all of them measured.

From all sample trees, an estimated 25% of the leaves were removed for fresh mass determination, since the leaves of *M. scabrella* are very fine and difficult to remove. To analyze the fresh mass of the root system, the growing space of the individual tree was estimated according to its crown size. According to Köstler et al. (1968), this method may be applied in field work, being the crown area a rough estimator for root system expansion. All roots with a diameter ≥ 0.5 cm were dug out and weighted. The tree stump remaining after felling was considered as stemwood and added to this compartment. Splitting of the root system starting directly below ground level was added to the root compartment. All fresh mass was measured using a mechanical balance with a maximum capacity of 100 kg and a precision of 10 g.

## 2.4 Dry Mass and Carbon Determination in the Laboratory

The biomasses of the sample tree were estimated by applying ratio estimation methods based on the moisture content of the sub-samples and the measured fresh mass of the tree compartments. From each compartment of the sampled trees, a sample of 500 g was taken immediately after fresh mass determination and packed in a plastic bag. These sub-samples were used to determine dry matter and carbon concentration in the laboratory. With a balance of a precision of 10 mg, fresh mass of the sample was measured again. After that, samples were oven-dried at 70°C until reaching constant mass and moisture content. Percentage of dry matter for each compartment was calculated by using the following equation:

$$\%\,\text{Dry matter} = \left(\frac{W_{dry}}{W_{fresh}}\right) \times 100 \quad (1)$$

where:
$W_{dry}$ = dry mass (g);
$W_{fresh}$ = fresh mass (g).

The oven-dried sub-samples were ground in a mill and used for determining carbon concentration. Using a LECO-144 combustion chamber, based on infrared gas detection, samples of 350 mg were analyzed. In this method samples are burned at ca. 1350°C in an oxygen-rich environment (99.7%).

## 2.5 Biomass Modeling Approaches

The modeling approaches applied were based on former studies about biomass and carbon modeling (Sanquetta 2002, Tobin et al. 2006). In these studies, it could be shown that the variables diameter at 1.3 m ($D$) and tree height ($H$), as well as logarithmic transformation and interaction of diameter and height are highly applicable for predicting biomass and carbon concentration of individual trees. The variables, their transformations and interactions used for testing the different model equations were taken from Mello (2004). Only simple tree measurement variables were used in this study because age and crown size are usually difficult to determine in ordinary forest inventories.

A correlation matrix of the tree measurement variables and total and partial biomass was constructed and analyzed. For estimating the biomass of the whole tree as well as its compartments, the following equations were tested using the software Statistica®:

$$P = \beta_0 + \beta_1 \times D \quad (2)$$

$$\ln P = \beta_0 + \beta_1 \times \ln D \quad (3)$$

$$P = \beta_0 + \beta_1 \times D^2 H \quad (4)$$

$$\ln P = \beta_0 + \beta_1 \times \ln(D^2 H) \quad (5)$$

$$\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H \quad (6)$$

where
$H$ = total tree height (m);
$D$ = diameter at a 1.3 m height (cm); and
$P$ = biomass (dry matter – kg) for the total biomass and respective compartments.

The ordinary goodness of fit statistics, e.g. coefficient of determination ($R^2$), standard error of the model ($S_{yx}\%$), and the graphical residual analysis (Schlittgen 2009) were used as indicators of the quality of adjustment. Correction of the logarithmic discrepancy was made by multiplying the estimated values of each tree by the correction factor of Meyer (after Machado et al. 2002):

$$M = e^{0.5\,S_{yx}^2} \tag{7}$$

where:
$M$ = Meyer´s correction factor;
e = 2.718281828;
$S_{yx}$ = Standard error of estimation.

### 2.6 Approaches to Calculate Individual Carbon Stock

Three approaches for calculating individual carbon stock were compared to the control by means of pair-wise t-tests. It was assumed that the control can be obtained from the sum of partial carbon stocks (compartments), which in turn is calculated from the biomass of a specific compartment multiplied by the respective carbon concentration. The first and simplest one consisted of using the estimated biomass from the best fitting regression equation previously fitted for the total biomass multiplied by the medium weighted carbon concentration of the species (0.4426). The second multiplied the biomass of each compartment by the respective average carbon concentration and resuming the total estimated carbon stock per tree by summing the compartment estimates. The third involved the directly fitting individual carbon stock from diameter at 1.3 m height (D) and height, in which the carbon concentration of each tree individually is used, as follows:

$$\ln C = \beta_0 + \beta_1 \times \ln D + \beta_2 \times \ln H \tag{8}$$

where:
$C$ = individual carbon stock.

As stated before, these approaches were compared to the control, which is the actual individual carbon stock calculated by multiplying the biomass by the carbon concentration. The objective of this analysis was to analyze whether the three carbon stock approaches produce statistically different results and to propose the use of one in individual carbon stock quantification of the studied species.

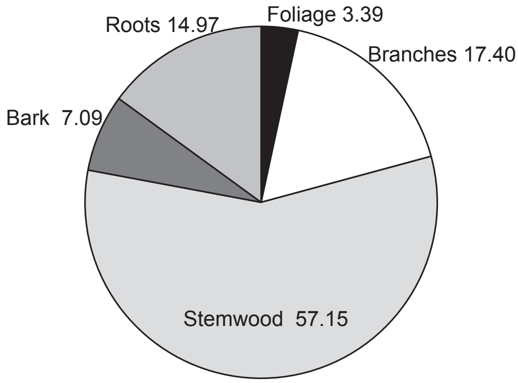


**Fig. 2.** Biomass distribution in the analyzed compartments of *Mimosa scabrella* trees (in %).

## 3 Results

### 3.1 Biomass Determination

Individual biomass of a *M. scabrella* tree is distributed in accordance with Fig. 2. Aboveground biomass accounts for roughly 85% of the total dry mass, whereas belowground (roots) for 15%. Stem with bark represents three fourths of the aboveground biomass and crown (foliage+branches) for one fourth. The usual firewood biomass includes stem and branches over 4 cm of diameter, but it has been changed nowadays due to the strong demand and scarce biomass supply in the region. Therefore, even twigs (thin branches) have been converted to fuel and charcoal. Hence, fuelwood (stem+bark+branches) corresponds to ca. 82% of the total biomass.

As stated before, *M. scabrella* is a broadleaved species with sympodial branching, in this specific case often leading to crooked growth or bifurcation. Though the sampled individuals represent the typical growth of the species in stands, the main stem (below the main bifurcation) accounts for only 56% of the total biomass.

### 3.2 Correlation Matrix

Correlations of all variables used in the present study are shown in Table 2. It is noteworthy that all of them were statistically significant. Diameter

**Table 2.** Correlation matrix for measurement and biomass variables of *Mimosa scabrella* ($D$ = diameter at 1.3 m height, $H$ = tree height).

| | | | Biomass | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $D$ | $H$ | Foliage | Branches | Stemwood | Bark | Roots | Total |
| $D$ | 1 | | | | | | | |
| $H$ | 0.877951 | 1 | | | | | | |
| Foliage | 0.903068 | 0.687467 | 1 | | | | | |
| Branches | 0.928599 | 0.737283 | 0.821114 | 1 | | | | |
| Stemwood | 0.967528 | 0.879969 | 0.861020 | 0.909797 | 1 | | | |
| Bark | 0.941392 | 0.836331 | 0.862979 | 0.859325 | 0.976052 | 1 | | |
| Roots | 0.944990 | 0.754860 | 0.913546 | 0.895590 | 0.950251 | 0.955584 | 1 | |
| Total | 0.976481 | 0.846170 | 0.886500 | 0.940671 | 0.993955 | 0.973307 | 0.970463 | 1 |

**Table 3.** Fitting statistics of the regression equations to estimate biomass of *Mimosa scabrella* ($S_{yx}\%$ = standard error of estimation, %; st. error = standard error).

| Biomass | Best fitting model | $\beta_0$ | $\beta_1$ | $\beta_2$ | $R^2$ | $S_{yx}\%$ |
|---|---|---|---|---|---|---|
| Total | $P = \beta_0 + \beta_1 \times D^2H$ | –0.49361 | 0.034865 | | 0.99 | 0.16 |
| st. error | | 2.367426 | 0.000666 | | | |
| Foliage | $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$ | –0.32716 | 2.704257 | –2.08824 | 0.77 | 35.27 |
| st. error | | 0.877615 | 0.369007 | 0.61397 | | |
| Branches | $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$ | –2.8062 | 3.407628 | –1.26391 | 0.86 | 2.27 |
| st. error | | 0.543147 | 0.228375 | 0.379979 | | |
| Stem | $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$ | –5.45448 | 1.728431 | 1.828572 | 0.98 | 0.44 |
| st. error | | 0.37127 | 0.156106 | 0.259736 | | |
| Bark | $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$ | –7.27226 | 1.550497 | 1.897916 | 0.96 | 5.36 |
| st. error | | 0.549486 | 0.23104 | 0.384414 | | |
| Roots | $\ln P = \beta_0 + \beta_1 \times \ln(D) + \beta_2 \ln H$ | –3.23191 | 2.881863 | –0.63720 | 0.96 | 1.70 |
| st. error | | 0.389447 | 0.163749 | 0.272453 | | |

at 1.3 m height ($D$) and height of *M. scabrella* showed strong correlation with each others, which is uncommon for many subtropical broadleaved species. Diameter at 1.3 m height showed closer relation to all biomass variables as compared to height. All the compartment biomasses were closely correlated among them.

### 3.3 Biomass Equations

The best fitting regression equations for the total and partial (compartments) biomass of *M. scabrella* are presented in Table 3. It is noticed that for the total biomass Eq. (4) gave the best fit and for all partial biomass compartments Eq. (6) showed the best performance in terms of adjustment.

The best fitting equations (showing the lowest standard error, the highest coefficient of determination, and the most adequate residual distribution) were obtained for the total biomass, followed by the stemwood. It is expected to happen due to less variability and size stability of these variables in comparison to the particular compartments. Models for roots, branches, bark, and foliage also fitted fairly well to the actual data, providing equations of good performance. Fig. 3 also indicates that estimates are more stable for large-sized trees and residuals are more scattered for the smaller size individuals.

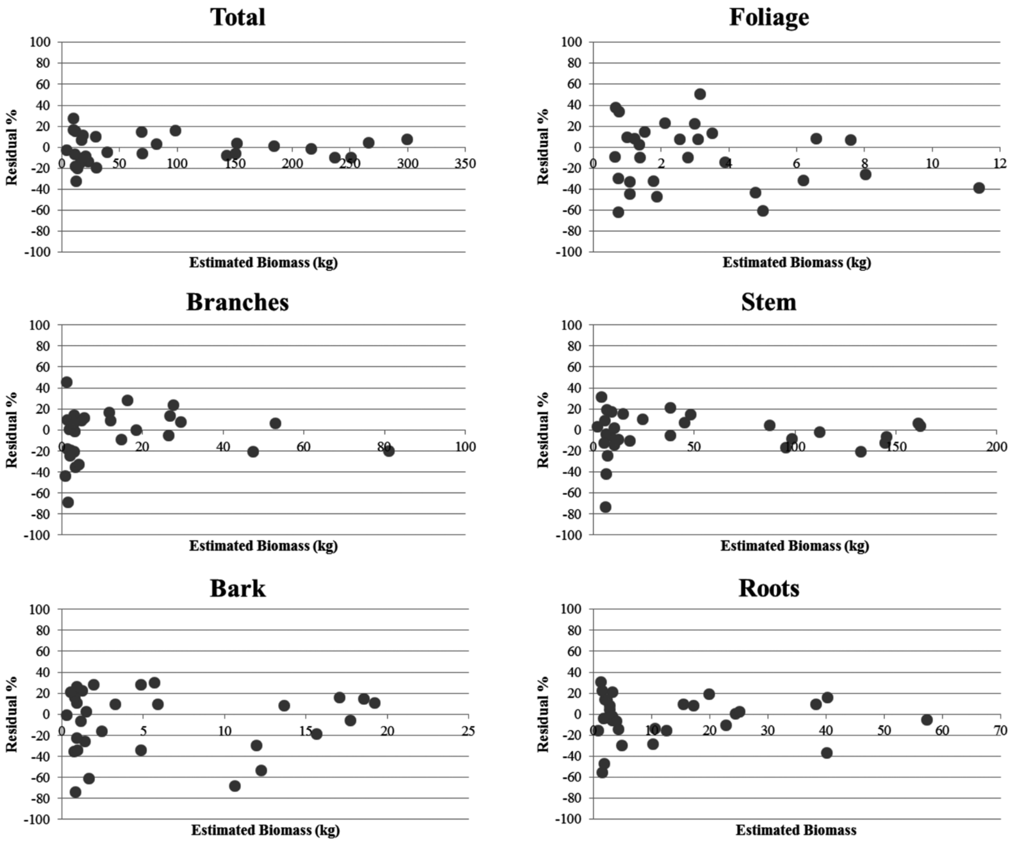


**Fig. 3.** Graphical residual analyses of the best fitting regression equations of individual biomass of *Mimosa scabrella.*

**Table 4.** Carbon concentration (in %) statistics of *Mimosa scabrella*.

| Compartment | Range | Mean | Standard Deviation |
|---|---|---|---|
| Foliage | 45.52–48.83 | 47.68 a | 0.7936 |
| Branches | 42.00–45.43 | 44.16 b | 0.8856 |
| Stemwood | 41.97–45.27 | 43.93 b | 0.7099 |
| Bark | 42.21–46.26 | 44.58 b | 0.9606 |
| Roots | 42.42–46.85 | 44.76 b | 0.9040 |

### 3.4 Determination of Carbon Concentration

The carbon concentrations of the sampled trees were analyzed separately for the different biomass compartments. It can be noted that of all compartments analyzed foliage has the highest carbon concentration, followed by roots, bark, branches, and stemwood (Table 4). ANOVA carried out on the carbon concentration indicated a statistically significant difference among compartments ($p < 0.001$), confirmed by a Tukey´s test that also showed that foliage presented higher carbon concentration than any other compartment.

### 3.5 Individual Carbon Stock Quantification

Pair-wise t-tests indicated no statistically significant differences between the three individual carbon estimation approaches and the control. This is also denoted by Fig. 4 that shows no trend on the estimates by the three approaches of estimating individual carbon stock of *M. scabrella*. Therefore, if the purpose is exclusively to estimate total carbon stock, more simple approaches may be used satisfactorily, e.g. by multiplying the total biomass estimate from a regression equation by

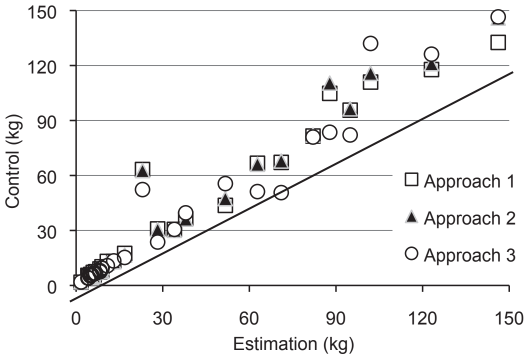


**Fig. 4.** Actual (Control) and predicted individual carbon stock of *Mimosa scabrella* by different quantification approaches.

the mean carbon concentration of the species. Nevertheless, it is noteworthy that the weighted mean shall be used instead of the simple arithmetic mean in order to not lead to unreliable estimation. Since total biomass is much more stable and easy-to-fit than the partial compartment estimates, reliable figures of individual carbon stock can be provided by this robust approach.

# 4 Discussion

According to official inventory data, significant areas of *M. scabrella* exist in southern Brazil, chiefly in Parana and Santa Catarina States (FAO 2010). Besides *Araucaria angustifolia* (Bertol.) Kuntze, which is under protection, the studied species is the most important native species in the region that shows the potential for commercialization. Belonging to the leguminous plants with the ability of nitrogen fixation, the species offers a high potential to be planted in poorer soils and by rural populations with no access to technology for soil amelioration (MacDicken 1994). There is strong evidence that the species will be promoted in the next decades and that area as well as volumes of *M. scabrella* will increase (Carvalho 2003). This also is a key species for promoting the so-called low-carbon agriculture through fuelwood substituting fossil fuels and electricity and for degraded land restoration (carbon sequestration). In this case, knowledge about biomass allocation and carbon storage will play a more important role in the future.

The percentage distribution of the biomass in the analyzed trees showed that more than 50% is located in the stem, followed by branches, roots, bark, and foliage. The portion corresponding to fuelwood corresponds to 85% of the total biomass in this species. Similar results were found elsewhere (Urbano 2007), for trees growing in pure and mixed stands of the species on the metropolitan region of Curitiba, the state capital, where firewood of *M. scabrella* is the preferred one for cooking and wooden poles. Depending on the market, part of the wood may supply the demand of the civil construction (sawnwood and roundwood) sector that generally pays a higher price. In such a case farmers must extend the management rotation up to 17 years (Weber 2007). Since the age range of the sample trees covered younger and older trees (2–19 years), the equations fitted may be applied for fuelwood (short rotation periods) or sawnwood (long rotation period) management regimes.

The biomass distribution in the different tree compartments (stemwood and branches are the most important for fuelwood) was also discussed by various authors. Deciduous tree species deviate significantly from each others in terms of biomass allocation (Bastien-Henri et al. 2010). According to the same authors, site conditions influenced significantly on biomass allocation among the different tree compartments.

However, for foliage the fit was only reasonable, due to the fact that the usual tree measurable variables (i.e. *D* and height) included in the models explain poorly the variability of foliage biomass, demonstrating that perhaps other variables (as age, site conditions, etc.) might also play a role. This can also be seen in Fig. 3 that plots the graphical residual analysis of the fitting equations. For the coniferous species *Picea abies* (L.) H. Karst., Pajtik et al. (2008) found that the needles and branches contribute more than 50% to the biomass. Another important factor for biomass partitioning within a tree species is tree age. With increasing age the proportion of stemwood in the biomass becomes more important (Peichl and Arain 2007, Nogueira et al. 2008, Sanquetta et al. 2011). For the material in the study, a higher variation could be observed in biomass produced in the smaller diameter classes, being the variance more constant with bigger diameters.

For predicting the biomass, most studies have used the variables *D*, basal diameter, tree height or a combination. In many cases, quadratic terms and the logarithmic or square root transformation of the predicting variables were also conducted (Zianis and Mencuccini 2003, Zianis et al. 2005, Peichl and Arain 2007, Nogueira et al. 2008, Zianis 2008, Basuki et al. 2009, Bastien-Henri et al. 2010). In the regression equations used in this study, tree diameter and tree height also showed up as being important for predicting the biomass. The goodness of fit of the regression equations for individual biomass of *M. scabrella* was surprisingly satisfactory. Since most broadleaved subtropical trees belong to species with sympodial branching, often linked with crooked growth and bifurcation, it would be expected a somewhat weak correlation of tree measurement variables and biomass, especially for partial compartment biomass. Hence, poor fitting would be expected in some cases. However, for *M. scabrella* it did not occur. The fitted equations could be used safely in all cases, even for foliage.

*Mimosa scabrella* carbon concentration, related to 1 kg of biomass, is the highest in foliage, followed by roots, bark, branches, and stemwood. Statistical analyses showed that only the mean value of the carbon concentration of foliage is significantly different from those of other compartments. Anyhow, for reliable carbon flow and carbon balance calculations as well as for life cycle assessment and substitution effects such information is important. Ganeshaiah et al. (2003) analyzed carbon concentration in different compartments of several tropical tree species. Compared with other broadleaved tree species the carbon concentration of bark was similar, whereas the carbon stored in the leaves was between 5 to 10% higher in *M. scabrella* (Ganeshaiah et al. 2003). Conversely, the carbon stored in stemwood is at a low level compared with other species. Detailed analysis on carbon allocation in eucalypt stands was also completed by Ryan et al. (2010) and Madeira et al. (2002), showing that management, water, light and nutrient availability significantly influenced the carbon allocation in different tree compartments. Bert and Danjon (2006) with *Pinus pinaster* Aiton, Kraenzel et al. (2003) with *Tectona grandis* L., Stape et al. (2008) with a clonal *Eucalyptus* sp. and Vallet et al. (2009) for *Quercus* and *Pinus* spp. showed that among species, among trees of the same species, among different compartments of the same tree, and also at different tree heights the carbon concentration can be significantly different.

Three different approaches of quantifying individual carbon stock were tested for the studied species. No statistical difference was noticed from the statistical analyses. Therefore, no matter if biomass multiplied by carbon concentration or directly carbon equations are used for carbon quantification. However, as stated by Koehler et al. (2002), who analyzed the deviations and accuracy of carbon stock estimates, the indiscriminate application of 0.5 as a universal carbon fraction is a fallacy and may lead to serious overestimates of carbon stocks. According to the authors, this assumption combined with other generalization frequently adopted in carbon inventories may lead to inaccuracy of 20 to 53%.

The Intergovernmental Panel on Climate Change (IPCC) (2003, 2006) has defined five carbon pools for greenhouse gas inventory, which were also included in the so-called Marrakesh Accord of the United Nations Framework on Climate Change (UNFCCC) (Ravindranath and Ostwald 2008). They are: aboveground and belowground biomass (roots), litter, dead wood, and soil organic carbon. In this study, necromass and soil were not taken into account because they are not individual tree variables and require specific methodological procedures. For this purpose, the user shall use the compartment-specific equations for foliage, branches, stem, and bark and sum the estimates to get the individual aboveground biomass and the root equation to calculate belowground biomass. At this place the assumption that expansion of root system is equal to the area covered by the crown must be discussed. In native forests, tree roots may extend to a much wider area than the crown. In many cases, the aboveground competition leads to asymmetric crown development, which does not correspond to belowground root expansion (Kutschera and Lichtenegger 2002). However, when digging out the roots for weighting, it could be observed that the approach used represented the root system well. Even so, the estimate of the distribution of tree biomass between above- and belowground compartments may be biased because of the root sampling method.

For the purpose of estimation biomass or carbon from firewood or wood debris after harvesting, for instance, the user shall use the biomass equations in separate and integrate them accordingly, as also stated by Urbano (2007).

# 5 Conclusions

The study was a first attempt to attain realistic data for the biomass and carbon storage of *M. scabrella*, which is available at significant volumes in southern Brazil in both mixed and pure stands (Weber 2007). That makes the species interesting for broad commercial uses and also for ecological restoration purposes, including carbon sequestration.

The developed equation for estimating individual biomass and carbon of different tree compartments with the help of the easily available variables diameter at the height of 1.3 m and tree height allow predictions with a high precision. The models can be used to estimate the fuelwood, quantify carbon stocks for greenhouse gas inventories, carbon offsets and or even compare the different harvesting forms and uses of *M. scabrella*. Life cycle assessment from the biomass produced in the forest until the final product for the carbon flows is also possible.

Even not considering the influence of different growth and site conditions, which are important parameters for carbon allocation in different tree compartments, the allometric functions for estimating biomass and carbon showed a high predictability.

# References

Bastien-Henri, S., Park, A., Ashton, M. & Messier, C. 2010. Biomass distribution among tropical tree species grown under differing regional climates. Forest Ecology and Management 260: 403–410.

Basuki, T.M., Laake, P.N.v., Skidmore, A.K. & Hussin, Y.A. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. Forest Ecology and Management 257: 1684–1694.

BEN – Brazilian Energy Balance Base Year 2010. 2011. Ministry of Mines and Energy. 265 p.

Bert, D. & Danjon, F. 2006. Carbon concentration variations in the roots, stem and crown of mature Pinus pinaster (Ait.). Forest Ecology and Management 222: 279–295.

Carvalho, P.E.R. 1994. Espécies florestais brasileiras: recomendações silviculturais, potencialidades e uso da madeira. Colombo: EMBRAPA-CNPF. 640 p.

— 2003. [Internet site]. Cultivo da Bracatinga. http://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/Bracatinga/CultivodaBracatinga/index.htm. [cited 03 Dec. 2009].

EMBRAPA. 1988. Centro Nacional de Pesquisa de Florestas (Curitiba-PR). Manual técnico da bracatinga (Mimosa scabrella Benth.). (EMBRAPA-CNPF. Documentos, 20). Curitiba. 70 p.

FAO – Food and Agriculture Organization. 2010. Global forest resources assessment 2010: Brazil Country Report. 111 p.

Ganeshaiah, K.N., Barve, N., Nath, N., Chandrashekara, K., Swamy M. & Shaanker, R.U. 2003. Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. Current Science 85(11): 1528–1531.

IEA – International Energy Agency. 2008. World energy outlook 2008. 18 p.

Intergovernmental Panel on Climate Change (IPCC). 2003. Good practice guidance for land-use, land-used change and forestry. Penman, J. et al. (eds.). IPCC National Greenhouse Gas Inventories Programme. IGES, Institute for Global Environmental Strategies, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Eggleston, S. et al. (eds). IPCC National Greenhouse Gas Inventories Programme. IGES, Institute for Global Environmental Strategies, Hayama, Japan.

Koehler, H.S., Watzlawick, L.F. & Kirchner, F.F. 2002. Fonte e níveis de erros nas estimativas do potencial de fixação de carbono. In: Sanquetta, C.R. et al. (eds.). As florestas e o carbono. Federal University of Paraná; Curitiba. p. 251–264.

Köstler, N., Brückner, E. & Biebelriether, H. 1968. Die Wurzeln der Waldbäume. Verlag Paul Parey.

Kraenzel, M., Castillo, A., Moore, T. & Potvin, C.

2003. Carbon storage of harvest-age teak (Tectona grandis) plantations, Panama. Forest Ecology and Management 173: 213–225.

Kutschera, L. & Lichtenegger, E. 2002. Wurzelatlas mitteleuropäischer Waldbäume und Sträucher. Leopold Stocker Verlag.

Madeira, M.V., Fabiao, A., Pereira, J.S., Araujo, C. & Ribeiro, C. 2002. Changes in carbon stocks in Eucalyptus globulus Labill. plantations induced by different water and nutrient availability. Forest Ecology and Management 171: 75–85.

Machado, S.A., Conceição, M.B. & Figueiredo Filho, A. 2002. Modelagem do volume individual para diferentes idades e regimes de desbaste em plantações de Pinus oocarpa. Guarapuava. Revista Ciências Exatas e Naturais 4(2): 41–50.

MacDicken, G.K. 1994. Selection and management of nitrogen fixing trees. Winrock International, Bangkok: FAO.

Mello, A.A. 2004. Planejamento de uma empresa florestal visando à maximização dos lucros e a manutenção do estoque de carbono. PhD thesis at Federal University of Paraná, Curitiba, Brazil. 204 p.

Nogueira, E.M., Fearnside, P.M., Nelson, B.W., Barbosa, R.I. & Keizer, E.W.H. 2008. Estimates of forest biomass in the Brazilian Amazon: new allometric equations and adjustments to biomass from wood-volume inventories. Forest Ecology and Management 256: 1853–1867.

Pajtik, J., Kanopka, B. & Lucak, M. 2008. Biomass functions and expansion factors in young Norway spruce (Picea abies [L.] Karst.) trees. Forest Ecology and Management 256: 1096–1103.

Peichl, M. & Arain, M.A. 2007. Allometry and partitioning of above- and belowground tree biomass in an age-sequence of white pine forests. Forest Ecology and Management 253: 68–80.

Ravindranath, N.H & Ostwald, M. 2008. Carbon inventory methods. Springer. 304 p.

Ryan, M.G., Stape, J.L., Binkley, D., Fonseca, S., Loos, R.A., Takahashi, E.N., Silva, C.R., Silva, S.R., Hakamada, R.E., Ferreira, J.M., Lima, A.M.N., Gava, J.L., Leite, F.P., Andrade, H.B., Alves, J.M. & Silva, G.G.C. 2010. Factors controlling Eucalyptus productivity: How water availability and stand structure alter production and carbon allocation. Forest Ecology and Management 259: 1695–1703.

Sanquetta, C.R. 2002. Fixação de carbono em plantações de Pinus. Revista da Madeira. Special edition. p. 48–52.

— , Dalla Corte, A.P. & Silva. F.S. 2011. Biomass expansion factor and root-to-shoot ratio for Pinus in Brazil. Carbon Balance and Management 6(6): 1–8.

Schlittgen, R. 2009. Multivariate Statistik. München, Oldenbourg. 559 p.

Somarriba, E. & Kass, D.C.L. 2001. Estimates of aboveground biomass and nutrient accumulation in Mimosa scabrella fallows in southern Brazil. Agroforestry Systems 51: 77–84.

Stape, J.L., Binkley, D. & Ryan, M.G. 2008. Production and carbon allocation in a clonal Eucalyptus plantation with water and nutrient manipulations. Forest Ecology and Management 255: 920–930.

Tobin, B., Black, K., Osborne, B., Reidy, B., Bolger, T. & Nieuwenhuis, M. 2006. Assessment of allometric algorithms for estimating leaf biomass, leaf area index and litter fall in different-aged Sitka spruce forests. Forestry 79(4): 453–465.

Urbano, E. 2007. Quantificação e estimativa da biomassa aérea e do carbono fixado em árvores de bracatingais nativos da região metropolitana de Curitiba. Master thesis at Federal University do Paraná. 140 p.

Vallet, P., Meredieu, C., Seynave, I., Belouard, T. & Dhôte, J.F. 2009. Species substitution for carbon storage: sessile oak versus Corsican pine in France as a case study. Forest Ecology and Management 257:1314–1323.

Weber, K.S. 2007. Manejo do crescimento diamétrico de bracatinga (Mimosa scabrella Benth.) baseado em árvores individuais. Master thesis at Federal University of Paraná, Brazil. 141 p.

Zianis, D. 2008. Predicting mean aboveground forest biomass and its associated variance. Forest Ecology and Management 256: 1400–1407.

— & Mencuccini, M. 2003. Aboveground biomass relationships for beech (Fagus moesiaca Cz.) trees in Vermio Mountain, Northern Greece, and generalised equations for Fagus sp. Annals of Forest Science 60: 439–448.

— , Muukkonen, P., Mäkipää, R. & Mencuccini, M. 2005. Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs 4. 63 p.

*Total of 37 references*