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Yield prediction of young black locust (*Robinia pseudoacacia* L.) plantations for woody biomass production using allometric relations

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Abstract. Black locust (*Robinia pseudoacacia* L.) is an increasingly popular tree species for the production of woody biomass for bioenergy generation with short rotation coppices. Due to its potential to produce large amounts of biomass yields even under unfavourable growth conditions, this tree species is especially suitable for marginal sites, such as can be found in the post mining area of NE-Germany. Current research aims to reliably predict the yield potential of black locust short rotation coppices, but suffers from a lack of sufficient exact allometric functions until recently. This is especially true for the early growth years, which are of special importance for short rotation coppices. The objective of this study was to develop allometric equations based on tree height and shoot basal diameter (*SBD*) for estimating yields of young black locust plantations. Therefore, dendrometric data were collected in a two, three, four and fourteen years old black locust short rotation forest located in the reclamation area of an opencast-lignite mining area in the Lower Lusatian region (Germany) and used for equation developing. Until measurement, none of the plantations had been harvested. Closed correlations between *SBD* and tree height were observed, as well as between these parameters and single tree mass. The scattering of single tree masses could be explained slightly better by the *SBD* than by the tree height. In the year before a harvest an even better prediction probability of woody biomass was obtainable when both parameters were simultaneously interrelated with the single tree mass. The results illustrate that the woody above ground biomass of young black locust plantations can be estimated sufficiently precisely based on the easy determinable parameters tree height and particularly *SBD*.
Keywords allometry, bioenergy, black locust, *Robinia pseudoacacia*, short rotation, yield prediction.

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Introduction

Black locust (*Robinia pseudoacacia L.*) is a foreign tree species for Europe, originating from eastern United States, and was introduced to Europe during the 17th century by Jean Robin (royal gardener in Paris, France) after whom the tree was named. In the following years, a rapid spreading ensued on the European continent, first due to planting as parkland or ornamental tree, later by extensive plantings for timber production and by natural propagation. Nowadays, large areas covered with black locust can be found in Central Europe and, especially, in the southeastern parts of Europe (Rédei et al. 2002).

Reasons for the popularity and the competitive capacity of black locust are manifold. Black locust is characterized by an extensive root system and thus widely used for land protection and soil erosion control (Zhou & Shangguan 2005). Furthermore, black locust is a light demanding pioneer species that demands well aerated, light soils, but tolerates a wide range of edaphic conditions. The species is comparatively drought-resistant, a legume and, therefore, belongs to the small group of atmospheric nitrogen fixing trees growing in temperate regions. For these reasons, black locust is deemed to be a suitable tree species for soil regeneration and reclaiming former mine sites (Zeleznik & Skousen 1996, Filcheva et al. 2000, Grünewald et al. 2009). Its ability to grow on bare soils under extreme conditions, its fast youth growth, the considerable resprouting ability after cutting (Boring & Swank 1984, Luken et al. 1991), and its high wood density (Waitkus & Richter 2001), proved to be particularly useful for the production of woody biomass for bioenergy in areas with marginal soils. A large amount of such sites can be found in the post-mining landscape of Lower Lusatia (Grünewald et al. 2009). In this region, black locust is increasingly planted in short rotation coppices (SRC). These tree plantations are characterized by high planting densities (up to 12,000 plants per hectare), mechanized management and short rotation periods of between 3 and 6 years. For SRC with black locust annual biomass yields of between 3 t dry mass ha^{-1} and 14 t dry mass ha^{-1} can be expected, depending on plant and plantation age, site conditions, rotation interval and planting layout (Werner et al. 2006, Unruh Snyder et al. 2007, Grünewald et al. 2009).

For developing a successful management plan for short rotation coppices (time of harvest, available technology of harvest, sales planning etc.), it is essential to have an accurate estimation of the expected yield biomass in advance, before a harvest. However, for black locust, currently this is not possible in practice with sufficient precision because there exist hardly any equations, based on parameters easy to measure such as tree height or stem diameter that facilitate a quick estimation of yield biomass and focus on the early growth years. However, some regression equations do exist for estimating wood volume of older and larger trees (Ertelt 1952), but there are very few publications that deal with the prediction of woody biomass of small black locust trees or shrubs (Bongarten et al. 1992, Burner et al. 2006). According to the author's state of knowledge, suchlike functions are missing completely for Central Europe.

This study aims to contribute to fill this gap. The objective was to develop an allometric function based on tree height and shoot basal diameter as dendrometric parameters derived from a comprehensive data pool of field measurements. Trees of four different-aged black locust stands were included in the study. The four plantations were designed as short rotation coppices, but until field measurements the trees had not been harvested. With the derived equation reliable estimates of the above ground woody biomass of young black locust plantations should become possible. Real harvest data were used for validating this equation in terms of the concrete site conditions.

Materials and methods

Study sites

Study sites are situated in the post-mining area of the lignite opencast mining "Welzow-Süd", which is located in Brandenburg State, Germany, about 150 km southeast of Berlin (Figure 1). The study area is characterised by an average annual precipitation sum of 560 mm and a mean annual temperature of 9.3 °C (1951-2003, meteorological station Cottbus).

The study site is adjacent to an extensive, low-structured and only partly vegetated post-mining reclamation area, which is characterised by frequently strong winds and distinct dry periods during growing season (compared with average weather conditions in Germany). Furthermore, there is no groundwater influence due to lowering of the groundwater level (deeper than 40 m) because of the ongoing mining activities. The soil formation of the dumped substrate is in an initial stage and the soil structure is still instable. There are mainly sands and loamy sands with a low content of total organic carbon, a low sorption capacity and deficient nutrient supply. More details about soil characteristics are given by Grünewald et al. (2009).

In order to obtain a wide range of allometric tree parameters measurements were carried out at four black locust plantations established in 2007 (BL-02), 2006 (BL-03), 2005 (BL-04) and 1995 (BL-14); that means that, at the time of measurements, the plantations were 2, 3, 4 and 14 years old. Site features regarding area, planting layout and planting density are given in table 1. At the time of data collection, trees had not been cut before on all sites.

Field measurements and analyses

Field measurements were conducted in winter 2008/2009 on leafless trees. Except the BL-14 plantation, data were collected in randomly distributed sampling plots, each of which had an area of 165 m², consisting of four double tree rows, each with 38 planting positions (failed trees included). Ten plots were laid out in BL-04 and BL-02 and nine plots were esta-

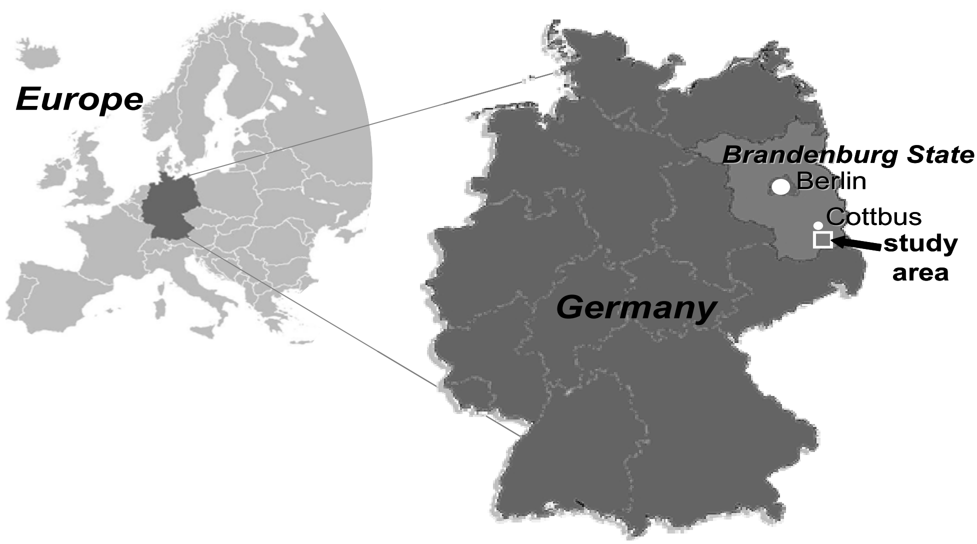

Figure 1 Location of study site in Brandenburg State. Germany

Table 1 Characteristics of the four different-aged black locust (*Robina pseudoacacia* L.) plantations investigated in this study

Feature	Study site			
	BL-02	BL-03	BL-04	BL-14
Establishment	2007	2006	2005	1995
Area (ha)	12.4	9.2	9.2	1.0
Age at sampling (years)	2	3	4	14
Planting layout	double row	double row	double row	single row
Plant spacing (m)				
• within row	0.85	0.85	0.85	0.75
• within double row	0.75	0.75	0.75	
• between (double) rows	1.80	1.80	1.80	2.00
Average initial planting density (trees ha^{-1})	9.200	9.200	9.200	6.600
Survival rate in sampling year (%)	85	91	84	95

blished in BL-03. Measurements were carried out at one double row at each plot in BL-02 and BL-03 and at two double rows at each plot in BL-04. In BL-14 allometric data were recorded at 30 trees located in a representative area of 500 m². Altogether, tree height, shoot basal diameter (*SBD*) and shoot biomass were determined from 1,243 trees. Tree height was measured from the soil surface to the top of the tallest branch using a Senshin telescopic height pole. SBD was measured with a caliper about 10 cm above soil surface.

After collecting dendrometric data, trees were cut approximately 10 cm above soil surface and weighed on-site separately with an electronic scale (precision ±1 g for trees with a mass of <5 kg and precision ±100 g for trees with a mass of >=5 kg). In each plot, one harvested representative tree was selected and shredded into wood chips, that were used for the determination of dry matter content. Therefore, a representative, plot-related aliquot of shredded tree biomass was dried in the laboratory at 105°C till weight constancy.

Statistics

Generally, medians should be used for the estimation of woody biomass, since typically, dendrometric parameters are often not normally distributed, as in this study, where data were positively skewed. This is particularly true for younger, less differentiate stands (Liu & Burkhart 1993, Podlaski & Zasada 2008). Furthermore, non-linear relations were observed between some parameters. Because of these aspects and in order to ensure comparability, nonparametric statistical methods were used. In concrete terms, the Mann-Withney-U-test was used for comparing differences between different-aged plantations. The Spearman correlation coefficient (*rS*) was computed to express relationships between two variables. Regression analysis was used to estimate the *a* and *b* values of the functions. Regression equations and coefficients of determination (r^2) were performed using the ordinary least squares regression method.

The relationships between tree height and single tree mass as well as between *SBD* and single tree mass were not linear. Relations between these parameters can be described in general by the allometric function as given in equation 1:

$$M = a\mathrm{X}^{b} \qquad (1)$$

where *a* and *b* are scaling coefficients (intercept and slope), *M* is the total weight of aboveground woody dry biomass of a single tree and X is the tree height or the *SBD*. Coefficients a and b were determined by the least-square linear regression of ln-transformed data. For that, single tree dry mass as well as tree height and *SBD* data were ln-transformed, in order to obtain linear functions. The basic form of these close log-linear relationships is given in equation 2:

$$\ln(M) = \ln(a) + b \cdot \ln(X) \tag{2}$$

In order to eliminate the bias that appears after back-transformation from logarithmic scale (Finney, 1941) a correction factor (CF) was determined for each function, based on logarithmic data. This factor was calculated from the standard error of estimate of the regression as described by Sprugel (1983) and Smith (1993). Based on equation 2 and taking account the correction factor, the single tree dry biomass (*M*) was calculated as follows:

$$M(kg) = CF \cdot e^{\ln(M)} \tag{3}$$

where the term ln(*M*) is equivalent to equations 6, 7 and 8 set up in this study.

For presenting the relation between tree height and *SBD*, data were not ln-transformed because of the linear dependency between these parameters. Besides, the coefficient of determination of this relation could not be improved when *SBD* and tree height were ln-transformed. Variance of the data describing the relation between tree height and *SBD* was verified regarding heteroscedasticity by plotting standardized residuals against standardized predicted values. The relationship between these parameters can be described by a linear function that is given as the basic form in equation 4:

$$tree\ height\,(m) = a + b \cdot SBD\,(cm) \tag{4}$$

All statistics were performed using the software Statsoft Statistica® version 7.0 (Statsoft Inc., Tulsa, Oklahoma, USA).

Validation

In order to validate the derived functions, predicted yields were compared with measured yield data from the four years old plantation (BL-04) harvested in the same winter as dendrometric data were collected. For this, ranges and medians of *SBD* and tree height were calculated separately for the 10 sampling plots, as well as for the whole data pool collected in this plantation. Single tree dry masses were estimated using equations 6 to 8 in the same way. Coefficients of determination and standard errors of estimate were determined for each plot as well as for all trees measured at the BL-04 site using the linear regression analyses as described in the “Statistics” subchapter.

Furthermore, the median absolute percentage error was calculated for each plot as well. The comparison of measured and predicted data was made not only for single trees but also for the whole stand. For that, woody dry biomass yield per hectare was estimated in consideration of plant density and survival rate and compared with the really yield of aboveground woody dry biomass determined in the course of the harvest of the whole plantation.

Results

Dry matter content

Dry matter contents (DM) of sampled black locust woody biomass originated from the study sites described above varied from 55.7% to 66.0%. Differences between the young plantations BL-2, BL-3 and BL-4 were small and no significant relation could be detected between stand age and DM. Therefore, an average DM of 59% (standard deviation = 2) was assumed for black locust woody biomass of all of these three sites. Compared to these plantations, the DM of the 14 years old trees at BL-14 was clearly higher. For woody biomass originated from this site a DM of 66.0% was used for calculating the dry biomass.

Relations between dendrometric parameters

The distribution of all measured single tree dry masses is presented in figure 2a. Collected data of single tree dry masses ranged widely, from less than 0.5 kg to 34 kg. However, due to the low age of the plantations investigated, more than half (55%) of the measured trees had a dry mass of less than 1 kg and only 7% of all measured trees had a dry weight of more than 4 kg. To these belong all of the 14 years old trees, less than 0.5% of the three years old trees and no trees of the two years old plantation. Single tree weights differed significantly ($P < 0.001$) between all stand ages. Generally, the range of data increased with plantation age (Figure 2b). The single tree dry masses of the 14 years old trees varied between 8 kg and 34 kg, while dry tree weights of the four, three and two years old trees were lower than 10 kg, 5 kg and 2.5 kg, respectively.

Tree heights and *SBD*'s depending on stand age are shown in figure 3a-b. The median tree heights amounted to 2.2 m, 3.2 m and 4.0 m at BL-02, BL-03 and BL-04. Black locust trees in the 14 years old plantation had a median height of 9.3 m (Figure 3a). Analogous medians of *SBD* amounted to 2.5 cm, 3.2 cm, 4.4 cm and 10.5 cm (Figure 3b). Despite the overlapping range of data, age-related differences in tree height and *SBD* were significant ($P < 0.001$), respectively. Altogether, tree heights and *SBD*'s considered for this study varied between 0.2 m and 10.4 m and between 0.5 cm and 13.4 cm, respectively (Figure 3). All allometric parameters, single tree mass as well as tree height and *SBD*, were log-normal distributed.

Tree height and *SBD* were highly correlated ($r_s = 0.91$, $P < 0.001$) regardless of age. The relationship between these parameters can be described by a linear function that is given in equation 5 and illustrated in figure 4. The coefficient of determination (r^2) is 0.85. Consequently, 85% of the data variance can be explained by this function. The mean standard error of estimate amounted to 0.60. Scattering, and hence, the statistical uncertainty tended towards an increase with increasing stand age. However, a heteroscedasticity is not very likely, since no recognizable relation could be detected between standardized residuals and standardized predicted values.

$$tree\ height(m) = 0.4874 + 0.7673 \cdot SBD(cm) \quad (5)$$

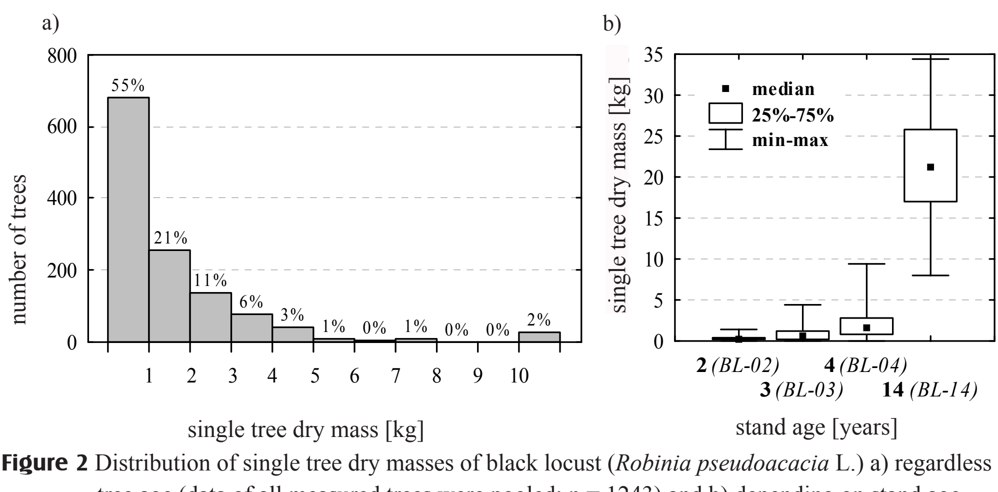

Figure 2 Distribution of single tree dry masses of black locust (*Robinia pseudoacacia* L.) a) regardless of tree age (data of all measured trees were pooled; n = 1243) and b) depending on stand age

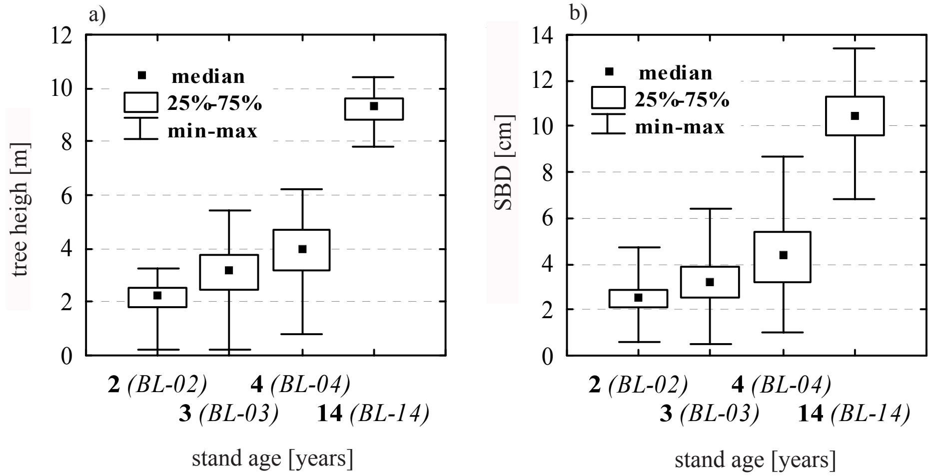

Figure 3 a) Tree height and b) shoot basal diameter (SBD) of black locust (*Robinia pseudoacacia* L.) depending on stand age (n = 280. 309. 624. 30 for BL-02. BL-03. BL-04. BL-14.

Relationships between tree height and single tree mass, as well as between *SBD* and single tree mass were log-linear. Dendrometric data transformed by the natural logarithm were significantly correlated on the linear scale (r_s = 0.95 for *SBD* and single tree dry mass and r_s = 0.93 for tree height and single tree dry mass; P < 0.001). The linear logarithmic relationships between these parameters are illustrated in figure 5a and 5b. *SBD* describes 91% of the single tree dry weight variance, while only 87% is explainable by the tree height. In both cases scattering is higher at smaller and thinner shoots. Higher coefficient of determination and thus a higher prediction probability can be obtained using both *SBD* and tree height as independent variables to predict woody biomass. Hence, the logarithmically transformed product of these parameters explains 93% of the variance of the log-transformed single tree dry mass (Figure 6). The functions, which describe these relationships, are given in equations 6, 7 and 8 that are listed in Table 2.

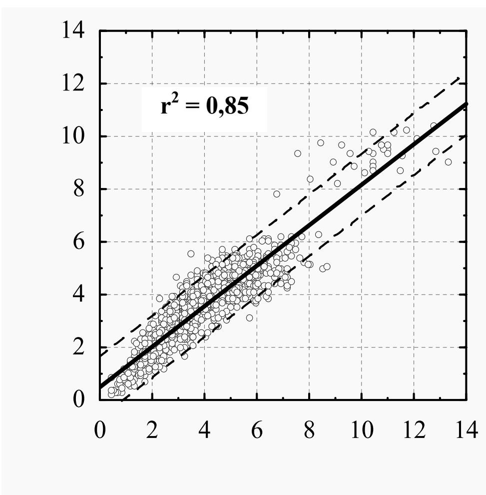

Figure 4 Relationship between tree height and shoot basal diameter (*SBD*) of less than fifteen years old short rotation plantations of black locust (*Robinia pseudoacacia* L.) (n = 1243; broken lines represent a 95% confidence interval)

Woody biomass yields to be expected theoretically for different *SBD*'s and tree heights calculated according to equations 6 and 7 are given in table 3.

Principally, single tree dry mass increases disproportionately with increasing *SBD* as well as with increasing tree height.

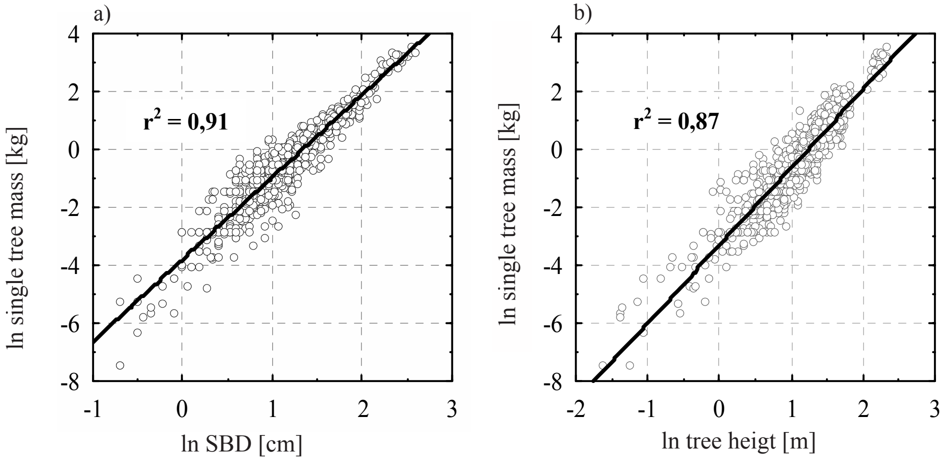

Figure 5 Relationship between ln-transformed single tree dry mass and a) ln-transformed tree height and b) ln-transformed shoot basal diameter (*SBD*) of less than fifteen years old short rotation plantations of black locust (*Robinia pseudoacacia* L.)(n = 1243)

Validation

Validation of derived equations was conducted on biomass data collected from the four years old plantation (BL-04). Figure 7 shows the comparison of measured versus predicted single tree dry masses, depending on dendrome-tric parameters used for the estimation. Gene-rally, differences mainly occur at bigger trees. Hence, the accuracy of the prediction seems to decline with increasing tree size. Especially within the tallest 25% of trees measured in the different plots predicted values were slightly higher when the single tree dry mass was estimated using the *SBD*. Contrary to that, tree masses were underestimated when the tree height or the product of *SBD* and tree height were used as predictors (Figure 7). The median difference between measured and predicted single tree masses amounted to around 0.3 kg (median absolute percentage error (MedAPE) = 20.3%), when *SBD* was used, and around 0.4 kg (MedAPE = 27.4%) when only tree height was used for calculation. The mean difference between measured and predicted single tree mass was only 0.3 kg (MedAPE = 17.6%) as well when the estimation based on the product of *SBD* and tree height (Table 3). Correlations between measured and predicted single tree masses were significant ($P < 0.05$) regardless of dendrometric parameters used (Table 4). However, the *SBD* is apparently

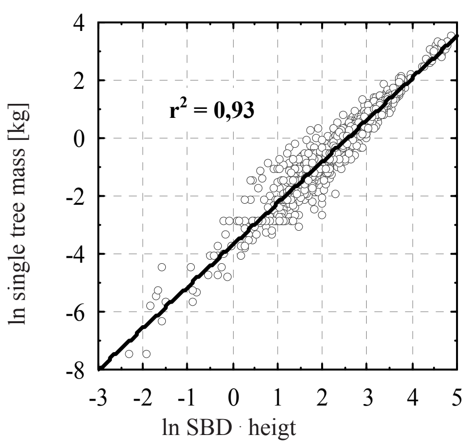

Figure 6 Relationship between ln-transformed single tree dry mass and the ln-transformed product of tree height and shoot basal diameter (*SBD*) of less than fifteen years old short rotation plantations of black locust (*Robinia pseudoacacia* L.) (n = 1243)

Table 2 Equations for calculating the ln-transformed total weight of aboveground woody dry biomass of a single tree (*M*) depending on shoot basal diameter (*SBD*) and tree height (*TH*)(r^2 = coefficient of determination; *SEE* = standard error of estimate; *CF* = correction factor according to equation [3]; n = 1242)

Equation number	Dendrometric parameters used for biomass prediction	Equation	*CF*	r^2	*SEE*
6	*SBD*	$\ln(M\ [kg]) = -3.7933 + 2.8407 \cdot \ln(SBD\ [cm])$	1.099	0.91	0.43
7	*tree height*	$\ln(M\ [kg]) = -3.3117 + 2.6847 \cdot \ln(TH\ [m])$	1.138	0.87	0.51
8	*SBD · tree height*	$\ln(M\ [kg]) = -3.6887 + 1.4412 \cdot \ln(SBD\ [cm] \cdot TH\ [m])$	1.075	0.93	0.38

Table 3 Estimation matrix of single tree dry mass depending on different shoot basal diameters (*SBD*) and tree heights according to equation 6 and 7 (biomass losses due to the harvest process are not considered)

SBD [cm]	*Tree height* [m]	Estimated single tree woody dry biomass [kg] based on	
		SBD acc. to eq. 6	Tree height acc. to eq. 7
1	1	0.0	0.0
2	2	0.2	0.3
3	3	0.6	0.8
4	4	1.3	1.7
5	5	2.4	3.1
6	6	4.0	5.1
7	7	6.2	7.7
8	8	9.1	11.0
9	9	12.7	15.1
10	10	17.2	20.1

more suitable for predicting aboveground woody biomass than the tree height. Thus coefficients of determination were clearly higher and standard errors of estimate were lower in the most cases when the estimation was based on the *SBD* compared to the tree height. Using the product of *SBD* and tree height resulted in a slightly higher coefficient of determination but in a clearly lower standard error of estimate (Table 4). This means that the probability of a right prediction increases, while the explained variance of the single tree dry mass can not be enhanced significantly by an additional consideration of the tree height.

The yield of dry woody biomass determined in the course of the harvest of the whole black locust plantation BL-04 amounted to 12.1 Mg dry matter ha^{-1}. Estimated plot-related yields ranged considerably between 8.3 Mg ha^{-1} and 20.1 Mg ha^{-1} depending on survival rate (varied between 64.5% and 98.7%) and plot-related medians of *SBD* and tree height. However, related to the whole plantation area the differences between calculated and measured yields varied only between 0.5 Mg ha^{-1} and 1.0 Mg ha^{-1}. A still more exact conformity between measured and predicted values will be obtained by considering biomass losses due to the harvest process. With the utilised harvesting machinery these losses amount to about

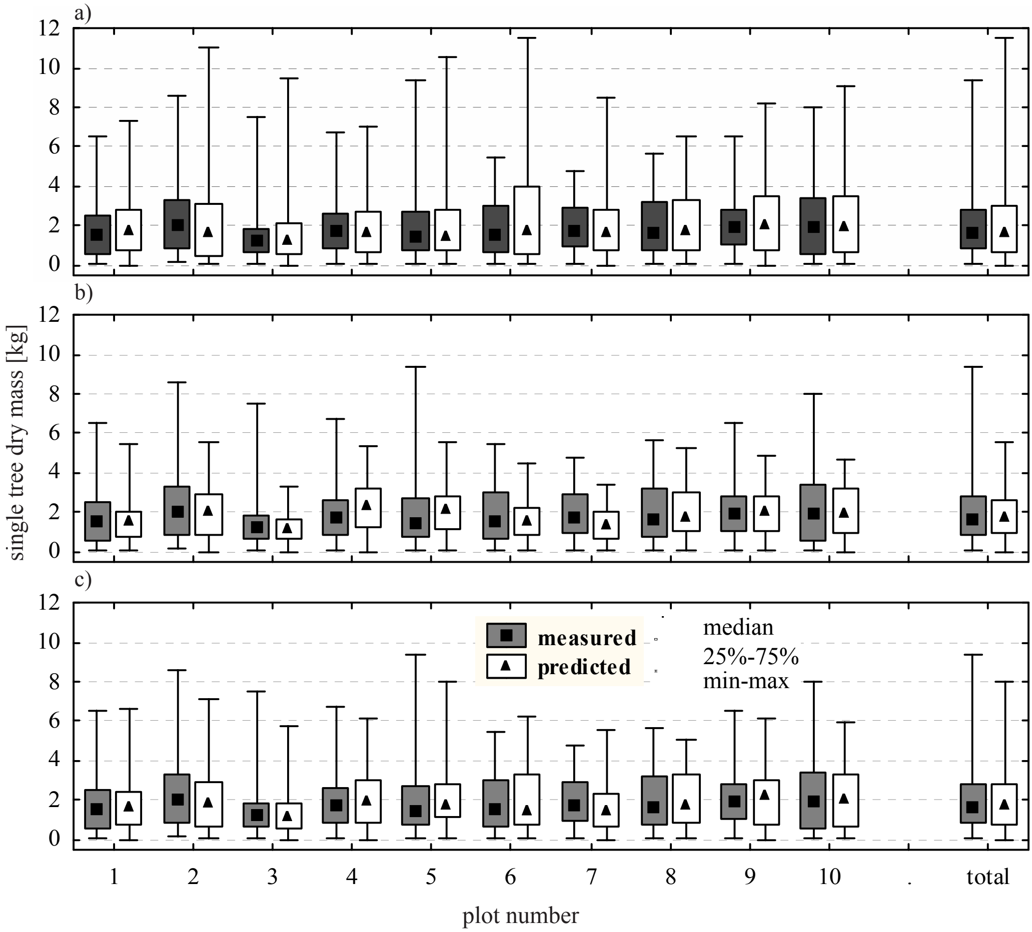

Figure 7 Measured versus predicted single tree dry masses based on a) the shoot basal diameter (*SBD*) (eq. 6). b) the tree height (eq. 7) and c) the product of *SBD* and tree height (eq. 8) separated for the ten sampling plots established in the four year old black locust (*Robinia pseudoacacia* L.) plantation (BL-04) and in total for all trees measured at this site (n = 49 to 623)

6% of harvestable woody biomass (Hofmann, 2009). If calculated biomass yields are corrected by this amount then discrepancy between measured and predicted woody dry biomass ranged only between 0.1 Mg ha^{-1} and 0.3 Mg ha^{-1}. Thus, there is a good general conformity between predicted and measured yields. Similar to the single tree weights the best agreement was obtained by using the product of *SBD* and tree height.

Generally, the absence of bias for equations set up in this work suggests that they work well for young black locust stands across the range of *SBD*'s and tree heights measured in this study. For an aboveground woody biomass estimation being as precise as possible, however, it is important to point out that the prediction of the really woody biomass yield must be made in consideration of the specific plant density. In this context, the precision of estimation of yields crucially depends on the accurate determination of the survival rate.

Table 4. Number of measured trees (*n*), coefficients of determination (r^2), standard errors of estimate (*SEE*) and median absolute percentage errors (MedAPE) for the prediction of the single tree dry mass depending on dendrometric parameters shoot basal diameter (*SBD*) and tree height; data are separated into the ten sampling plots established in the four year old black locust (*Ro binia pseudoacacia* L.) plantation (BL-04) and in total for all trees measured at this site.

Plot number	n	*SBD* acc. to eq. 6			*tree height* acc. to eq. 7			*SBD* · *tree height* acc. to eq. 8		
		r^2	*SEE*	MedAPE (%)	r^2	*SEE*	MedAPE (%)	r^2	*SEE*	MedAPE (%)
1	62	0.87	0.65	17.1	0.63	0.71	31.7	0.84	0.57	20.2
2	49	0.92	0.65	19.0	0.61	0.84	32.4	0.91	0.49	18.2
3	62	0.94	0.41	21.8	0.67	0.41	29.8	0.92	0.30	19.7
4	75	0.93	0.44	13.5	0.66	0.73	24.7	0.91	0.41	15.4
5	58	0.93	0.53	18.6	0.59	0.88	35.4	0.87	0.59	22.4
6	59	0.84	0.94	28.5	0.68	0.63	27.9	0.89	0.50	16.8
7	63	0.78	0.81	23.8	0.79	0.39	28.1	0.87	0.42	19.1
8	65	0.87	0.59	19.9	0.69	0.71	30.7	0.87	0.51	15.4
9	64	0.90	0.62	23.0	0.72	0.59	22.2	0.92	0.41	17.2
10	66	0.93	0.57	18.6	0.77	0.62	23.8	0.93	0.43	12.9
Total	623	0.87	0.68	20.3	0.64	0.72	27.4	0.88	0.50	17.6

Discussion

The results illustrate that the woody above ground biomass of young black locust plantations can be estimated based on the easy determinable dendrometric parameters tree height and *SBD*, whereby better results were got using the *SBD*. The accuracy of yield estimation increases only slightly by using both variables, which corresponds to results by Verwijst (1991) or Dickinson & Zenner (2010). Thus, the effort for measurements can be reduced by determining only the *SBD*, because this parameter describes single tree mass effectively and better than tree height. These finding corresponds to results reported by numerous authors such as Aravanopoulos & Zsuffa (1993), Zianis & Mencuccini (2003) or Lieurance (2007). However, compiled yield functions should be regarded as exemplary for black locust plantations with a low degree of growth performance. Thus, the transferability of these equations to other black locust plantations, which differ considerably from that of this study in terms of site conditions, but also in regards to stand density or provenience, could be problematical, since relations between tree height, *SBD* and single tree mass may be influenced by these variables. The diameter-height relation is important for the application of the derived equations. The rate of tree height growth compared to relative to the rate of growth in shoot diameter is greater for trees growing in dense stands than for trees growing in open fields (Niklas 1995). Close-standing trees are characterized by a rapid vertical growth and a suppression of lateral branches due to the competition for sun light (Addlestone et al. 1999, Unruh Snyder et al. 2007). Changes in stand density might thus result in a deviation of the nearly proportional relation between *SBD* and tree height found in this study. At black locust plantations investigated, however, existing differences in stand density between the older BL-14 plantation and the younger stands were not reflected in the diameter-height ratio that was comparable between these plantations. Furthermore, allometric relations change with shoot age. Heinsoo et al. (2002), for example, observed in a five years old willow plantation that older shoots were heavier than younger ones with the same diameter. They explained this with differences in tree height, wood density and branching. Such age-related differences could not be verified in this study. Typical age-related changes in allometric relations caused by the natural growth curve should not be crucial at short rotation coppices because of their common short rotation periods of 3 to 6 years. However, allometry may be also influenced by site conditions and management practices, such as the quantity of precipitation (Converse & Betters 1995) or fertilization (Heinsoo et al. 2002). However, Bongarten et al. (1992) found no interactions of *SBD* or tree height with irrigation or nitrogen treatment in one to three years old black locust stands, which is why they used one age-related equation for all treatments. Also, Burner et al. (2006) reported that different phosphorus fertiliser applications did not affect allometry in pollarded shoot mass (Burner et al. 2006).

Regardless of site and management conditions the collection of data derived from trees that are representative for the whole plantation in terms of *SBD* and tree height is of high importance for precise yield prediction. Furthermore, the correct estimation of the survival rate is a crucial factor for a successful prediction of woody biomass yields.

Additionally, estimated single tree masses quoted in tables 2 and 3 represent dry weights. The dry matter content of black locust woody biomass depends on shares of bark, sapwood and heartwood as well as on the time of harvest. Seasonal changes in water content of woody biomass are negligible because the harvest is carried out within the dormancy period. However, the proportion of the comparatively moist bark declines relatively and the share of dryer heartwood increases with increasing tree age. For black locust the formation of heartwood typically commences at a shoot age of five years (Ertle et al. 2008). Hence, the woody biomass of older black locust plantations has usually lower water content than younger plantations. However, for the three young black locust plantations investigated in this study, changes in water content were not proportional to stand age. Therefore, lower water content was considered only for the 14 years old plantation.

At the time of investigations the black locust stands were plantations. That means that trees were not cut before and thus had largely only one main shoot. After cutting several equally dimensioned shoots per tree resprout. In such short rotation coppices the relevance of the dendrometric parameter tree height likely declines due to the different number of shoots per tree having the same height. On the one hand, the probability that trees with the same height differ considerably in terms of their mass increases and on the other hand the correlation between tree mass and tree height decreases. In contrast, the importance of the *SBD* most likely increases for estimating woody biomass. Existing shoot biomass estimations of pollarded black locust stands (Burner et al. 2006) indicates a good transferability of equation 4 to resprouting black locust stands and thus to short rotation coppices.

Conclusion

In conclusion, the results show that the tree height and the *SBD* are suitable dendrometric parameters in order to estimate the woody above ground biomass of young black locust plantations. However, the allometric functions based on the data collected in this study reflect the vigorous growth of young black locust plantations at sites with unfavourable growth conditions. The derivation of allometric functions based on data of plantations growing on more fertile soils should be the next step as it is a prerequisite for assessing the biomass growth on a wider scale of sites. Furthermore, it should be verified to what extend these functions are applicable at coppiced trees.

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