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BIOMASS MODELS FOR SHORT ROTATION WILLOW PLANTATIONS IN LITHUANIA

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Despite of increasing areas of short rotation willow plantations in Lithuania, only few studies have been done so far regarding the biomass production in these plantations. To fill this gap, the aim of this study was to develop biomass equations for fresh and for oven drywillow biomass and to estimate the yield of short rotation plantations as expressed in fresh and oven dry biomass.
The data required by this study was gathered in the western part of Lithuania, in the Šilutė and Tauragė regions. For this purpose, sample plots were established in 21 short rotation willow plantations managed by "Klasmann-Deilmann Bioenergy". All of them were first rotation plantations grown for 3 to 4 years.
It was found that mean annual oven dry biomass increment varied in these plantations from 0.2 to 7.6 tons per hectare per year. Surprisingly, the productivity was not related to soil fertility. Additionally, the relations between stand level values were evaluated and a stand biomass yield model based on the mean height was developed. Relations on the shoot level were analysed as well. As a result we developed biomass models based on the individual shoot diameter for shoot height as well as for fresh and for oven dry biomass.

Keywords: Short rotation willow plantations, fresh and oven dry biomass, mean annual increment, biomass models.

INTRODUCTION

Even though more and more short rotation willow plantations (SRWP) are grown and bioenergy production from it steadily increases, only few studies regarding SRWP have been carried out so far in Lithuania. For example Gradeckas (2005) investigated biological and ecological aspects. Lygis el al. (2006) prepared recommendations for establishment and management of SRWP. Bačkaitis et al. (2012) set up the practical guide for private owners of SRWP. Konstantinavičienė (2017) evaluated the main factors that affect expansion of SRWs in Lithuania.

In other countries, particularly in Finland, Sweden, and Germany, scientific research on SRWP is well established and has long traditions. Mitchell (1995) reported that the average annual increment in oven dry tons (odt) of biomass for *Salix* species was as follows: In Austria it reached 3.6, in Canada 4.6, in Denmark 7.0, in Sweden 10.2, in the USA 13.5 and in the UK 8.1 odt per hectare and per year (odt/ha/year). Röhle et al. (2008) reported that in East Germany mean annual increment of SRWP can reach from 6 to 10 odt/ha/year.

The model most commonly applied so far to estimate fresh and oven dry biomass in SRWP from the diameter of the shoots has been the power model. For example studies performed by Hytönen et al.(1987),Verwijst and Telenius (1999), Röhle et al. (2006) and Ali (2009) employed this approach. The biomass production potential also could be evaluated by using geospatial analysis methods (Jenifer et al. 2015).

Some first attempts to estimate yield and develop yield curves for fresh and oven dry biomass under Lithuanian conditions were done by Glumbakas (2015). However, this study was limited to certain sites and a narrow range of growth conditions. In traditional forestry there is the simple Eichhorn (1902) rule which is used to estimate standing volume from mean height. This approach was also applied in this study but delivers only average results that are not representing the whole range of possible site factors and growth conditions. Consequently there is still a considerable lack of simple methods to reliably estimate the available biomass in an arbitrary stand. The overall objective of our work was therefore to develop biomass equations for first rotation and three growth seasons SRWP. The following tasks had to be fulfilled to reach this goal:

1. To estimate fresh and oven dry biomass yields in three-years old SRWP,

2. To analyse the relations between mean squared diameter / mean height with the fresh and oven dry biomass in these plantations per hectare.
3. To develop combined fresh and oven dry biomass models based on shoot (tree) diameter.

MATERIALS AND METHODS

Description of the inventory fields used for the analysis. The database used for the analysis comprised 21 short rotation willow plantations (SRWP) fields (Table 1). All fields are located in the western part of Lithuania, close to the towns Šilutė and Tauragė. This region of Lithuania is influenced by higher mean annual temperature (about 9 °C) and higher mean annual precipitation (about 800-900 mm) compared to the other Lithuanian regions. Analysed SRWPs were planted on soils whose productivity is indicated by the wide range of the "yield points" (a regionally common expression of yield expectation, Highest productivity soils 47.1-52, High productivity soils 42.1-47, Productive soils 37.0-42.0, Lower productivity soils 32.1-37.1, Low productivity soils 27.1-32.0, Mažvila et al. 2015). For example, field 12 was established on a soil with a yield-point value of 27.2 (lowest) while field 14 exhibits a yield point value of 48.1(highest). So the data set covered a wide range of soil types from low to high productivity (see Table 1).The size of the established fields varied from 1.4 ha (Field 14) to 15.1 ha (Field 5). Most shoots in the fields were planted in 2014 and in some fields in 2013. For all the fields it was the first rotation. The planting density for all fields was the same and equal to 13.000 cuttings per ha.

Field measurements. Methods of field measurements in SRWPs were developed by Röhle (2003), Röhle et al. (2005) and Röhle et al. (2006). The same methods to collect field data were also used by Ali (2009).

The first step of this approach is to establish sample plots in the field to be inventoried. Regardless of the size of the sample plot, the number of the shoots measured per plot was not lower than 200. The number of the sample plots was related to the field size. It was set at one sample plot per 2 hectares of the field. Thus, the number of sample plots per field varied from 1 to 8 and the size of these sample plots varied from 100 to 400m^2. Consequently, in each field from 1 to 4% of the total field area was inventoried.

The measurements were started when the leaves of plants were fallen down, in second part of November and ended in December, year 2016. In each sample plot the following measurements were done. Since in these fields a double-row system was applied, all shoots in these double rows were measured. All measurements were done including bark of the shoots. For each shoot, the diameter at breast height (dbh; exactly at 1.3m according to a standardised stick) was recorded. Length and width of the respective sample plot were derived: The length of the plot was taken from the distance between the first and the last shoot in the sample plot. The width of the plot was estimated as average distance from one set of double rows to the next set.

In the next step 15 shoots, randomly distributed in the field (not necessary in the sample plots), were cut for the height and biomass measurements. Shoots were selected to evenly cover the complete diameter range found in the field (from the smallest to largest shoot).The height of these shoots was taken by laying them on the ground and then measuring their length with a tape at a precision of 1cm. Immediately afterwards the shoots were weighted with field scales. Shoots up to 5 kg were weighted at 2g precision and shoots heavier than 5 kg were weighted at 10g precision.

To prepare them for the process of oven-drying in the laboratory, shoots with a dbh smaller than 25 mm were cut to small pieces and packed into individual bunches comprising the above-ground biomass of the respective shoot. Shoots larger than 25 mm in dbh were also cut to pieces but only a sample selected from different parts of the shoot (butt-end, middle, and top of the stem, large and small branches) was used for drying. Normally, to form the sample, 30% of the total shoot weight was taken. So if a shoot had a total weight of 6kg, the weight of the sample was about 2kg. Prepared samples were weighted a second time and then packed and transported to the laboratory for drying.

All prepared samples were weighted again in the laboratory to obtain fresh biomass. Then the samples were dried in special ovens at 105 °C until their weight had reached a constant value. Drying lasted more than 48 hours. Results of the last weighting were taken and recorded as oven dry biomass (Röhle et al. 2006, Ali 2009).

Data analysis methods. To model fresh and oven dry biomass from mean diameter and height, firstly mean squared diameter (Dq) and mean height (Hq) were determined. Equation (1) was used to calculate Dq.

$$D_q = \sqrt{\frac{\sum_{i=1}^{N} d_i^{\,2}}{N}} \tag{1}$$

where: Dq=quadratic mean diameter in mm; d=shoot dbh in mm; N=number of shoots per plot.

Mean height for each field was derived as follows. Firstly, Michailoff (1943) formula was applied separately to the diameter–height relations in each stand. Then the specific parametersa_0 and $a_1$from Michailoff's regression model were put into Equation (2).

$$H_q = 1.3 + e^{\left(\frac{a_0}{D_q} + a_1\right)} \tag{2}$$

where: Hq=mean height in m; Dq=quadratic mean diameter in mm; a_0 and a_1=regression coefficients taken from the stand height curve.

Most common fresh and oven dry biomass functions are power functions (Hytönen et al. 1987, Verwijst&Nordh 1992,Verwijst et al. 1999, Röhle et al. 2006, Ali 2009), visualised in Equation (3). Thus, for each field fresh and oven dry biomass (BM) models were constructed of the following type (Equation (3)).

$$BM = a_0 \cdot d^{a_1} \quad (3)$$

where: d=shoot dbh in mm; a_0 and a_1=regression coefficients.

These models were used to estimate fresh and oven dry biomass for each shoot in the sample plots.Knowing the size of the sample plots it was easy to derive total fresh and oven dry biomass in the field. These values were then used to model fresh and oven dry biomass in the field per hectare from the mean diameter and mean height by applying the following formulas (Equations (4) and (5)):

$$BM = a_0 \cdot Dq^{a_1} \quad (4)$$

$$BM = a_0 \cdot Hq^{a_1} \quad (5)$$

where: Dq= quadratic mean diameter in mm; Hq=Mean height in m;a0 and a1=regression coefficients.

To develop combined shoot-level models for fresh and oven dry biomass of three-year old first rotation shoots, all sample shoots with measured dbh and estimated biomass were joined into one dataset. In total 274 sample shoots were available. Equation 3 was applied for model development. The main parameter used to evaluate the derived model was the coefficient of determination (R^2).

RESULTS

Yield results. The yield of fresh and oven dry biomass in the inventoried short rotation willow plantations varied remarkably (Table 1). The lowest yield level was estimated in the field 17, despite it was established on high productivity soils with the yield point 42.7 . The mean annual fresh biomass increment (MAI) in this field was only 0.5 t/ha/year which is slightly more than 0.2 odt/ha/year. In contrast, the highest productivity was shown in field 6, which was also established on high productivity soils, with a fresh MAI of 16.3 t/ha/year and 7.6 odt/ha/year. This study did not analyse the reasons that caused these differences on the same productivity soils. During last winter, only very few fields were harvested. Thus, there was no possibility to validate yield results in each field.

Table 1. Main yield characteristics of the investigated short rotation willow plantations.

Field Number	Yield points	Dq mm	Hq m	Age	N/ha	Fresh biomass		Oven dry biomass		Moisture content % of biomass
						t/ha	MAI, t/ha	t/ha	MAI, t/ha	
17	42.7	6,7	2.3	3	6528	1.1	0.4	0.5	0.2	53,6
15	29.7	9.3	2.6	3	14033	3.5	1.2	1.7	0.6	51,5
22	52.0	9.6	3	4	13478	3.9	1	1.6	0.4	58,2
5	42.8	15	3.3	3	14893	9	3	4.1	1.4	54,2
9	28.8	14.5	3.7	3	14870	9.2	3.1	4.2	1.4	54,8
8	37.0	15	3.8	3	19853	10.2	3.4	4.8	1.6	52,7
12	27.2	16	4.2	3	14912	10.4	3.5	4.7	1.6	54,4
3	27.9	16.6	3.7	4	11826	11.2	2.8	5.2	1.3	53,8
14	48.1	13.7	3.8	3	18430	13.3	4.4	5.9	2	55,6
11	42.8	13.4	3.9	3	14966	13.5	4.5	6.3	2.1	53,3
19	41.9	16	3.9	3	16161	14.3	4.8	6.4	2.2	54,8
7	34.7	16.7	4.7	4	21842	19.1	4.8	8.5	2.1	55,6
10	44.1	17.9	4.5	3	18471	19.7	6.6	9.4	3.1	52,5
4	39.1	20.1	5	3	17394	20.1	6.7	9.2	3.1	54,1
1	44.0	21.6	5.6	3	15406	21.2	7.1	11.2	3.7	47
21	32.0	22	5.6	3	12456	21.2	7.1	9.8	3.3	53,7
18	29.2	21.2	5.3	3	21470	27.8	9.3	13	4.3	53,1
13	38.0	24.3	5.6	3	17443	29.1	9.7	13.2	4.4	54,6
2	42.7	26.6	6.4	3	17072	35.3	11.8	16.2	5.4	54
16	39.2	23.4	5.9	3	19869	39.9	13.3	16.9	5.6	57,8
6	42.6	26.7	6.8	4	24940	65.1	16.3	30.5	7.6	53,2

The relation between soil productivity, expressed by yield points and mean annual (MAI) fresh and oven dry biomass, is presented in Figure 1. Surprisingly, there was found no relation between MAIs and soil yield points. In both cases coefficients of determination were lower than 0.01. The reasons that could cause these results were not analysed by this study.

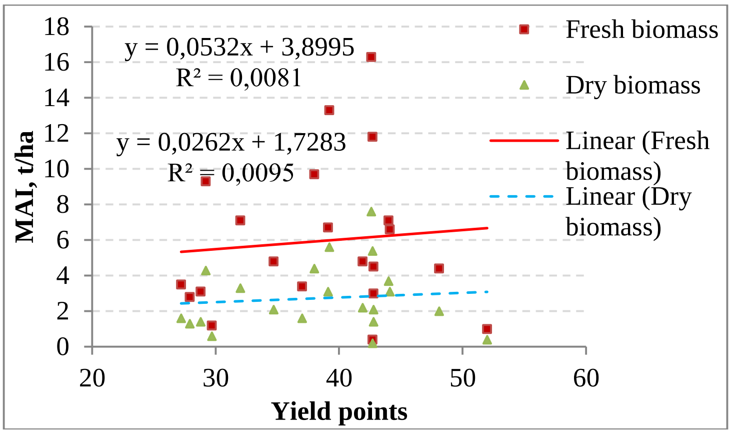

Figure 1. The relation between yield points, indicating site fertility and mean annual increments of fresh and oven dry biomass

Modelling stand biomass from mean diameter and height. Fresh and oven dry biomass was modelled from the mean diameter and also from the mean height. It has to be pointed out that mean height is a slightly better predictor of biomass in the investigated stands. According to the results presented in Table 2 the coefficient of determination for both fresh and oven dry biomass models was slightly higher (0,883 versus 0,879 and 0,917 versus 0,908).

Table 2. Parameter estimates for combined data biomass models from mean diameter and height.

Biomass models	Parameter estimates		
	a_1	a_2	R^2
Fresh biomass = f(mean diameter)	0.0495	2.0231	0.879
Oven dry biomass = f(mean diameter)	0.0249	1.9940	0.908
Fresh biomass = f(mean height)	0.4725	2.3565	0.883
Oven dry biomass = f(mean height)	0.2256	2.3342	0.917

The visualisation of both biomass models is presented in Figures 2 and 3. These figures also confirm that the selected model type (power model) fits well to the analysed data. The diagrams additionally show the higher variation of the fresh biomass values compared to those for oven dry biomass. This is also visible in the differing coefficients of determination (see Table 2).

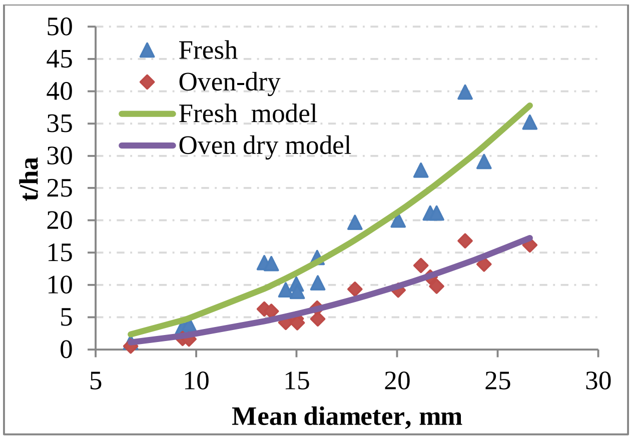

Figure 2. Freshand oven dry biomass models from mean diameter

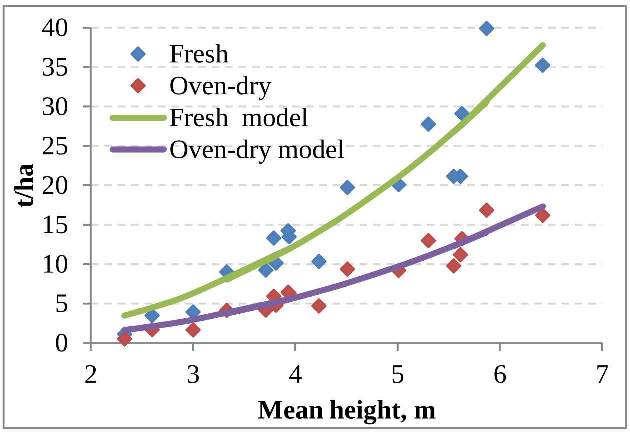

Figure 3. Freshand oven dry biomass power model from mean height

Combined shoot level fresh and oven dry biomass models. The modelling results for fresh and oven dry biomass at the shoot level based on Equation (3) are presented in Table 3. It has to be highlighted that the coefficient of determination for these models is very high (more than 0.96 despite of the different plots from which the shoots were selected) which emphasises the model's outstanding capabilities to provide reliable prognoses.

Table 3. Combined fresh and oven dry biomass model's parameters (see Equation (3)).

Models' parameters			
	a1	***a2***	**R2**
Wet weighted	1,9595	2,1608	0,9692
Dry weighted	0,7153	2,2374	0,9689

Figure 4 visualises both models. Obviously both estimated models fit very well to the analysed data. This is expressed by the comparably low variation of the data from the modelled best-fit curves.

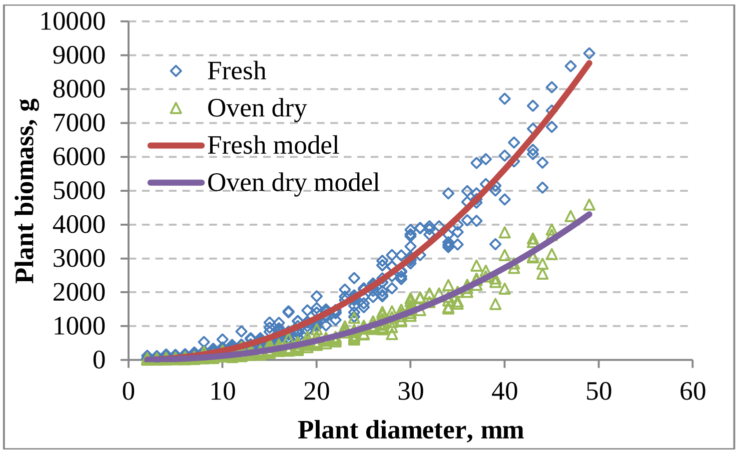

Figure 4. Fresh and oven dry biomass models established from all fields' individual-shoot data.

Summarising these results we could show that the developed models for fresh and oven dry biomass fit very well to the original data. Thus, these models are suggested to be used for biomass estimation for three-year old first rotation willow plantations as long as other and more appropriate models are not available.

DISCUSSION

This study focused on the estimation of biomass in short rotation willow plantations. A rather high variability was found in the available biomass in the stands. It is well known that the yield of SRWPs predominantly depends on climate, clone/species, nutrient availability or soil fertility and water availability (Röhle et al. 2008). This study did not focus on the analysis of the mentioned factors to the available amount of biomass but concentrated on the establishment of reliable models to estimate biomass yields under a wide range of conditions. The developed fresh and oven dry biomass models from the quadratic mean diameter or the mean height can be used for the rough estimation of available biomass. If higher precision is required, the shoot-level models should be used.

CONCLUSIONS

1. There was a high variability of fresh and oven dry biomass yield in analysed fields that was not related with productivity of the soils.
2. The developed biomass power models from the mean diameter and mean height are reliable to determine stand-level biomass when only mean diameter or mean height is available.
3. For other stands, if diameters of shoots are available to model fresh and oven dry shoot biomass, we recommend individual-shoot power models that were produced by this study and show a comparably high coefficient of determination at R^2>0.96.

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