Estimation of Production Potential of Short Rotation Forestry On Agricultural Land of Saxony

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Introduction

Biomass energy represents one of the most promising alternatives, because it is a renewable source that can be produced and used in a clean and sustainable manner (HALL et al., 1992). Additionally, biomass energy has significant benefits to the environment and to the rural socioeconomic development. These advantages of biomass have raised the interest to cultivate woody crops on agricultural land, particularly, in intensive manner for short rotation periods. The type of practice of woody crop cultivation is called Short Rotation Forestry (SRF), and it is done in order to provide wood to meet the energy markets demands while taking into account the environmental issue (VERWIJST, 1998; KARACIC, 2005).

Studies investigating aboveground biomass (BM) from SRF tree species on agricultural lands at TU Dresden, Institute of forest growth and computer science in forestry, started in 1997 (e.g. RÖHLE, 2003; RÖHLE, et al., 2005; RÖHLE, et al., 2006). BM production is highly influenced by soil and climate conditions in SRF. Thus, the overall goal of the studies is to model the relationship between BM production and soil and climate conditions. Specific objectives of the current work are to develop models for predicting production potential of BM from fast growing tree species on fallow agricultural land; and to apply the models to the entire State of Saxony on the basis of communes' data. Free State of Saxony has large agricultural areas (56 % of total land cover) with wide soil and climatic variations. Therefore, it is important to have an overview on the available land that can be utilized for SRF. The total agricultural land in Saxony is approximately 1025000 ha, which is distributed into 187000 ha of permanent grassland; 5000 ha for houses, gardens, and tree fruits; while the remaining part of 721000 ha is allocated for arable land. Under arable utilisation there are 413400 ha used for cereals, 278100 ha for oil seeds, root crops, and forage plants, and 33200 ha are fallow land.

Materials and Methods

To develop the models for prediction of BM production, the following data are needed:

- Climatic data: the daily precipitation and temperature for the trial areas from age 1 to 7 years;
- Soil data which include:
  1. Soil bore samples from depth 0 – 50 cm, from these samples the Available Water Storage Capacity of soil (AWSC) was calculated; and
  2. Soil Quality Indices (SQI) of the sites.

  In the current study, both soil and climatic data were obtained from GRAUPA in Dresden (Saxon Forest Research Station);
- Trees' measurements like tree height, diameter at breast height and BM between age 1 and 5 were done permanently by GRAUPA and later at ages 6 and 7 measurements were carried out by the institute; however tree numbers per hectare (N/ha), stem volume (V/ha), basal area (G/ha), total aboveground dry biomass (t/ha) mean diameter (d_m), and mean height of trees (h_m) were calculated.

Study Sites

The study sites cover wide soil and climate variations. In table 1, the main information about areas is shown. Mean annual temperatures range from below 7 °C in Arnsfeld to 8.5 °C in Nochten, Skäßchen and Thammenhain. Mean annual rainfalls vary from 550 to above 850 mm. Altitude ranges between 120 – 625 m above see level.

Table 1: General information about study areas and poplar clones planted:

Experimental Area	Area Size [ha]	Year of Planting	Soil Quality Index	Altitude [m]	Mean Annual Temperature [°C]	Mean Annual Rainfall [mm]	Poplar Clones
Methau II	13.4	1999	67	200	8.1	690	Max 1, Max 4, Münden; Androscoggin
Thammenhain	11.5	1999	42	130	8.5	575	Max 1, Max 4, Münden, Androscoggin
Nochten	3.6	1998	30	140	8.5	640	Max 4, Münden, Androscoggin
Skäßchen	17.5	1998	38	120	8.5	575	Max 1, Max 4, Münden, Androscoggin
Arnsfeld	4	1999	29	625	< 7.0	> 850	Max 1, Matrix Androscoggin

Model Construction

As a first step clone Max (Populus maximowiczii x nigra) with stem density of 1400 trees/ha and tree age from 2 to 7 years was investigated. The model was to estimate BM depending on climate and soil conditions. Due to difficulties in modelling BM directly with dependence on soil and climate variables, indirect method was used. It is known that dominant height of trees (h_{dom}) is considered as an indicator for site conditions. Therefore, h_{dom} was correlated to site variables using multiple linear regression. The estimated h_{dom} was used again to predict BM.

The variables tested are BM [t/ha], h_{dom} of stands, age, soil quality index, available water storage capacity of soil, sum of precipitation (P) and mean temperature (T) for several time spans (Table 2). All modelling and calculations were performed using SPSS software.

Table 2: Variables tested during the process of h_{dom} modelling:

Variables			
ΣP4-5 [mm]	ΣP5-8 [mm]	Mean T4-5 [°C]	Mean T5-8 [°C]
ΣP4-6 [mm]	ΣP5-9 [mm]	Mean T4-6 [°C]	Mean T5-9 [°C]
ΣP4-7 [mm]	ΣP5-10 [mm]	Mean T4-7 [°C]	Mean T5-10 [°C]
ΣP4-8 [mm]	ΣP6-7 [mm]	Mean T4-8 [°C]	Mean T6-7 [°C]
ΣP4-9 [mm]	ΣP6-8 [mm]	Mean T4-9 [°C]	Mean T6-8 [°C]
ΣP4-10 [mm]	ΣP6-9 [mm]	Mean T4-10 [°C]	Mean T6-9 [°C]
ΣP5-6 [mm]	ΣP6-10 [mm]	Mean T5-6 [°C]	Mean T6-10 [°C]
ΣP5-7 [mm]	ΣP1-12 [mm]	Mean T5-7 [°C]	Mean T1-12 [°C]
Age	h_{dom} [m]	SQI	AWSC [mm/dm]

Results

Variables shown in table 2 were tested and finally just the variables which correlated best to h_{dom} were selected. The variations that occur in the selected variables are explained in (Table 3).

Table 3: Variations in the selected variables which correlated significantly with h_{dom}:

Variable	**Values**	
	Study Areas	**Saxony**
SQI	29 - 67	14 - 87
AWSC [mm/dm]	118 - 171	50 - 310
ΣP_{5-6} [mm]	91 - 159	105 – 200
Mean T_{4-7} [°C]	11,5 – 15,2	9 – 15,2
Age (years)	2 - 7	2 - 7

SQI varies from 14 to 87 in Saxony and from 29 to 67 in the experimental areas. The total amount of precipitation in the time span May to June ΣP_{5-6} ranges from 91 to 159 [mm] in the areas and from 105 to 200 [mm] in Saxony. Mean temperature from April to July Mean T_{4-7} is between 11,5 – 15,2 [°C] for the sites and between 9 – 15,2 [°C] for Saxony.

In order to improve h_{dom} model, the selected variables were processed (they were multiplied and divided by each other). Finally just the processed variables that significantly correlated with h_{dom} were included in the model.

Using multiple linear regression h_{dom} Model was developed for a given number of trees per ha and ages (Table 4 and Table 5). The model can estimate h_{dom} according to age, soil and climate conditions, with adjusted R^2 of 0,98. As an exponential function of the estimated h_{dom}, BM per ha can be estimated with adjusted R^2 of 0,93. During the prediction of h_{dom}, there is a bias of only 1,3 % and it is about 5,3 % in case of BM estimation (Table 4 and Table 5).

Table 4: Models for prediction of h_{dom} and BM of Poplar:

Model	**Model Expression**	**N**	**R^2 adj.**	**Sig.**	**Bias [m], [t/ha]**	**Bias %**
h_{dom}	h_{dom} = a1*Age + a2*MeanT_{4-7}*SQI + a3*ΣP_{5-6}*AWSC	25	0,980	1,55445E-19	0,07	1,311
BM	BM = a1*hdom^a2	25	0,927	3,6159E-15	0,301	5,272

Table 5: Coefficients' values of the developed models:

h_{dom}	BM
a1 = 0,57217223	a1 = 0,044578455
a2 = 0,00063862	a2 = 2,6
a3 = 3,18382E-05	

In order to verify the developed models, the observed values were plotted against the estimated ones (Figure 1).

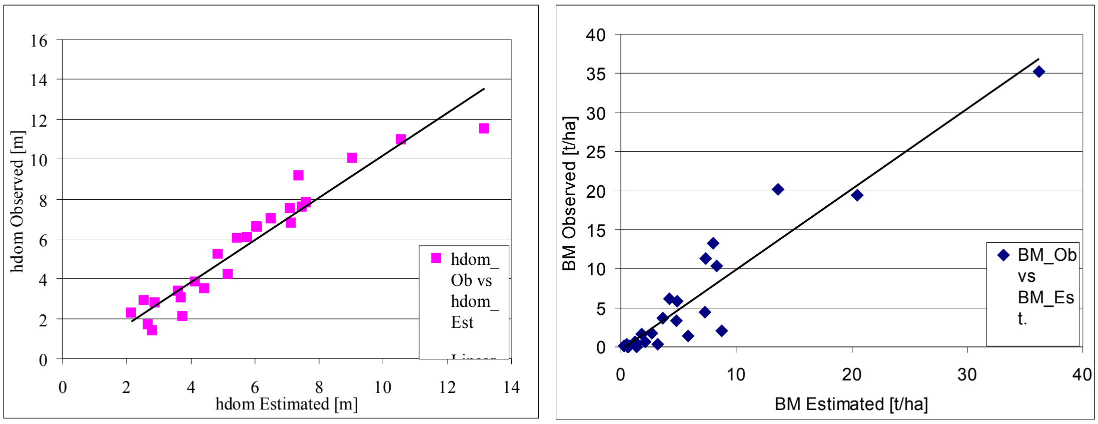

Figure 1: a: h_{dom} Observed against h_{dom} estimated, b: BM Observed versus BM estimated

Different tests were done to validate the ecological plausibility and flexibility of the models. When precipitation and temperature are held constants ($\Sigma P_{5\text{-}6}$= 140 [mm] and $MeanT_{4\text{-}7}$ = 13,5 [°C]) and SQI varied, at a given age, the estimated h_{dom} increased as SQI increased (Figure 2a).

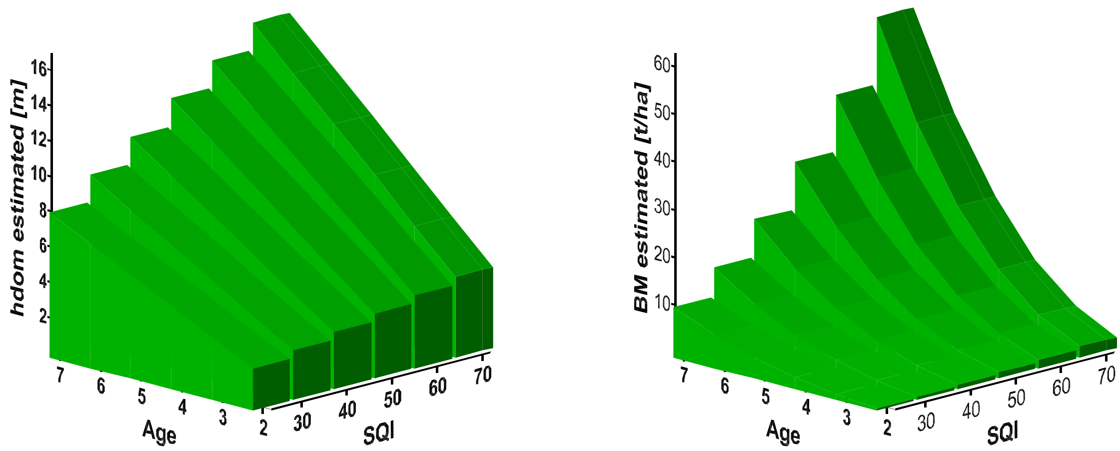

Figure 2: a: h_{dom} estimated against age and SQI, b: BM estimated versus age and SQI

By increasing SQI at specific age, the estimated BM also increased, this can be notably observed at ages 5, 6 and 7 (Figure 2b). At age 7 for instance, a mean annual increment MAI of BM of only 1,5 [t/ha*a] can be obtained if SQI is 25; whereas MAI can be 8,7 [t/ha*a] if SQI is 70.

When we fix SQI and AWSC at values 50 and 177 [mm/dm] respectively and vary precipitation, at a given age both h_{dom} and BM increased as precipitation increased (Figure 3b). For a range of precipitation between 110 – 170 [mm], h_{dom} at age 7 ranged between 11,7 – 13,2 [m] (Figure 3a) and BM between 26,68 and 36,31 [t/ha] (Figure 3b).

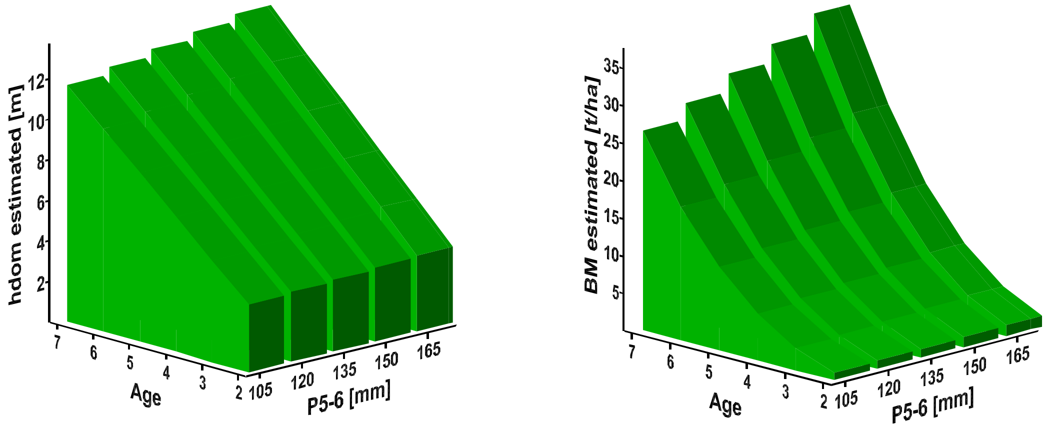

Figure 3: a: h_{dom} estimated against age and precipitation, b: BM estimated versus age and precipitation

Application the models to whole Saxony

In order to apply the models to the whole State, data required are:

- Climatic data: include monthly precipitation and mean temperature.
- Soil data: include Soil Quality Indices SQI and AWSC of Saxon soils.

Climatic data and soil data were obtained from GRAUPA and from Landsamt für Umwelt und Geologie.
Free State of Saxony has 515 Communes, for each commune mean values of SQI, AWSC, monthly mean temperature and precipitation were computed and visualized using GIS Programme (Figure 4 as an example).

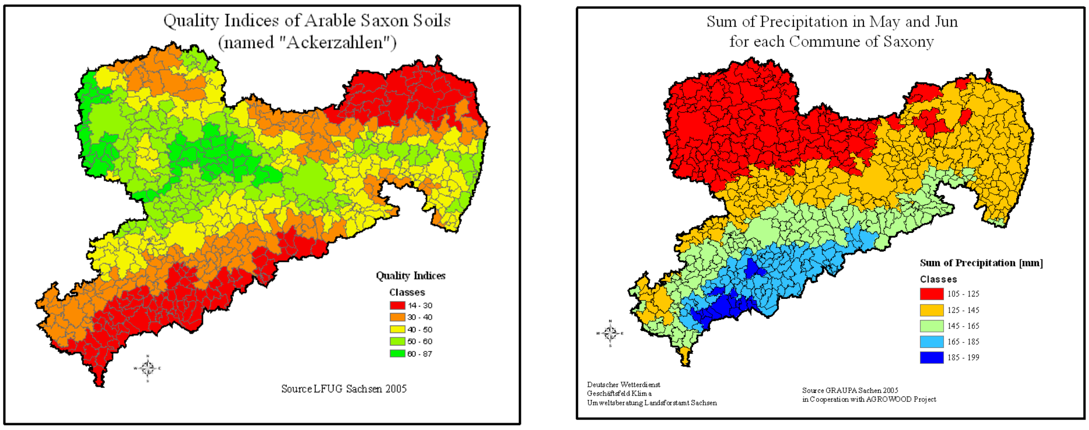

Figure 4: a: SQI for Arable Saxon Lands, b: Sum of Precipitation in May and June for Saxon Communes

Good soils are located in the middle and western parts of Saxony (Figure 4a). Sum of precipitation in May and June ranges from 105 to 200 mm (Figure 4b) and the highest amount of rainfall occurs in the southern part of Saxony where the soil quality indices are low.
The middle part has the best potential to produce biomass from poplar trees if all soil and climate conditions are considered.

Conclusions and Summary

- An estimation of production potential of SRF based on soil and climate conditions is possible for a given tree numbers per ha;
- A mean annual increment of BM at age 7 between 1,5 – 8,7 [t/ha*a] could be obtained if fallow lands are planted with poplar clone Max of 1400 trees/ha;
- Modelling of biomass production for further tree densities and clones should be done;
- Visualizations of different models with different scenarios using GIS software should be also implemented;

- Establishment of SRF plantations on fallow agricultural land can ensure many social and economical benefits to the farmers and also several environmental benefits can be gained at the same time;
- Wide database is necessary to ensure ecological plausibility and flexibility of models.

References

KARACIC, A. 2005: Production and Ecological Aspects of Short Rotation Poplars in Sweden. Doctoral thesis. ISSN 1652-6880. Swedish University of Agriculture Sciences Uppsala. 92 pages.

HALL, D. et al. 1992: Biological Systems for Uptake of Carbon Dioxide. Lecture, given in occasion of the 7Th Conference on Biomass for Energy and Environment, Florence, Italy, 522-528.

RÖHLE, H. 2003: Waldwachstumskundliche Untersuchungen zur Ermittlung der Trockenbiomasse an der Weidenklonen Jorr Tora und Ulv auf der Demonstrationsanlage der Agrargemeinschaft Methau. TU Dresden. Arbeitsbericht unveröffentlicht.

RÖHLE, H.; HARTMANN, K.-U.; STEINKE, C.; WOLF; H. 2005: Wuchsleistung von Pappel und Weide im Kurzumtrieb. AFZ Der Wald, 60 (14), 745-747.

RÖHLE, H.; HARTMANN, K.-U.; GEROLD, D.; STEINKE, C.; SCHRÖDER, J. 2006: Überlegungen zur Aufstellung von Biomassefunktionen für Kurzumtriebsbestände. AFJZ 177 (10): 178 – 187.

VERWIJST, T. et al. 1999: Biomass Estimation Procedures in Short Rotation Forestry. Forest Ecology and Management, 121: 137-146.