ESTIMATION OF THE YIELD OF POPLARS IN PLANTATIONS OF FAST-GROWING SPECIES WITHIN CURRENT RESULTS

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Received: January 26, 2009

Abstract


Current results are presented of allometric yield estimates of the poplar short rotation coppice. According to a literature review it is obvious that yield estimates, based on measurable quantities of a growing stand, depend not only on the selected tree species or its clone, but also on the site location. The Jap-105 poplar clone (\(P. \text{nigra} \times P. \text{maximowiczii}\)) allometric relations were analyzed by regression methods aimed at the creation of the yield estimation methodology at a testing site in Domaníněk. Altogether, the twelve polynomial dependences of particular measured quantities approved the high empirical data conformity with the tested regression model (correlation index from 0.9033 to 0.9967). Within the forward stepwise regression, factors were selected, which explain best examined estimates of the total biomass DM; i.e. d.b.h. and stem height. Furthermore, the KESTEMONT’s (1971) model was verified with a satisfying conformity as well. Approving presented yield estimation methods, the presented models will be checked in a large-scale field trial.

yield estimation, allometric relations, regression analysis, short rotation coppice, poplar

The development of costs of traditional fossil fuels, their expected unavailability and particularly ecological impacts of their use in the form of markedly increasing greenhouse effect result in considerations to replace part of their consumption by renewable resources of energy with markedly lower ecological impacts of their use. One of such available resources of the transformation of solar energy is biomass, which represents the most important potential renewable resource in the CR (e.g. VÁŇA, 2003).

For the energy use of biomass, it is necessary to consider (because of economic reasons) highly yielding crops requiring minimum demands for agronomical practices. Thus, perennial herbs are recommended (e.g. PETŘÍKOVÁ, 2005) or using agricultural land for plantations of fast-growing trees. More species rank among fast-growing species – e.g. willows, poplars, alders and hazel (e.g. WEGER and HAVLÍČKOVÁ, 2002). At present, however, several certified clones of willows and poplars are permitted for growing production stands.

Growing these species using a short rotation coppice (SRC) sometimes termed as short or mini-rotation forestry (SRF, MRF) is characteristic of using agricultural land (most often arable land) for planting clones of fast-growing tree species. The stand remains on the site some 15–30 years being, however, harvested in regular intervals (3–7 years). A potential of these stands is used to create high amounts of shoots and to create coppice shoots after harvest. Through repeated felling natural death of a stand is simulated, for example after a windstorm or fire. At the same time, thanks to a developed root system, the creation of bulky biomass occurs (SENNERBY-FORSSE et al., 1992). Thus, the total yield of biomass is markedly increased during the first rotations thanks to the development of the tree root system. Subsequently, however, its depression occurs thanks to the gradual exhaustion of the stand site.

Although in the CR an increased interest in fast-growing species occurs recently thanks to the financial support of biomass and increased demand after wood biomass for energy purposes, there is always a number of reasons for hesitation on the site of po-
tential growers. It is necessary to take into account reservation of appropriate places for a relatively long time and partly a farmer waits for the first yield and thus a possible realization of the biomass production for the whole rotation period (3–7 years). Nevertheless, the farmer is not sure to achieve economic profitability.

According to experience, the first two years after the stand establishment are critical to ensure the yield. Therefore, it would be suitable to have a chance to estimate a future yield without destructive methods in the course of vegetation. Thus, this paper is aimed at the compilation of a simple operationally feasible method to estimate the future yield of the poplar stand biomass on the basis of current results of monitoring poplars grown in plantations (P. nigra x P. maximowiczii, P. maximowiczii x P. berolinensis) under conditions of the Bohemian-Moravian Upland.

Allometric estimates of the yield have been worked out in various tree species with the aim to estimate the weight of an individual, yield of the specific part of a plot or the estimate of total losses as against the expected ideal yield. Most of estimates are based on the stem diameter and tree height. Authors often try to determine regression dependences of these two quantities and to simplify the estimate to one measured quantity. For example, for the calculation of the above-ground biomass of trees from 2 to 20 cm, PALÁT (1991, 1997) used a modification of KESTEMONT’s equation (1971):

\[ Y = 0.00486 X^{2.502}, \]  

where: \( Y \) is the girth at breast height of 1.3 m, \( Y \) is the above-ground biomass in dry matter.

Similarly BRENNERMAN et al. (1978) compiled an empirical equation with power coefficient compared with the diameter at breast height (d.b.h.). Generally, however, this approach results in considerable errors because particular clones of the same species show the high variability of habit and also in various years of their growth, the ratio of the stem and branches weight in the total biomass volume is changed, which cannot be recorded by the diameter value.

LAUREYESENS et al. (2005) similarly criticize this approach. They lay stress on the knowledge of the growth dynamics, thus changes in the number of branches and their mortality within the growth of an individual. At the same time, they suppose the growth of an individual upwards, the area occupation in radial direction and the biomass increment of the individual grown part. The natural competition of individual trees within a plantation leads to a fact that some individuals develop more slowly thanks to the competition of others, often with the different distribution of total weight between a stem and branches. MATTHEWS et al. (2003) published an extensive study of allometric estimates of yields and the stem diameter at a height of 1 m selected as basic data, but at the calculation of total biomass started also from the branch weight estimate. Estimation of the total weight of the above-ground part of plants they complete by the estimate of the root system weight. CASELLA and SINOQUET (2003) published detailed allometric estimates of the poplar habitus including the total cover by leaves. Using their paper, it is possible to determine allometric relationships of main components of above-ground parts of poplars.

The common factor of operations mentioned above is, however, considerable complexity of measurements carried out on a plot, which does not represent a suitable method for a farmer. For operating conditions, an improved equation on the basis of stem diameter (in some cases completed by the height of an individual) can be sufficient and if need be, completed by the branch weight estimate. AL AFAS et al. (2008) mention an approach dependent on the stem diameter determining regression coefficients including their variability by means of an equation \( M = aD^c \) (\( M \) is dry matter yield, \( D \) is stem diameter at a height of 22 cm above the ground and \( a, c \) are regression coefficients). In this respect, TELENIUS (1997) mentions a regression equation with three coefficients, where the improvement of estimate can occur: \( W = a + bD + cD^2 \) (\( W \) is total weight, \( D \) is stem diameter and \( a, b, c \) are regression coefficients). DILLEN et al. (2007) mention a more sophisticated approach. The estimate of total weight is divided to the estimation of the stem weight, branch weight and the number of branches accruing in the given year. They carried out this analysis in three states on five clones and results obtained proved the necessity of different regression equations not only for clones but also for a locality. Although the regression equations are linear, in some cases they require either a logarithmic or quadratic transformation of the yield estimate obtained.

Thus, it is evident that according to the requirement for the yield estimate accuracy, but also for particular clones, it is necessary to modify an approach to operational measurements and subsequent evaluations. The effect of a locality is surprising, which only confirms the necessity of differentiated approach. Thus, the transfer of results from abroad is limited and, therefore, we present a basic model of an approach in this paper, which could lead to satisfactory results under operational conditions of the Czech Republic.

**MATERIAL AND METHODS**

**Description of the locality and material used**

In April 2002, a high-density experimental field plantation for verification of the performance of selected clones of *Populus* sp. and *Salix* sp. with the total area of 3.5 ha was established in Domanínek (Czech Republic, 49°32’ N, 16°15’ E and altitude 530 m). The plantation was established on agricultural land previously cropped predominantly for cereals and potatoes. During the last year of cropping, an oat-pea mixture was used as a pre-crop to prepare the field for plantation establishment. Soil sampling took place prior to planting in August 2001. Soil conditions at the location are representative to the wider region.
with deep luvic Cambisol influenced by gleyic processes and with limited amount of stones in the profile. Table I contains basic soil and climate characteristics of the experimental site. The site itself is situated on a mild slope of 3° with an eastern aspect within a wire fence against unwanted disturbances by herbivores. The area is generally subject to cool and relatively wet temperate climate typical of this part of Central Europe with mingling continental and maritime influences (Table I). Although the area represents limitation conditions for SRF based on Populus sp. clones due to its climate conditions, the site itself is suitable for planting. Weather parameters are based on the meteorological station Bystřice nad Pernštejnem (Czech Republic, 49°32’ N, 16°16’ E, altitude 560 m) of the Czech Hydrometeorological Institute, which is less than 1000 m from the experimental plots. The seven-year rotation period (2002–2008) was characterized by favourable first two years but with higher incidence of droughts in the latter years. As might be seen in the Tab. I, temperatures during the summer, winter and the entire vegetation period were higher than during 1961–1990 reference period with the precipitation close to the normal level.

I: Climate and soil characteristics of selected location (TRNKA et al., 2008)

<table>
<thead>
<tr>
<th>CLIMATE CHARACTERISTICS</th>
<th>Units</th>
<th>January–December</th>
<th>April–September</th>
<th>June–August</th>
<th>December–February</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean air temperature (°C)</td>
<td>1961–1990</td>
<td>6.6</td>
<td>12.8</td>
<td>15.5</td>
<td>−2.7</td>
</tr>
<tr>
<td>Mean air temperature (°C)</td>
<td>2001–2006</td>
<td>7.3</td>
<td>13.8</td>
<td>16.9</td>
<td>−2.3</td>
</tr>
<tr>
<td>Precipitation sum (mm)</td>
<td>1961–1990</td>
<td>580.6</td>
<td>359.6</td>
<td>208.3</td>
<td>113.0</td>
</tr>
<tr>
<td>Precipitation sum (mm)</td>
<td>2001–2006</td>
<td>590.6</td>
<td>358.3</td>
<td>208.3</td>
<td>124.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SOIL CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
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<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Sand</td>
</tr>
<tr>
<td>Silt</td>
</tr>
<tr>
<td>Clay</td>
</tr>
<tr>
<td>Bulk density</td>
</tr>
<tr>
<td>Organic matter</td>
</tr>
<tr>
<td>Total Nitrogen</td>
</tr>
<tr>
<td>pH(KCl)</td>
</tr>
<tr>
<td>Available P</td>
</tr>
<tr>
<td>Available K</td>
</tr>
<tr>
<td>Available Mg</td>
</tr>
<tr>
<td>Available Ca</td>
</tr>
</tbody>
</table>

Hardwood cuttings were planted in a double row design with inter-row distances of 2.6 m and spacing of 0.7 m within rows accommodating density of 10,000 trees/ha. Prior to planting, the area was levelled and cleared of larger stones. In 2000–2001, ploughing followed by a rotor tiller was used for the final pre-planting preparation. All clones were planted as 25 cm long dormant, unrooted hardwood cuttings, after being soaked in water for 48 hours prior planting. Cuttings were planted manually to a depth of 22–23 cm leaving terminal buds above the soil surface. No replacement of individuals within the trial was done in order to simulate conditions of large-scale farming; only mechanical weeding was carried out in May and June. Rotor tiller tilled the inter-rows on September 20. In order to allow for good plantation establishment under significant weed pressure the plantation was not coppiced after the first year allowing it to close canopy during the 2nd year. During 2002–2003, the weed growth in inter-rows was managed by cutting combined with mulching 3-times a year. No irrigation, fertilization and herbicide treatments were applied during the experiment.

The trial included a set of 5 Populus sp. and 3 Salix sp. clones, nevertheless, results are presented for one clone only in this paper (J-105 – P nigra x P ma-
The main purpose of the plantation is to serve as a model field (both in terms of size and composition) to the prospective future plantations in the region and it was used to evaluate survival rates of *Populus* sp. clones under field conditions taking advantage of a large number of individuals.

**Methods of the operational measurement**

In the part of the stand planted by the J-105 clone, a 10 m section of double-rows was randomly selected, which represents 28 trees (in ideal case) thanks to spacing between individuals. The laid out plot was inventoried from the aspect of disappeared individuals within the plot and in the immediately adjacent rows and on faces of the plot. While the harvest of the whole stand occurred at the end of November 2008, the plot was harvested manually in March 2008. Stem girths in the place of cut (about 0.1 m above the ground), at the original height of 1 m and at original d.b.h. were measured by means of a gauge and then also the stem length (the stump height was not taken into account at measuring the length of the felled stem). Thanks to the gauge, through the girth measurement the stem diameter was directly read and thus, effects of ovality of some stems were reduced. Moreover, the total length of a felled stem was measured and branches of a diameter over 10 mm were calculated.

Samples from stems and branches were randomly taken to determine dry matter (DM), the samples were immediately converted to the form of sawdust and weighed. After drying, the DM of stems and branches was determined.

**Methods of the yield estimate determination**

The yield estimate determination was carried out on the basis of the regression analysis of relationships of particular measured quantities as an estimate of the total weight of a stem and branches and the total above-ground weight in DM. After the determination of relationships of particular factors within regression analysis for quadratic dependencies, the most important factors to estimate the yield of branches, stems and the total above-ground weight were determined by the method of step-by-step regression.

For the selection of independent variables – factors, which are the most important for the quantitative determination of each of the previous dependent variables the method of step-by-step analysis by forward selection was used in the first stage. The final selection of variables was carried out with respect to the elimination of colinearities, accidentalities and the general logic of selection.

Subsequently, regression analysis was also carried out according to an equation determined by KESTERMONT (1971).

**RESULTS**

By means of polynomial regression, functions were calculated of the stem of poplars, DM biomass of branches, stems and whole plants depending on the stem diameter at a height of 10, 100 and 130 cm. The significance of calculated regression functions was tested by F-test. The degree of relationship was evaluated by means of the correlation index. The F-test proved in all cases that it referred to the very high significance of calculated regression functions.

Also values of correlation indexes give evidence on the high degree of relationship of calculated dependencies. Regression functions are given in Tab. II and Figs. 1–13.

<table>
<thead>
<tr>
<th>Relationship</th>
<th>n</th>
<th>I</th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:4</td>
<td>22</td>
<td>0.9033</td>
<td>2.55769</td>
<td>1.05280 E–01</td>
<td>–4.91062 E–04</td>
</tr>
<tr>
<td>1:5</td>
<td>22</td>
<td>0.9710</td>
<td>7.41823 E–01</td>
<td>–3.64875 E–02</td>
<td>1.30896 E–03</td>
</tr>
<tr>
<td>1:6</td>
<td>22</td>
<td>0.9430</td>
<td>8.45499 E–01</td>
<td>–4.69439 E–02</td>
<td>7.75935 E–04</td>
</tr>
<tr>
<td>1:7</td>
<td>22</td>
<td>0.9771</td>
<td>1.58099</td>
<td>–8.31704 E–02</td>
<td>2.08307 E–03</td>
</tr>
<tr>
<td>2:4</td>
<td>22</td>
<td>0.9255</td>
<td>2.54674</td>
<td>1.22498 E–01</td>
<td>–6.58897 E–04</td>
</tr>
<tr>
<td>2:5</td>
<td>22</td>
<td>0.9903</td>
<td>1.23742</td>
<td>–6.34934 E–02</td>
<td>1.98148 E–03</td>
</tr>
<tr>
<td>2:6</td>
<td>22</td>
<td>0.9625</td>
<td>1.08678</td>
<td>–6.49087 E–02</td>
<td>1.15229 E–03</td>
</tr>
<tr>
<td>2:7</td>
<td>22</td>
<td>0.9967</td>
<td>2.31532</td>
<td>–1.27991 E–01</td>
<td>3.13029 E–03</td>
</tr>
<tr>
<td>3:4</td>
<td>22</td>
<td>0.9287</td>
<td>2.63869</td>
<td>1.24593 E–01</td>
<td>–6.96244 E–04</td>
</tr>
<tr>
<td>3:5</td>
<td>22</td>
<td>0.9871</td>
<td>7.35626 E–01</td>
<td>–3.72238 E–02</td>
<td>1.76757 E–03</td>
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<tr>
<td>3:6</td>
<td>22</td>
<td>0.9666</td>
<td>8.73012 E–01</td>
<td>–5.52754 E–02</td>
<td>1.08426 E–03</td>
</tr>
<tr>
<td>3:7</td>
<td>22</td>
<td>0.9956</td>
<td>1.60199</td>
<td>–9.21556 E–02</td>
<td>2.84882 E–03</td>
</tr>
</tbody>
</table>

Values:
1 – diameter at a height of 10 cm above the ground (mm),
2 – diameter at a height of 100 cm above the ground (mm),
3 – d.b.h. (mm),
4 – stem height (m),
5 – stem biomass DM (kg),
6 – branch biomass DM (kg),
7 – above-ground biomass without leaves DM (kg),
I – correlation index
Tab. II gives coefficients of calculated regression equations in a general form $y = a + bx + cx^2$ for interrelationships of studied factors including correlation indexes.

Particular graphic expressions of interrelationships of particular factors are presented in Figs. 1–12.

1: Height of stem in relation to the diameter at a height of 10 cm above the ground (relation 1:4)

2: Height of stem in relation to the diameter at a height of 100 cm above the ground (relation 2:4)

3: Height of stem in relation to the diameter at breast height (d.b.h.) (relation 3:4)
4: Biomass of stem in relation to the diameter at a height of 10 cm above the ground (relation 1:5)

5: Biomass of stem in relation to the diameter at a height of 100 cm above the ground (relation 2:5)

6: Biomass of stem in relation to d.b.h. (relation 3:5)
7: Biomass of branches in relation to the diameter at a height of 10 cm above the ground (relation 1:6)

8: Biomass of branches in relation to the diameter at 100 cm above the ground (relation 2:6)

9: Biomass of branches in relation to d.b.h. (relation 3:6)
10: Above-ground biomass without leaves in relation to the diameter at a height of 10 cm above the ground (relation 1:7)

11: Above-ground biomass without leaves in relation to the diameter at a height of 100 cm above the ground (relation 2:7)

12: Above-ground biomass without leaves in relation to d.b.h. (relation 3:7)
Based on diagrams, particularly of the DM weight of whole plants depending on the stem diameter at all examined heights, it is evident that calculated regression functions represent very well measured values.

Within step-by-step regression with selection ahead, factors were selected, which explain best examined estimates of the DM weight of stems, branches and total biomass. Extracted factors and coefficients of regression equations are given in Tab. III.

III: Parameters of regression equations. Fitted curves of relationships between biomass fraction, d.b.h and stem height

<table>
<thead>
<tr>
<th>Quantity examined (kg)</th>
<th>Coefficients of equations for a given factor</th>
<th>Correlation index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant</td>
<td>d.b.h</td>
</tr>
<tr>
<td>DM of branches</td>
<td>1.3396</td>
<td>0.1273</td>
</tr>
<tr>
<td>DM of a stem</td>
<td>–4.9429</td>
<td>0.1722</td>
</tr>
<tr>
<td>Total DM</td>
<td>–1.2963</td>
<td>0.2993</td>
</tr>
</tbody>
</table>

To test data obtained with literature sources an equation according to KESTEMONT (1971) and used by PALÁT (1991, 1997) was selected to calculate the above-ground biomass of trees of a diameter from 2 to 20 cm. The equation obtained for J-105 poplar clone is of a following form:

\[
Y = 0.006985028 \cdot X^{2.3212576},
\]

where: \(X\) is the girth (cm) at breast height of 1.3 m, \(Y\) is the above-ground biomass in dry matter (kg). Graphical presentation is in Fig. 13.

13: Above-ground biomass without leaves in relation to the girth (cm) at b.h.

**DISCUSSION**

Determined mathematical dependencies explain very well the variability and dependencies of input factors. They are statistically highly significant in all cases. Although it refers to results obtained from one plot and one clone only, they serve as a model example and these equation will be further tested at other clones. Thus, the importance of relationships obtained cannot be overestimated; nevertheless, values of correlation coefficients have explained quite conclusively examined dependencies and the equations can serve as a highly significant model of the stand yield estimation.

It is evident that some input values are redundant. To determine the yield estimate of total biomass it is quite sufficient to measure d.b.h. and to determine the stem length.

**CONCLUSION**

Results obtained serve as a basis to determine the DM yield in plantations of fast-growing tree species, particularly poplar and clone J-105. The data obtained will be subsequently tested for other clones and specified for condition of a given locality. Other verification, which is necessary to obtain regression dependencies, refers to their validity within
the length of overgrowing between particular rotation periods or the stand age till the first rotation. The equations explain very well allometric relationships in the seventh year of growth of a given clone but with the highest probability, they will not be so much accurate for early growth stages.

Nevertheless, this model can serve for the under-demanding and fast determination of the yield estimate or for deciding the plantation owner whether to carry out harvest in the current year or to postpone it to the next year expecting an increment.

SOUHRN

Odhad výnosu topolů na plantážích rychle rostoucích dřevin v rámci průběžných výsledků

Nejvyšší potenciál obnovitelných zdrojů energie vykazuje v České republice energie biomasy a jednou z cest jejího ziskávání je pěstování vybraných dřevin v krátkém obmýtí (3–7 let). V době mezi obmýtím, resp. do prvního obmýtí je vhodné sledovat růstové parametry a odhadovat budoucí výnos pomocí alometrických veličin. Cílem předkládaného textu je nalézt alometrické závislosti pro klon topolu Jap-105 (P. nigra x P. maximowiczii) na lokalitě Domanínek. Lokalita se nachází na Českomoravské vysočině, která je hraniční oblasti pro pěstování sledovaných dřevin. Sestavením metodického postupu odhadu výnosu, resp. ověření metod vyhodnocení na průběžných výsledcích, je předpokladem úspěšné realizace následného rozsáhlého pokusu.

Pro stanovení závislosti bylo použito 22 jedinců, v náhodně zvolené parcele uvnitř porostu pro minimizaci hraničního efektu. Měřenými veličinami byly délka kmene, průměr ve výšce 10 cm, 1 m a tzv. prsní výška (1,3 m). Po skácení a změření uvedených veličin byl zvážen kmen a celková hmota větví. Z odebraných vzorků byla stanovena sušina kmene a větví a váženě dopočtena celková sušina nadzemní hmoty jedince.

Na základě studia literárních pramenů byly zvoleny kvadratické funkce jako základní modelové rovnice odhadů vzájemných závislostí. Sledované závislosti v rámci polynomické regrese druhého stupně vykázaly vysokou shodu seho teoretického modelu a empirických dat (index korelace od 0,9033 do 0,9967). Cílem statistických analýz bylo dále identifikovat nejvýznamnější faktory pro odhad odhady výnosu sušiny kmene, větví a celkové nadzemní hmoty vhodné pro energetické užití. Pomocí krokové regrese byla odhalena dvojice základních veličin – délka kmene a průměr ve výšce, která s dostatečnou přesností postačuje pro kvalifi kovaný odhad výnosu.

Získané výsledky jsou v obecné shodě s literárními prameny, prokazujícími vhodnost použití zvolených statistických metod k alometrickým odhadům výnosu. Jejich precizace pro jednotlivé dřeviny, jejich klony a lokality se ukazuje jako nezbytná, proto předkládaný text mapuje podmínky na základě studia literature.

odhad výnosu, alometrické závislosti, regresní analýza, plantáže rychle rostoucích dřevin, topol

The presented study was supported by the Research plan No. MSM 6215648905 “Biological and technological aspects of the sustainability of controlled ecosystems and their adaptability to climate change” financed by the Ministry of Education, Youth and Sports of the Czech Republic.

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