UNIVERSITY OF WEST-HUNGARY
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THESES OF DOCTORAL (PHD) DISSERTATION

NURTIENT SUPPLY WITH NATURAL MATERIALS IN SHORT ROTATION COPPICE

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1. BACKGROUND, AIMS OF RESEARCH

The growing energy demands of modern societies depend mostly on fossil fuels. Growing political and social tensions threaten the continuous supply. The reduction in fossil energy stocks made it necessary to also treat the use of renewable energy sources as a priority on a global scale.

Besides decreasing external energy dependence, further potential benefits of the generation of energy from biomass as a renewable source are widely published in scientific literature[1][2].

As high biomass production in short time is the goal of SRCs, high nutrient losses of the soil can be estimated in each case. In the case of short-rotation coppice in every 2-3 years a large amount of woody mass is harvested from the area, so addition of nutrients is needed. Literature sources show the possibility of treatments with wood ash as well as wood ash combined with manure.

In our long-term research we examine the technological steps of an energy wood plantation establishment, survival effectiveness, yield, nutrient supply, ways of nutrient supply and the impact on soils and vegetation.

The general aim of this study was to provide scientific data for the use of different tree species and their clones in short rotation coppices in Hungary to obtain best quality and yield in biomass production. Results are reported in terms of species/clone survival rate, stand growth, effects of different fertilization methods, and soil investigation data.

2. HYPOTHESES

After setting the aims of the research the author has outlined the hypotheses of the doctoral work as follows:

H1: The used poplar and willow clones are adopted to different site conditions, their site tolerance and growth vary. In Hungary we expect better

[1]**ERICCSON, K.**, **NILSSON, L. J.**(2006): Assessment of the potential biomass supply in Europe using a resource–focused approach. Biomass Bioenergy **30**:1–15.
[2]**BLASCHKE, T., BIBERACHER, M., GADOCHA, S., SCHARDINGER, I.**(2013): ‘Energy landscapes’: Meeting energy demands and human aspirations. *Biomass Bioenergy***55**:3–16.

applicability and higher yields of south-born, new poplar clones in SRC plantations.

H2: Selected clones can take up significant amounts of nutrients from the soil in connection with rapid growth; therefore we presage their excess growth in case of fertilization.

H3: The intensive growth is coupled with large leaf area formation, whose rate is proportional to the biomass yields.

H4: Biomass yield is in correlation with tree height, base diameter and diameter at breast height, this can be described with functions.

H5: The growth of individual trees responds within a short time to changing growing space; in case of larger growing space specimens biomass yield will be significantly higher.

H6: Nutrient supply effects the economic efficiency of the plantations due to significantly increased biomass yield.

H7: Based on the experiment we can recommend specific cultivation technology for the nutrient supply of woody energy plantations.

3. MATERIALS AND METHODS

3.1. Experimental set–up and plant material

In May 2011, a 5 ha short rotation coppice (SRC) plantation was established in a nursery of Ipoly Forest cPlc., Dejtár, Hungary. We configured 60 experimental plots with 4 types of treatments with three replicates for each.

We used three poplar clones and one willow cultivar, representing the most frequently used trees in Hungary – Pannónia poplar (*Populus x euramericana cv. Pannonia*), Italian AF2 (*Populus x canadensis*), Italian Monviso clones (*Populus x generosa X Populus nigra*) and *Salix alba* ''Dékány'' bred in Hungary. The planting was made with the usual 25–30 cm cuttings in 3x0.5 m initial space (6660 pcs ha^{-1}). In some plots, we planted approx 3 m long unrooted pole cuttings in 3x1 m space (3330 pcs ha^{-1}). The nutrient supply was 5 t ha^{-1} wood ash and 40 t ha^{-1} organic fertilizer which means manure, separately and combined. The application was made by disking, before tree planting.

3.2. Soil and plant nutrient analyses

In April 2011, before the establishment of the plantation, a site survey was done. We analyzed the soil by opening 2 soil pits to a depth of 2.2 m, and disturbed soil samples were taken from the profile from each horizon, for a general description of soil types of the research site.

In 2011 and 2013 soil nutrient analyses were performed (% C, % N, % S, % H, AL-P, AL-K), for soil samples taken in all plots from 0-20 cm depth.

The nutrient status of the plants (C, N, P, Ca, Mg, Mn, Fe, Cu, Zn) was also tested in all 60 plots; the leaf samples were taken in August of 2011, 2013 and 2014.

For the characterization of plantation hydrology, pF-measurements, soil water level and meteorological parameter monitoring were carried out.

3.3. Survival analyses

After planting (5–6 May 2011) we conducted the first survival examination on 25–26 May 2011. We sampled 2 lines each per plot, and classified single trees into 4 categories:

- Cat. 0: dead
- Cat. 1: buds swollen, but leaves are smaller than 2 cm
- Cat. 2: leaves with size of 2-5 cm
- Cat. 3: blooming leaves bigger than 5 cm

3.4. Dendrometric measurements

3.4.1. Height measurement

The height of trees was measured annually from the first year of the plantation. In the case of the plots planted with short cuttings, height was measured only in the first two growing seasons. In the case of plots with pole cuttings, measurements went on each following year. The heights were measured with 5 cm accuracy with a telescopic height gauge.

3.4.2. Biomass measurement

We used fish scale with 0.01 g accuracy for biomass measurement. For the plots planted with short cuttings, biomass was measured only in the first two growing seasons. For plots with pole cuttings, measurements went on each following year. Nine specimens were cut out and measured from each plot originating from short cuttings, and then their average was calculated.

For the calculations a base diameter (d) and mass correlation was used published by *Vágvölgyi (2013)*[3] (R2 = 0.911):

$$Mass = 0{,}00001096 * d3 + 0{,}00083985 * d2 - 0{,}00286573 * d$$

We report the biomass results in dry (atro–) tons per hectare (t ha^{-1}).

3.4.3. Circumference measurements

The circumference measurement was realized in mm precision with a millimeter level accuracy tape measure. Diameter was calculated from the circumference. Measurement was taken each September beginning from the first year of the plantation. In the case of the plots planted with short cuttings, circumference was measured only in the first two growing seasons. In the case of plots with pole cuttings, measurements went on each following year. From 2012, parallel to height measurements, we measured the circumference at the base of all trees planted as pole cuttings.

3.4.4. Growing space test of pole cutting plots

The growing space test started at March 25, 2013. The diameter at breast height and weight was measured each individual. Each second tree was

[3]**VÁGVÖLGYI, A.** (2013): Fás szárú energetikai ültetvények helyzete Magyarországon napjainkig; üzemeltetésük, hasznosításuk alternatívái. Nyugat-magyarországi Egyetem, Doktori (PhD) értekezés, Sopron

cut out in 4 rows per plots and whose height was measured. From the cut rows an average row was selected with completion of weight and height measurements as well. The next test took place in December 2013.

3.4.5. Examination of leaf area index

In 2011 and 2013 before the defoliation all leaves of an average tree were collected from each plot, the foliage was laid on an A2 size paper (420 × 594 mm) and photographed. The sequence was carried out in three replicates per plot, and a program called Pixel Counter was measured the area of black pixels on the photos. Afterwards, we determined the leaf area of a tree and of 1 ha with commensuration, and then the dimensionless index value for the parcel.

3.5. Statistical analyses of the results

Data from the first three vegetation periods were analyzed. The statistical evaluation was performed with Microsoft Excel and STATISTICA 11 software. In the analyses, the general descriptive statistics, t–test, regression analyses and one–way analyses of variance (one–way ANOVA) were used, specified with the Duncan's test.

3.6. Registering of the groundwater well and TDR probe data

In spring 2012 to monitor the changes in the ground-water level a 4 m deep groundwater well have been installed at the 33 plots. Registering the depth of the groundwater was done with an automatic recording unit each 10 minutes, with mm precision. To determine the evaporation the general meteorological data were obtained and analyzed. To calculate the evapotranspiration among the daily regime of groundwater level data within the examined period characteristic sections were selected (28.06.2012 - 01.07.2012; 18-24.08.2012).

Soil moisture measuring units were installed on 20.06.2012, near the groundwater well. The probes were placed in 4 depths (30, 80, 130 and 190 cm). Data was registered every 10 minutes.

4. SUMMARY OF THE RESULTS

4.1. Summary of research results

In our small-scale comparative experiment in Hungary, based on examination of SRC plots established with short cuttings and pole cuttings, Alasia New Clones® Monviso poplar clone showed the best survival rate, while AF2 clone had the highest growth rate, and both performed better AF2 and Monviso poplar clones showed the best survival rate and the highest growth rate, as against the lower yield producing Hungarian Pannonia species or the *Salix alba* 'Dékány' willow clone, which became extinct after the first growing season due to drought occurring in 2011. This is probably related to the different site requirements of the compared clones: the Southern–born poplar clones have a higher temperature demand and better drought tolerance than the willow clone. In drought periods, the survival of 2.5–3 m long pole cuttings set down to a depth of ca. 1.2–1.3 meters was more favored than that of short cuttings, which could extend their roots only in the fast drying sandy topsoil that was heated up much more due to sun exposure.

At the end of the first growing season, the highest values for height and diameter were found in the control plots, so the effects of the fertilization has not yet been reflected in these parameters of the trees. The fertilization had also no significant effect on the biomass production during first year.

During second growing season, the base diameters showed significantly different (p value) results due to the application of organic manure. We think that in the nutrient–poor sandy soil, nutrient ratios have also played an important role; probably the low nitrogen accessibility could not be compensated by the addition of wood ash compared to organic fertilizers, so that in this case nitrogen could have been a factor limiting the uptake of other nutrients.

Our fertilization experiment showed that although important nutrients had already been present in optimal amounts from the start of the investigations, their contents were increased due to all treatments. At the end of the second growing season, in the case of pole cuttings the manure + wood ash combined treatment, and in the case of short cuttings the manure treatment resulted in the highest significant biomass yield. Pole cuttings yield tests carried out in the third vegetation period also showed a continuation of this trend. However, plant (leaf) nutrient analyses carried out in the fourth growing season no longer showed a significant effect of the one–off application of fertilizers.

The results of the pole cuttings were considerably different from the normal cuttings. Height and biomass of AF2 pole cuttings was significantly higher in the combined treatment plots compared to all other plots. The diameter of all treated plots was notably higher than that of the control.

In 2013, i.e. after the third growing season of the plantation, base diameter of combined treated plots was significantly higher compared to all other treatments. At the height measurement, the highest and most significant values came also from the combined treatment.

In the case of height for pole cutting plots, the effect of the combined treatment stood out again. The areas treated only with organic or wood ash had nearly equal results to each other, and much lower results were obtained in the control plots. The combined treatment produced significant difference as well. The yield in two years achieved the expected results. The combined treatment was substantially higher than the single treatments and the control area, with the lowest weight results given by the control area. Under these circumstances we conclude that the different methods of fertilization have already shown significant effectsin the end of the second growing season. These effects are manifested also in the organic and inorganic treated blocks, only their quantity was lower than by the combined application.

At the end of the third growing period, results obtained in the pole cutting plots reflected the same tendencies as at the end of the second year. In the case of the base diameter, the values of combined fertilization plots had significantly different results compared to all other treatments. The wood ash or manure–fertilized plots didn’t show significant differences from each other and from the control. In the case of height, the combined treatment showed a significantly high value again. However, the lowest value was not in the control, but in the wood ash treatment. Similar results were obtained in the analyses of yield after three years. The highest yield was showed by the combined treatment, the lowest was by the wood ash. This can be again a result of the limiting effect of nitrogen due to the low organic content of the soil. We can conclude that for optimal biomass production on poor sandy soils, nutrient addition is crucial, with great emphasis on proper nutrient proportions.

The average annual yield of the plantation was 5 odt ha^{-1} $year^{-1}$.

A year after the fertilization, measurements showed no significant changes in the soil organic carbon content of the 0–30 cm layer, however values were higher in the manure and in the the combination–treated area compared to the control. In the case of %N, the nutrient supplied plots showed the highest values. So it can be concluded that due to the manure mineralization, the nutrient concentrations in the soil were raised. The average N value of the soil measured in our experiment is considered as low in comparison with Hungarian forest soils.

The total N supply of the plants in the research area is adequate for good growth of the trees. As the amount of N was significantly reduced during the period of 2011–2013, it is expected that additional N fertilization is required to achieve good yield in future. Comparing the treatments, in the beginning the organic fertilized plots utilized N in the most effective way; therefore, the strongest attenuation was detected in that treatment after 2 years.

There were no significant differences in the leaf area during the fertilization tests either 2011 or 2013. Accordingly, within this time period the nutrients have not been utilized to the extent that this also show subsequent on leaf, but less than 2 years the LAI values tripled.

The data of economic calculations clearly show that although the nutrient supply receiving blocks were capable of producing higher yields, high costs of nutrient supply were not covered by surplus yield income. Further investigations are needed to determine if after multiple sprouting the nutrient supply of SRC in the untreated plots becomes critical.

In the first half of the examined vegetation period, trees were able to cover up to 80-100% of potential evapotranspiration from the near-surface groundwater, but later when ground water level decreased in the second half of the growing season below the rooting depth, plant growth declined significantly due to atmospheric drought and lack of further water supply by rain. Based on analysis of the soil pore size distribution, in sandy soils with small water-holding capacity but high water conductivity, capillary water lifting may result in significant surplus of tree growth.

4.2. Theses of the dissertation

T1: In a small-scale clone comparison experiment Alasia New Clones®, 'AF2' and 'Monviso' poplar cultivars showed the best survival and the highest growth rates, compared to the Pannonia species which produced lower yield or the *Salix alba* ‘Dėkány’ willow species which was completely extinct after the first growing season due to drought. This corresponded to the experiences that the habitat spectrum of the authorized three species is different: the heat demand and drought tolerance of the Southern-born poplar clones is greater that of willow, the latter needs continuous water surplus. In drought conditions, the survival of the 100-120 cm deep drilling pole cuttings was higher in the fast drying sandy topsoil than that of short cuttings.

T2: In our nutrient supply experiment in case of pole cuttings the organic fertilizer combined with wood ash, in case of short cuttings the organic fertilizer treatment resulted the most significant surplus biomass yield at the end of the second growing season. In the third year in case of pole cuttings the yield trials also showed a continuation of this trend. Plant (leaf) nutrient analyses showed that in the fourth vegetation period after application, no detectable significant effect was detectable any more.

T3: We found no statistically verifiable, unambiguous correlation between the effect of the evolution of leaf area index (LAI) and the different fertilization treatments on different biomass yields. From this we draw the conclusion that in the early years with a not closed crown-storey, the evolution of the photosynthetic surface is not the decisive factor for growth, but rather nutrient supply and access to water. LAI values will probably be useful for estimation of growth only after the closing of the canopy. Between the first and third growing season the LAI values roughly tripled.

T4: Based on our detailed research data regarding site conditions, plant nutrient status and growth analyses, carried out over several growing seasons, clear, quantifiable functions as relations were established specific tree diameters and biomass yield. Our measurements confirmed and extended with new data the conclusion, that the above-ground biomass showed the closest correlation with diameter at breast height. It resulted in a weaker correlation with tree height, and in an even weaker one in case of base diameter.

T5: After increasing the growing space of the two-year pole cuttings from 3x1 m to 3x2 m, significant (approx. 8-10%) surplus growth was recorded in the size of individual trees and in biomass after the first growing season. This ability of a fast reaction to extended growth space has a significant role plantations established for industrial timber use.

T6: Based on economical calculations, the use of different fertilization methods resulted in growth surplus in the first rotations, but high costs of nutrient addition couldn't be covered by economic surplus derived from higher biomass yield.

T7: We worked out a practical guidance for SRC management in terms of nutrient supply implementation:

- After pre-planting soil preparation (30-40 cm deep plowing and surface smoothing) 40 t / ha of cattle manure are spread with traditional agricultural equipment manure spreader. Further 5 t / ha of wood ash derived from residual untreated wood are added in their natural moisture status with a disc fertilizer spreader;
- The applied manure and wood ash is worked into the upper soil by disking;
- Repetition of the treatment in every third year.

LIST OF PUBLICATIONS

Printed scientific publications

1. **SZABÓ O.**, KOVÁCS G., HEIL B. (2016): Effects of nutrient supply and planting material quality on yield and survival rate of a short rotation coppice culture in Hungary. Agronomy Research
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3. **SZABÓ O.**, HEIL B., KOVÁCS G. (2011): Tápanyag-utánpótlási kísérlet egy fás szárú energetikai ültetvényben. Tudományos Doktorandusz Konferencia, Konferencia-kötet, p. 70-73.
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5. **SZABÓ O.**, HEIL B., KOVÁCS G. (2013): Nurient Supply in Short Rotation Coppice. Science for Sustainability - International Scientific Conference for PhD Students, Proceedings, p. 263-267.
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1. **SZABÓ O.**, HEIL B., KOVÁCS G. (2011): Tápanyag-utánpótlási kísérlet egy fás szárú energetikai ültetvényben. Tudományos Doktorandusz Konferencia, Nyugat-magyarországi Egyetem, Erdőmérnöki Kar, Sopron. 2011. április 13.
2. **SZABÓ O**. (2011): Tápanyag-körforgalom és –utánpótlás vizsgálata fás szárú energetikai ültetvényben a Kelet-Cserháti Erdészet területén. NymE Tudományos Diákköri Konferencia az Erdőmérnöki Karon
3. **SZABÓ O.**, HEIL B., KOVÁCS G. (2011): Tápanyag-utánpótlási kísérlet egy fás szárú energetikai ültetvényben. Környezeti problémák a Kárpát-medencében
4. **SZABÓ O**. (2012): Energiaerdő – környezettudatos földhasználat. Nemzedékek együttműködése a tudományban, IV. PhD konferencia, Földtudomány - Környezettudomány Szekció
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3. KOVÁCS G., ILLÉS G., MÉSZÁROS D., **SZABÓ O.**, VIGH A., HEIL B. (2012): Termőhelyi tényezők változásának nyomon követése a Noszlopi erdőtömb példáján. Erdészettudományi Közlemények, 2. évf., 1. sz., p. 47-60.