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Effects of nutrient supply and planting material quality on yield and survival rate of a short rotation coppice culture in Hungary

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Abstract. In May 2011, a short rotation woody energy plantation (SRC) was established near Dejtár village in Northern–Hungary. The goal of the experiment was comparative analyses of different fertilization treatments on three clones of Populus (AF2, Monviso, Pannonia) and one Salix cultivar ('Dékány'). We used three fertilization treatments: (1) 5 t ha^{-1} of wood ash, (2) 40 t ha^{-1} of farmyard manure and (3) both 5 t ha^{-1} of wood ash and 40 t ha^{-1} of farmyard manure. The Monviso clone had the highest survival rate (92%), followed by Pannonia (80%) and AF2 (78%). Initially, the white willow 'Dékány' cultivar was also included in the experiment, but due to differing site preferences of this cultivar, it was not viable in the area. Based on the data of the first three growing seasons, it was demonstrated that the important nutrients had already been present in optimal amounts from the start of the experiment, and their contents were increased due to the treatments. At the end of the first growing season, the effect of the fertilization treatment could not be detected, but by the third year the results showed a significant positive effect. Already in the second, but mostly at the end of the third growing season, the wood ash + manure fertilizer treated plots showed significant increases in height growth and biomass yield.

Key words: *Populus* Spp; Farmyard manure; Wood ash; Biomass production.

INTRODUCTION

The growing energy demands of modern societies depend mostly on fossil fuels. Growing political and social tensions threaten the continuous supply. Political decision makers in the European Union (EU) have set joint strategies to ensure energy supply including the generation of energy from renewable sources, mainly biomass (European Commission, 1996). The EU goal is to get 20% of its energy from renewable energy sources by the year 2020, including renewable sources such as solar, hydro–electric, wind, geothermal energy, and biomass.

Hungary's Renewable Energy Plan has set the target of a 14.65% minimum share of renewable energy in gross final energy consumption by 2020, with more than 60% originating from biomass (Vágvölgyi et al., 2014a). 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 (Ericcson & Nilsson, 2006; Blaschke et al., 2013).

The two main tree species for biomass energy generation in Europe are willow and poplar. Willow is more useful in the Northern countries, while the growth region of poplar is more widely extended in Central, Southern and Eastern Europe. Among tree species used in plantations in Hungary, poplar has been shown to have the greatest yield potential (Kovács et al., 2011). Substantial areas of poplar had already been established in the 1960's and 70's, revealing that Hungary has a long tradition of poplar cultivation, as from 1,939 thousand hectares of forested area 6.2% are planted with Euramerican poplar cultivars, and further 4,4% with domestic indigenous poplars. In a European comparison of poplar SRC plantations we are second after Italy (Weitz et al., 2013). Farmers here are attracted to woody energy plantations, with a continuously increasing interest in the management of short rotation coppices.

As high biomass production in short time is the goal of SRCs, high nutrient losses of the soil can be estimated in each case (Paris et al., 2015). Literature sources show the possibility of treatments with wood ash as well as wood ash combined with manure for nutrient addition in plantations (Holzner et al., 2011; Holzner, 2014).

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.

MATERIALS AND METHODS

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 (48°02'01.8"N, 19°12'12.6"E). The nursery was established in a former forest compartment in the 1960's, and is still surrounded by forests. The topography of the area is flat with sandy soils. Mottling of oximorphic colors appeared from 80 cm depth, and gleyic color pattern from 100–120 cm, indicating a high groundwater level. The soil type is Eutric Cambisol (IUSS, 2014), which poor in colloids, but this is partly equilibrated by the humus content. The soil contains humus to a depth of 80 cm, but only in low concentrations (1.1–0.2%). The nutrient supply depends mostly on this humus, reaching a medium rate (Járó, 1963). The soil pH (H_2O) is slightly acidic to neutral (pH 5.4–6.5 in 0–25 cm depth).

The plant available P content of the soil is 12.5–17.2 mg 100 g^{-1} through the whole soil profile, implying a weak to medium phosphorus supply. The available K content is 4.2–6.9 mg 100 g^{-1} soil, implying low potassium content.

The altitude above sea level is 150 m, the annual mean temperature is 10.0 °C, the annual precipitation is 650 mm, and the long term groundwater level average is 150–220 cm below soil surface in April.

We used three poplar clones and one willow cultivar, representing the most frequently used trees in Hungary (Vágvölgyi et al., 2014b) – Pannónia poplar (*Populus x euramericana cv. Pannonia*, female) (PAN), Italian AF2 (*Populus x canadensis*, male, 1994, Alasia New Clones) (AF2), Italian Monviso clones (*Populus x generosa X Populus nigra*, female, 1991, Alasia New Clones) (MON) and *Salix alba* ''Dékány'' bred in Hungary.

Literature suggests 5,000–20,000 ha^{-1} planting density (Dickmann, 2006), therefore the planting was made with the usual 25–30 cm cuttings in 3 x 0.5 m initial space (6,660 pcs ha^{-1}). In some plots, we planted approx. 3 m long unrooted pole cuttings in 3 x 1 m space (3,330 pcs ha^{-1}). We configured 60 experimental plots with 4 types of treatments. Each treatment – as in other experiments (Fortier et al., 2010) – has Latin square design with three replicates for each (Fig. 1).

WA+OF AF2 1.	WA+OF MON 2.	WA+OF AF2 PC 3.	WA+OF PAN 4.	WA+OF SAL 5.	OF AF2 6.	OF MON 7.	OF AF2 PC 8.	OF PAN 9.	OF SAL 10.
WA+OF AF2 PC 20.	WA+OF PAN 19.	WA+OF SAL 18.	WA+OF AF2 17.	WA+OF MON 16.	OF AF2 PC 15.	OF PAN 14.	OF SAL 13.	OF AF2 12.	OF MON 11.
WA+OF SAL 21.	WA+OF AF2 22.	WA+OF MON 23.	WA+OF AF2 PC 24.	WA+OF PAN 25.	OF SAL 26.	OF AF2 27.	OF MON 28.	OF AF2 PC 29.	OF PAN 30.
WA AF2 40.	WA MON 39.	WA AF2 PC 38.	WA PAN 37.	WA SAL 36.	C AF2 35.	C MON 34.	C AF2 PC 33.	C PAN 32.	C SAL 31.
WA AF2 PC 41.	WA PAN 42.	WA SAL 43.	WA AF2 44.	WA MON 45.	C AF2 PC 46.	C PAN 47.	C SAL 48.	C AF2 49.	C MON 50.
WA SAL 60.	WA AF2 59.	WA MON 58.	WA AF2 PC 57.	WA PAN 56.	C SAL 55.	C AF2 54.	C MON 53.	C AF2 PC 52.	C PAN 51.

Legend: C: control, WA: wood ash, OF: manure as organic fertilizer, PC: pole cutting, SAL: *Salix alba,* MON: Monviso, PAN: Pannonia

Figure 1. Layout of the experimental design.

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.

Measurements and sampling

Survival analyses

After the planting (5–6 May 2011) we conducted the first survival examination on 25–26 May 2011. We sampled 2 lines each per plot, the 4th line from the left or right hand side each.

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. We assessed soil nutrient status with disturbed soil samples taken from the upper 30 cm from each plot of all treatments, before planting and treatments were applied. A second soil sampling in the same depth of 0–30 cm for each plot was done one year after the fertilization.

The soil pH was measured potentiometrically in a 1:2.5 mass proportion soil:water suspension. Determination of soil organic matter content was done using the wet combustion method described in FAO (1990) and humus was calculated with a multiplication of organic carbon content by 1.72. Nitrogen contents were determined by Büchi B–426 and B–323 apparatus with titration after sulfuric acid digestion (Bellér, 1997). Determination of ammonium lactate/acetic acid extractable phosphorus (plant available P) is done colorimetrically (Bellér, 1997). Determination of K used the same soil extract as obtained for available phosphorus measurement, and ammonium lactate/acetic acid extractable (plant available) potassium determination was done by flame photometry (Bellér, 1997). For the determination of plant nutrient concentrations from each plot of all treatments, a mixed sample per plot was made from leaves of 3 trees in August 2011. Plant leaf C– and N–contents were measured again in 2013. Plant total nutrient–amount (Ca, Mn, Zn, Cu) analyses from leaves were done after a H_2O_2–HNO_3 total digestion with ICP–measurement (Buzás, 1983).

Altimetry and circumference 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. In addition, in March 2013 (before beginning of third growing season) we measured the height and circumference at the base of each tree which was originally planted as 3 m long unrooted pole. The heights were measured with 5 cm accuracy with a telescopic height gauge.

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.

Dendromass measurement

We used a 25 kg strength, 0.01 kg accurate fish scale for dendromass measurement. For the plots planted with short cuttings, dendromass was measured only in the first two growing seasons. For plots with pole cuttings, measurements went on each following year.

All shoots from the same stump were measured together. In coppice systems, the total mass estimation relies on an estimation function, including stock number and tree parameters. Nine specimens were cut out and measured from each plot originating from short cuttings, and then their average was calculated.

We considered that at the normal planting the initial spacing was 3 x 0.5 m and the number of plants was 6,660 per hectare. From the weight of the nine samples, we calculated the average weight of the plots, and then converted to dry weight assuming 55% moisture content (determined with weight measurements). We report the biomass results in dry (atro–) tons per hectare (t ha^{-1}). In the case of the pole cuttings, beginning from the second vegetation period we measured the weight of poles by thinning 1 3^{-1} of the plots; i.e. thinning of 4 rows each year, beginning from the eastern side of the plot, removing each second tree.

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. The goal of the analyses was to make general descriptive statistics and to determine whether there are significant differences between different treatments and between tree varieties. In the analyses, the general descriptive statistics (*t–test, F–test*) and one–way analyses of variance (*one–way ANOVA*) were used, specified with the *Duncan's test*. These tests helped to look for significant differences of plant growth due to treatment, tree species and/or planting material.

RESULTS

Soil and plant nutrient analyses

One year after treatment, the average of %N was 0.07. Significant differences were not found between the different treatments (Table 1).

Table 1. Results of soil nutrient analyses, one year after treatment (Mean ± S.E.)

Treatment	N (%)	H (%)	K (mg kg^{-1})	P (mg kg^{-1})
Control	0.07 ± 0.01	1.10 ± 0.08	62.5 ± 4.87	102.7 ± 13.19
WA+OF	0.07 ± 0.01	1.02 ± 0.08	54.1 ± 4.87	163.0* ± 13.19
OF	0.09 ± 0.01	1.14 ± 0.08	56.4 ± 4.87	181.6* ± 13.19
WA	0.07 ± 0.01	1.17 ± 0.08	60.3 ± 4.87	94.0 ± 13.19

Legend: WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (%N: p = 0.23964, %H: p = 0.59000, K: p = 0.62413, P: p = 0.00001).

In case of the plant available P, the control (9.4) and wood ash (10.2) plots lag behind the fertilized (18.2) and combined (16.3) treatment (Table 2).

Table 2. Plant leaf total–nutrient contents depending on nutrient supply treatment (Mean ± S.E.)

Treatment	N (%) 2011	N (%) 2013	C (%) 2011	C (%) 2013	P (mg kg^{-1}) 2011
Control	2.41 ± 0.18	2.24 ± 0.07	45.17 ± 3.69	42.71 ± 0.20	7,204.97* ± 1,233.27
WA+OF	2.67 ± 0.18	2.23 ± 0.07	44.92 ± 3.69	41.99* ± 0.20	1,3853.44 ± 1,233.27
OF	2.62 ± 0.19	2.06* ± 0.07	44.92 ± 3.41	42.11 ± 0.20	1,6441.16 ± 1,233.27
WA	2.58 ± 0.18	2.28 ± 0.07	39.18 ± 3.69	42.88 ± 0.20	1,1099.55 ± 1,233.27

Treatment	Ca (mg kg^{-1}) 2011	Mn (mg kg^{-1}) 2011	Zn (mg kg^{-1}) 2011	Cu (mg kg^{-1}) 2011
Control	7,897.38 ± 619.15	750,98* ± 107.94	51.36 ± 12.33	5.03 ± 0.41
WA+OF	7,895.30 ± 619.15	705,00* ± 107.94	117.08* ± 12.33	6.19 ± 0.41
OF	8,641.96 ± 619.15	388,38 ± 107.94	96.00 ± 12.33	5.12 ± 0.41
WA	6,589.34* ± 619.15	336,31 ± 107.94	57.87 ± 12.33	6.45* ± 0.41

Legend: WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (%N 2011: p = 0.76533, %N 2013: p = 0.14907, %C 2011: p = 0.56194, %C 2013: p = 0.00337, P: p = 0.00026, Ca: p = 0.16210, Mn: p = 0.02423, Zn: p = 0.00312, Cu: p = 0.05146).

Plant analyses of total phosphorus showed that the control plots lagged far behind the treated plots; all treated areas showed significantly higher results (Table 2). The amount of total calcium was the smallest in the case of wood ash–treated plots; the highest value was measured in the manure treated block. In the case of the wood ash treatment the total manganese content was more than double of those of that of control. The zinc concentration greatly increased due to the manure treatment, and the highest amount was found in the combined treatment.

In case of plant–%C and –%N, there was no significant difference between treatments in the 2011 measurements, but in 2013, there were considerable differences. In the block fertilized with manure, the %N was markedly lower after two years compared to wood ash plots. Changes of %C after two years were small and not significant.

Survival analyses

In the case of the examination of survival in the first growing season, we evaluated the different clones and the two different varieties of cutting type as well (Table 3).

Table 3. Survival rate of different species (Mean ± S.E.)

	AF2	Monviso	Pannonia	Salix 'Dékány'	AF2 (pole)
Survival (%)	77.65 ± 2.65	92.03 ± 2.65	80.3 ± 2.65	61.76* ± 2.65	96.82 ± 2.65

*: significance at 5%, (*F(4, 55)*=26,681, *p* = 0.00000).

At the end of the second week the short cutting survival was significantly lower than that of 3 m long AF2 poles. During the first growing season, *Salix alba* 'Dékány' had 100% mortality, due to a longer drought period during summer.

Yield analyses

The results of the pole cuttings were considerably different from the normal cuttings (Szabó, 2016). Height and biomass of AF2 pole cuttings was significantly higher in the combined treatment plots compared to all other plots (Table 4). The diameter of all treated plots was notably higher than that of the control.

Table 4. Yield analyses due to different fertilization treatments of pole cutting plots (Mean ± S.E.)

	Pole cuttings					
Treatment	H 2012 (cm)	d 2012 (cm)	Mass 2012 (dry t ha^{-1})	H 2013 (cm)	d 2013 (cm)	Mass 2013 (dry t ha^{-1})
Control	465.61 ± 13.47	6.91* ± 0.07	5.97* ± 0.16	689.87 ± 10.39	9.73 ± 0.09	13.74 ± 0.39
WA+OF	519.32* ± 12.16	7.26 ± 0.09	9.98* ± 0.25	759.15* ± 12.72	10.34* ± 0.14	16.30* ± 0.59
OF	470.19 ± 13.26	7.29 ± 0.09	7.65 ± 0.21	696.07 ± 10.95	9.61 ± 0.12	14.37 ± 0.51
WA	475.01 ± 7.46	7.24 ± 0.07	7.84 ± 0.17	685.67 ± 13.41	9.82 ± 0.10	13.13 ± 0.41

Legend: H: height, d: diameter, WA: wood ash, OF: manure as organic fertilizer, *: significance at 5% (H 2012: *p* = 0.00677, d 2012: *p* = 0.00324, Mass 2012: *p* = 0.0000, H 2013: *p* = 0.00013, d 2013: *p* = 0.00047, Mass 2013: *p* = 0.00015).

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.

DISCUSSION

Soil and plant nutrient analyses

Soil pH was mildly acidic before treatment. This made the wood ash additions reasonable due to its well–known alkalizing effect.

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. Humus contents are altogether low compared with other Hungarian forest soils (Stefanovits et al., 1996). 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. Taking into account the sandy texture, the amount of AL–K in the soil (5.83) was very low (Bellér, 1997). For AL–P it was clearly shown that after one year, the amount of phosphorus from the manure was not taken up by the plants, possibly it was not mobilized or leached out (Heckrath et al., 1995). The AL–P contents of the wood ash treated and control plots were low (6–10), the fertilized areas were in the good to medium (17–25) category (Buzás, 1983).

Plant leaf analyses strongly showed the fertilization effect in the case of total phosphorus (Table 2). The phosphorus in the topsoil gets rapidly immobilized after the microbial digestion, making it available for the plants. The average nutrient supply of poplars is between 0.18 and 0.30% (Lyr et al., 1992). Based on this, the amount of phosphorus in the plants was sufficient in the control area, and continued to grow with the treatments, reaching the highest rate in the manure treatment block. Lowest amount of total calcium was found in the wood ash treated plots which was still within the optimum range (3,000–15,000 mg kg^{-1}) for plant growth (Lyr et al., 1992). Plants optimal manganese content is 35–150 mg kg^{-1} (Lyr et al., 1992), in our case double the optimum amount was already present prior to treatment, and was further increased with the wood ash treatment. The optimal quantity of copper in the plants is 6–12 mg kg^{-1} (Lyr et al., 1992). This amount was not available in the untreated area, but the wood ash application increased copper contents significantly to the optimal zone. For zinc, the optimal quantity for plants is 15–50 mg kg^{-1} (Lyr et al., 1992). In our case, this amount has already been exceeded prior to treatment but increased values were even significantly higher in the manure and combined treatments. Zinc is normally bound with organic compounds, explaining why the quantity was higher in treated blocks.

According to the literature, the optimum N supply of poplar is between 1.8–2.5% (Lyr et al., 1992). Table 2 shows that 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.

Survival analyses

During the experiment plots planted with the pole cuttings showed the highest survival rate (Table 3). Treatments didn't have a significant effect on survival rates of the first year, probably due to the more important role of planting material, as well as a later utilization of added nutrients only. This is probably due to the planting method: approximately 3 m long poles were set to a depth of 100–120 cm and possibly could reach the deeper to the wet soil layers. Another important factor for survival after planting is the high quality of planting material. The planting was preceded by a wet year (918 mm $year^{-1}$), the soil moisture conditions were favorable, with groundwater partly appearing in the planting holes. High survival rates of pole cuttings show also the good quality of the planting material. Cuttings were soaked in water before planting to store as much water as possible for the period until rooting. As the willow 'Dékány' has a high demand for water, it was not able to cope with the drought and low water holding capacity of the sandy soil. It had a low survival rate, and after the first growing season it disappeared from the area. From the meteorological data it appears that in 2011 the average minimum temperature was slightly lower than usual (4.5 °C), but this didn't effect higher survival rates of the clones AF2 and Monviso, which were selected originally for Italy, where average temperatures are higher than in Hungary. The literature data and nursery descriptions showed that even in extra favorable conditions these varieties are able to produce a 95–100% survival rate (Paris et al., 2011).

There was no significant difference between the different fertilizer treatments in terms of survival rate. In the case of the varieties, the low result of the 'Dékány' willow and the outstanding survival of the Monviso significantly differed from the other varieties.

The treatments were applied a few weeks before planting. The experimental data clearly showed that its effect has not influenced plant growth in the first few weeks. Therefore the extra nutrient amount of the wood ash and manure fertilization was not utilized in a rate which could cause detectable differences in the initial survival of the cuttings. This is consistent with past experience; when cuttings are taking root, the stored nutrients are utilized first, and initially the water supply has the greatest impact on survival.

Compared with other experiments, the survival results (about 85%) give cause for satisfaction (Dillen et al., 2013) and show that it is not uncommon that a variety fails to survive for some reason (Al Afas et al., 2008). According to Kaczmarek et al. (2013), the ability of root initiation may be one of the main factors in survival. In addition, the quality of the propagation material and size can greatly affect the survival and growth.

Yield Tests

Yield data were obtained in the first and second growing season from all plots, in the third growing season only in the pole cutting plots, due to work capacity reasons.

First we analyzed data of all plots (independently from planting material type) together. 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, but the results were still satisfactory, as the literature results were similar (Al Afas et al., 2008). During second growing season, the base diameters showed significantly different (p value) results due to the application of organic manure. In case of plant height, the manure and manure–wood ash treated plots showed the maximum values (Szabó, 2016), the positive impact of organic fertilizer has already been shown, but the wood ash effect is less noticeable. 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 (Goodmann & Perkins, 1968).

The organic fertilized block showed the highest level of dendromass, followed by the mixture–treated block, control, and the wood ash treatments in the second growing season (Table 4.). This might be due to the positive effects of manure application. The measurement data slightly lagged behind those from the literature (10–14 odt ha^{-1}) (odt=oven dry ton measured after drying by 105 °C till constant weight reached) (Al Afas et al., 2008). From the data we can conclude that the height and the base diameter positively correlated with each other (Vágvölgyi et al., 2014a).

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 effects in 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} $year^{-1}$. Compared to some experiments, our yield results were slightly lower (Berthelot et al., 2000; Al Afas et al., 2008), conversely to other sources, which presented similar yields (Johansson & Karačić, 2011), or sometimes even lower ones (Laureysens et al., 2004; Walle et al., 2007).

CONCLUSIONS

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; the latter requires water surplus for the more intense evaporation needed for growth (Guidi et al., 2005). 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.

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.

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REFERENCES

Al Afas, N., Marron, N., Van Dongen, S., Laureysens, I. & Ceulemans, R. 2008. Dynamics of biomass production in a poplar coppice culture over three rotations (11 years). *For. Ecol. Manage* **255**, 1883–1981.

Bellér, P. 1997. *Soil Testing Methods*. University of West–Hungary, Faculty of Foresty, 52–95 pp. (in Hungarian).

Berthelot, A., Ranger, J. & Gelhaye, D. 2000. Nutrient uptake and immobilization in a short-rotation coppice stand of a hybrid poplar in north–west France. *For. Ecol. Manage* **128**, 167–179.

Blaschke, T., Biberacher, M., Gadocha, S. & Schardinger, I. 2013. ‘Energy landscapes’: Meeting energy demands and human aspirations. *Biomass Bioenergy* **55**, 3–16.

Buzás, I. 1983. *The Handbook of Plant Nutrition.* Mezőgazdasági Kiadó, Budapest, 45–67 pp. (in Hungarian).

Dickmann, D.I. 2006. Silviculture and biology of short–rotation woody crops in temperate regions: Then and now. *Biomass Bioenergy* **30**, 696–705.

Dillen, S.Y., Djomo, S.N., Al Afas, N., Vanbeveren, S. & Ceulemans, R. 2013. Biomass yield and energy balance of a short-rotation prplar coppice with multiple clones on degraded land during 16 years. *Biomass Bioenergy* **56**, 157–165.

Ericcson, K. & Nilsson, L.J. 2006. Assessment of the potential biomass supply in Europe using a resource–focused approach. *Biomass Bioenergy* **30**, 1–15.

European Commission 1996. *Energy for the future: Renewable sources of energy*. COM (96) 576 final (20/11/96).

FAO 1990. *Guidelines for Soil Profile Description*. Third edition (revised). Soil Resources, Management and Conservation Service, Land and Water Development Division. Rome.

Fortier, J., Gagnon, D., Truax, B. & Lambert, F. 2010. Biomass and volume yield after 6 years in multiclonal hybrid poplar riparian buffer strips. *Biomass Bioenergy* **34**, 1028–1040.

Goodman, G. & Perkins, D. 1968. The Role of Mineral Nutrients in Eriophorum Communities: IV. Potassium Supply as a Limiting Factor in an E. Vaginatum Community. *J. Ecol.* **56**(3), 685–696.

Guidi, W., Bonari, E. & Bertolacci, M. 2005. *Water consumption of poplar and willow short rotation forestry used as vegetation filter: Preliminary results*. Integrated Land and Water Resources Management: Towards Sustainable Rural Development, 15–19.

Heckrath, G., Brooks, P.C., Poulton, P.R. & Goulding, K.W.T. 1995. Phosphorous leaching from soils containing different P concentrations in the Broadbalk experiment. *J. Environ. Qual.* **24**, 904–910.

Holzner, H., Obernberger, I., Berger, T., Danzer, M., Humer, J., Jurik, P., et al. 2011. Richtlinie für den sachgerechten Einsatz von Pflanzenaschen zur Verwertung auf land- und forstwirtschaftlich genutzen Flächen. 66. Wien, Österreich: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Holzner, H. 2014. *Nährstoffrücklieferung aus Holzasche zu Energieweiden und -pappeln im Kurzumtrieb. Central European Biomass Conference*, Graz, Austria, 65 pp.

IUSS Working Group WRB 2014. *World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps.* World Soil Resources Report No. 106. FAO. Rome.

Járó, Z. 1963. *Soil Types.* Országos Erdészeti Főigazgatóság, Budapest, 36–38 pp. (in Hungarian).

Johansson, T. & Karačić, A. 2011. Increment and biomass in hybrid poplar and some practical implications. *Biomass Bioenergy* **35**, 1925–1934.

Kaczmarek, D.J., Coyle, D.R. & Coleman, M.D. 2013. Survival and growth of a range of Populus clones in central South Carolina USA through age ten: Do early assessments reflect longer-term survival and growth trends? *Biomass Bioenergy* **49**, 260–272.

Kovács, G., Magyari, Cs., Heil, B. & Győri, T. 2011. *Standortverhältnisse und Wuchsleistungen von Energieholzplantagen in Ungarn. Central European Biomass Conference*, Graz, Austria, 123 pp.

Laureysens, I., Bogaert, J., Blust, R. & Ceulemans, R. 2004. Biomass production of 17 poplar clones in a short–rotation coppice culture on a waste disposal site and its relation to soil charasteristics. *For. Ecol. Manage* **187**, 295–309.

Lyr, H., Fiedler, H.J. & Tranquillini, W., 1992. *Physiologie und Ökologie der Gehölze*. Gustav Fischer Verlag, Jena, Stuttgart.

Paris, P., Mareschi, L., Sabatti, M., Pisanelli, A., Ecosse, A., Nardin, F. & Scarascia-Mugnozza, G. 2011. Comparing hybrid Populus clones for SRF across northern Italy after two biennial rotations: Survival, growth and yield. *Biomass Bioenergy* **35**, 1524–1532.

Paris, P., Mareschi, L., Sabatti, M., Tosi, L. & Scarascia–Mugnozza, G. 2015. Nitrogen removal and its determinants in hybrid Populus clones for bioenergy plantations after two biennial rotations in two temperate sites in northern Italy. *iForest* **8**, 668–676.

Szabó, O. 2016. *Nutrient supply with natural materials in short rotation coppice.* Doctoral thesis, University of West–Hungary, Hungary (in Hungarian).

Stefanovits, P., Filep, Gy. & Füleky, Gy. 1996. *Soil Science*. Mezőgazda Kiadó, Budapest, Hungary, 169–187 pp. (in Hungarian).

Vágvölgyi, A., Heil, B. & Kovács, G. 2014a. *Development trends of woody energy plantations in Hungary. Central European Biomass Conference*, Graz, Austria, 149 pp.

Vágvölgyi, A. 2014b. *Woody energy crops development tendencies in Hungary.* Doctoral thesis, University of West–Hungary, Hungary (in Hungarian).

Walle, I.V., Van Camp, N., Van de Casteele, L., Verheyen, K. & Lemeur, R. 2007. Short–rotation forestry of birch, maple, poplar and willow in Flanders (Belgium) I – Biomass production after 4 years of tree growth. *Biomass Bioenergy* **31**, 267–275.

Weitz, M., Klippel, C. & Peschel, T. 2013. Energieholzplantagen. (Germany), Lignovis GmbH, 22–23.