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Economic Modelling of Poplar Short Rotation Coppice Plantations in Hungary

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Abstract: No study has been previously completed on the range of sites, potential yield, and financial characteristics of poplar short rotation coppice plantations (SRC) in Hungary. This paper conducts a literature survey to reveal the biomass production potential of such plantations and presents a model that is used to analyze their financial performance. The results indicate that the break-even-point of production is between 6 and 8 oven-dry tons per hectare per year once a minimum cost level and wood chip price within a 10% range of the 2020 value are considered. The higher the wood chip price, the lower the break-even-point. Since the model excluded the administrative costs that depend on the type and size of the management organization, the break-even-points can be significantly higher in reality, which suggests that short rotation energy plantations can be a financially reasonable land-use option in above average or even superior poplar-growing sites. The rotation period of industrial poplar plantations that produce high quality veneer logs ranges from 12 to 25 years. Though such sites can provide higher returns on investment, short rotation plantations have the advantage of providing a more evenly distributed cash flow. To facilitate the wider application of poplar SRC, the related policies need to apply specific subsidies and allow the rotation cycle to be extended up to 20–25 years, which is currently limited to 15 years.

Keywords: *Populus* sp.; biomass; bioenergy; short rotation woody crops; SRC; financial analysis; break-even-point; net present value

1. Introduction

Short rotation coppice (SRC) is a woody plantation system in which fast-growing tree or shrub species are planted in high density and coppiced in short harvesting cycles (2–8 years) at ground level for a 15–25-year lifecycle. From a management intensity perspective, SRC stands between agricultural crop production and managed forests. The reduction of management intensity originating from converting agricultural land use to SRC cultivation results in additional environmental benefits, especially in soil protection and the enhancement of soil life. These benefits, however, lag the services close-to-nature forests can provide, both in range and magnitude [1,2].

The distinctive characteristic of this type of woody plantation is that under favorable circumstances—including proper site conditions, fast-growing cultivars, and proper technological choices—SRCs can provide high yield in short harvesting cycles and can be maintained for over 20 years depending on their health status [3]. The financial performance of productive plantations is comparable to that of annual crops, which creates opportunity for diversifying farmer income [4]. Furthermore, SRCs have a favorable carbon and energy balance [5], and their products can contribute to available wood supply that might have been reduced by nature conservation measures in close-to-nature forests [6].

However, the above-mentioned ecological and economic benefits can only be realized if SRCs are financially viable. For this reason, financial performance of SRCs should be evaluated under a multifactorial financial environment, which considers the local ecological and financial conditions as determinant factors.

SRC as a land-use option has been thoroughly investigated in recent decades. Numerous international studies have dealt with the economic analysis of SRCs, and the conclusions in these studies highlight the most important aspects and considerations influencing successful SRC application. Biomass yield plays a significant role in generating sufficient revenue. Yield can be increased by selecting superior cultivars [7] and is markedly influenced by plantation site quality [8]. The break-even price of woodchips depends on plantation yield [9] and determines the harvesting cycle [10]. In addition to the natural yield, plantation profitability is particularly influenced by woodchip prices and subsidies [11–15]. Overall, plantation profitability depends both on biomass price and biomass yield [16]. Plantation establishment, maintenance, harvest, and wood transportation costs also affect the financial result. Cultivation costs can contribute 75% to the costs of woodchips at power plants [17,18]. Under less-than-optimal site conditions or less than ideal financial circumstances, alternative methods to increase plantation profitability are available. These include harvesting cycle extension, woodchip drying using waste heat [19], and irrigation and fertilization with wastewater and sewage sludge [20]. The establishment of an SRC system is a long-term investment requiring careful planning based on evaluations of environmental site conditions, financial circumstances (rental costs of land, cash flow, and return), and mathematical models [21,22].

The forest area of Hungary is slightly greater than 2 million hectares [23], which represents a 22.7% forest ratio. Forest stands and plantations consisting of different poplar species (*Populus* sp.) represent a 10.6% share of forested land and an 8.4% share in standing volume [24]. Apart from black locust (*Robinia pseudoacacia* L.), hybrid poplars can be considered as the main species of Hungarian plantation forestry and are cultivated on more than 105 thousand hectares. The number of cultivated hybrid poplar clones exceeds 20, with most belonging to the Euramericana poplar group [*Populus* × *euramericana* (Dode) Guinier]. The current set of cultivated clones in Hungary include many of foreign origin (Italy, Belgium, and the Netherlands), but the Hungarian poplar breeding program has also produced numerous successful clones since its launch following the Second World War. The most frequently used cultivars in afforestations and reforestations in Hungary are I-214, Pannonia, Kopecky, Agathe-F (OP-229), and Koltay.

Hybrid poplar cultivars prefer semi-humid or humid climates combined with loose or medium-hard soils preferably with high humus content, or semi-arid climates with high groundwater levels. Concerning Hungary's ecological conditions, in the absence of available shallow ground water, sites with 600 mm or greater annual precipitation and sandy loam or loamy soils (without any soil failures) can be considered suitable for planting poplar SRCs. Since Hungary is in the xeric limit zone of forests [25], even minor changes in site conditions can result in perceivable wood increment differences; thus, plantations can show these mosaic differences [20].

Hybrid poplar clones are extremely susceptible to weed competition and various damaging agents [26,27], the occurrence and severity of which depend on many factors. Therefore, these are considered risks rather than calculable yield losses or additional costs. Hybrid poplar growth is strongly connected to high precipitation or ground water within reach of the root system. Climate change projections raise concerns of shifting climate zones and the possibility that a large proportion of currently available poplar growing sites will not be suitable for this purpose in the next 50–100 years [28–30]. These prospects are especially worrying since the groundwater level in the Great Plain, which covers approximately two-thirds of the country, is decreasing. Moreover, investigations have not arrived at any clear conclusions concerning the outcome of this change. The interplay between plantations and the changing ground-water-level is also not fully understood [31,32].

Although field experiments of poplar SRCs in Hungary started in the 1980s, their wider utilization began in 2007 following the implementation of an SRC subsidy scheme. This financial support covered establishment costs, which included site preparation, soil fertilization, purchasing/storage of reproductive materials, and planting, as well as initial maintenance, pavement construction, fencing, etc.

Newly bred, fast-growing Italian poplar cultivars (AF-2, Monviso) and well-known forestry cultivars (I-214, Pannonia, Kopecky, Koltay) comprised 55% of the very short rotation plantations. The area of poplar SRC reached a few thousand hectares, but sources recording the actual area contradict each other. This plantation process ceased in 2013 after the subsidy scheme was terminated.

Experiences with poplar SRCs reveal some of the systematic weaknesses of this land-use form. Plantation yield did not meet expectations. Moreover, harvesting services were difficult to reach and turned out to be expensive due to the small scale of the plantations. Expectations on wood chip demand and calculations on transportation costs were overly optimistic. Many poplar SRCs became unprofitable despite the above-mentioned subsidy scheme. These widespread failures triggered the need for deeper financial analysis in this field.

The current study aims to survey the range of natural yields of poplar SRCs in Hungary that are based on sound evidence, to construct realistic and efficient model-technologies that can be applied in various poplar-growing sites, and to evaluate the financial performance of poplar SRCs.

2. Materials and Methods

2.1. Data Sources

Scientific and other literature from 1996 to 2018 have been used to survey the various combinations of sites, cultivars, and technologies [33–37]. In addition to these data sources, unpublished results of the authors' own field experiments have also been utilized.

Financial data were collected from various sources, as no single source provided all the necessary items. The National Land Centre in Hungary operates a statistical program that collects the contractor fees of various forestry-related operations, as well as the prices of wood products and other forest products such as propagation materials [38]. Items that were not included in this source were collected through oral interviews with producers [39].

2.2. Technology

The current paper defines plantation management technology as both the major characteristics of the plantation, such as the poplar cultivar, spacing, rotation cycle, and lifecycle, as well as the series of operations from establishment through maintenance and periodic harvests to liquidation. Good technology choices will result in a near-optimal use of the site potential, which is reflected in the financial results of production. However, such optimization is greatly limited in practice. For instance, weather conditions during the short production period can diverge significantly from predictions, which affects growth rate, health status, weed control, nutrient supply, etc. Available machinery may also determine spacing, maximum dimension of the trees, and harvesting methods.

The model applied in this study is designed to reflect the most typical spacing, life-cycle, and rotation cycle of poplar plantations in Hungary. Moreover, it only contains the minimum number of operations. The model is divided into three yield-categories representing the full spectrum of poplar-sites that have been recorded in the literature.

The model includes three yield categories: high yield, average yield, and low yield with 12 t_{OD}/ha/year, 8 t_{OD}/ha/year, and 4 t_{OD}/ha/year nominal growth rates, respectively. Nominal growth rate refers to the mean growth rate in the first two rotations combined. Growth rates in the various rotation periods are calculated with the nominal growth rate and the modification factor presented in Table 1.

Table 1. Modification factors of nominal growth rate over the rotation periods of poplar Short Rotation Coppices (SRC) in this study.

Rotation Period	1	2	3	4	5
Growth rate modification factor	100%	100%	95%	90%	85%

Due to legal restrictions, plantation lifecycles are limited to 15 years in all three models. The high yield and average yield categories have three-year rotation cycles, while in the low yield category has a four-year cycle. This differentiation is justified by the fact that a lower growth rate allows for a longer growth period before the growing space is fully used up and the increasing competition induces significant mortality.

Establishing the plantation includes planning, soil preparation, and planting. Planning is based on site inspection and the plan is submitted to the Forest Authority for approval. Soil preparation depends on the current state of the specific land lot. In the case of poplar, it is essential to provide well-cultivated, loose soil for maximum growth. The model assumes that one ploughing and one disking before planting is sufficient. In total, 5556 poplar cuttings were planted with 3.0 × 0.6 m spacing. The above characteristics of plantation establishment is uniformly applied in all three yield categories.

Harvesting takes place according to the rotation cycle. Harvesting, chipping, storage, and transportation methods may vary in practice, and they are not specified in the model, as we only need to assume that the same methods apply to the three yield categories. The harvest costs are calculated on an oven-dry matter basis, and the unit cost depends on the harvested amount per hectare. The harvest-fee of an oven-dry ton is smaller in the higher yield scenario than it is in the average and low yield categories.

Harvest was followed by plantation maintenance, which includes weed control, plant protection, and nutrient recycling into the soil. Unless applied preventively, plant protection is not a periodic activity; however, since the need for it cannot be predicted, it is incorporated into the model as such.

Under excellent site conditions, the plantation can provide high yield, which implies that precipitation or ground water provide sufficient amounts of water and that there is no nutrient shortage in the soil. To fulfill the latter condition, the model includes nutrient recycling at a rate of 150 kg/ha after each harvest. Soil fertilization is decreased in the average yield category and is not applied in the low yield category because under less favorable conditions, available water poses a stronger limitation than nutrient supply. Therefore, nutrient recycle would not increase the growth rate.

Overhead costs, especially business administration expenses, depend largely on the type and scale of the organization at hand. Since it is not within the focus area of this study, these costs are excluded from the calculations. Only two overhead cost items are considered, both of which are essential regardless of the scale and legal form of the operation. One of these is the cost of a technical advisor, which is constant in all three categories. Another is the land rental fee, which represents site quality. Better site conditions entail higher land rental fees since the growth potential of the site correlates to its humus content. Higher humus content is also an advantage in agriculture.

At the end of the lifecycle, the plantation needs to be liquidated according to legal regulations. This includes the removal or grinding of stumps and roots.

2.3. Financial Evaluation

This paper applies four indicators to describe and compare the financial performance of the yield categories in the model. The cash flow of the three yield categories can be calculated based on the land management operations in the model and their unit costs.

The mean annual net income (MANI) is the quotient of the total net income and the lifecycle of the investment. The total net income of the investment is the cash flow sum. Net present value (NPV) is applied to describe the absolute financial value of the plantation as an investment at the time of its establishment. Annuity (A) is used to represent a theoretical series of constant annual income for the life period of the investment that could replace the actual cash flow without changing its NPV. Internal rate of return (IRR) is the interest rate at which the NPV of the investment is zero. The equations of these financial parameters are as follows:

$$\text{MANI} = \frac{\sum_{i=0}^{n} CF_i}{n} \tag{1}$$

$$\text{NPV} = \sum_{i=0}^{n} \frac{CF_i}{(1+p)^i} \tag{2}$$

$$\text{A} = \text{NPV} \frac{p * (1+p)^n}{(1+p)^n - 1} \tag{3}$$

$$\text{NPV} = 0 = \sum_{i=0}^{n} \frac{CF_i}{(1+IRR)^i} \tag{4}$$

where i is years, n is lifecycle of investment, p is interest rate, CF_i is total cash flow in year i, MANI is Mean Annual Net Income, NPV is Net Present Value, A is annuity of the Net Present Value, and IRR is internal rate of return.

3. Results

3.1. Growth Rate of Poplar SRCs

To evaluate biomass yield levels that can be considered typical under Hungarian ecological circumstances, biomass yield data were collected from articles and other scientific works. The data sources and the parameters of the experiments are summarized and referenced in Table 2.

The cited experimental plantations represent all major geographical regions (Great Plain, Transdanubia, and Northern Hungary) and cover the range of sites suitable for poplar growing in the country. The most frequently used poplar clones were AF-2, Agathe-F, I-214, and Pannónia. Most of the sites have a sand soil texture, but loamy sites can also be found (Hanságliget and Bajti). Three sites (Dejtár, Karancslapujtő, Tiszakécske) are characterized by seasonal natural additional water supplementation, which in the site classification terminology in Hungary means that groundwater in springs is no deeper than 1.5 m, implying that it remains accessible to tree roots during most of the growing season. No irrigation was reported at any site. Soil fertilization was applied in two cases; in Dejtár the experiment focused on the effects of manure fertilization and combined manure and ash fertilization compared to no fertilization. The planting densities and spacing show great variations: the highest planting density was 13,333 pieces per hectare (1.5 × 0.5 m spacing), while the lowest was 2500 trees per hectare (2.0 × 2.0 m spacing); both were used in Hanságliget where the primary aim of the experiment was to study the effects of spacing on growth. The plantations were harvested in different rotation periods between 2 and 8 years. The Helvécia, Karancslapujtő, and Tiszakécske experiments were dedicated to investigating optimal harvesting cycles.

In addition to data gained from the literature, biomass yields measured in an experimental plantation in Bajti Nursery, located next to Sárvár, in Western Transdanubia, were used for evaluation as well. The experimental short-rotation plantation was planted in 2007 using a randomized block design, three repetitions, and a planting density of 8333 tree/hectare (3.0 m between the rows and 0.4 m in the rows). In addition to black locust and willow cultivars, 59 different poplar clones were planted in single-row parcels, with 100 cuttings per row. The soil type of the garden is loamy forest soil on alluvial subsoil with low humus content. The second and the third repetitions were harvested after the first vegetation period. Following the second vegetation period, the third repetition was harvested again. As a result, the plantation had 1-, 2-, and 3-year-old shoots after the third year. Only the 3-year-old shoots (repetition) were harvested after the third vegetation period. The biomass yield of most of the clones was measured each year after harvesting.

Based on the results of the literature survey, the lowest measured yield in Hungary was 0.8 t_{OD}/ha/year, while the highest was 14.1 t_{OD}/ha/year. Though other sources [40] from similar bio-geographic conditions suggest that even higher yields could have been achieved, we accept the results above for the case of Hungary.

Table 2. The summary of experimental poplar SRCs used in this study.

Sources	Cultivars	Soil Texture	Add.Water Suppl.	Nutrition Supplement	Spacing (m × m)	Planting Density (Stems/ha)	Rotation Length (Year)	Yield (t_OD/ha/Year)	Location
[33]	n.d.	n.d.	n.d.	n.d.	3.0 × 0.5	6667	2	12.0 *	Szakoly **
[34]	AF-2	Sand	Seasonal	Manure	3.0 × 1.0	3333	6	13.1	Dejtár
[35]	AF-2	Sand	Seasonal	Manure, wood ash	3.0 × 1.0	3333	2	6.6–8.2	Dejtár
[36]	Pannónia	n.d.	Seasonal	n.d.	1.5 × 1.0 2.0 × 1.0 2.0 × 1.5 2.0 × 3.0	6667 5000 3333 1667	3, 7, 8 3, 7, 8 3, 7 3, 7, 8	1.7–9.1 0.9–7.4 0.8–7.9 1.5–7.0	Karancslapujtő
	Agathe-F	Sand	No	n.d.	1.5 × 0.5 1.5 × 1.0 1.5 × 2.0	13,333 6667 3333	4, 5, 8 4, 5, 8 4, 5, 8	2.4–6.3 1.8–5.5 1.6–6.4	Helvécia
	BL Constanzo I-214 Pannónia Agathe-F S-298-8	Sand	No	n.d.	1.5 × 1.0 1.5 × 1.0 1.5 × 1.0 1.5 × 1.0 1.5 × 1.0	6667 6667 6667 6667 6667	3, 4, 5, 8 3, 4, 5, 8 3, 4, 5, 8 3, 4, 5, 8 3, 4, 5, 8	2.2–5.9 1.8–3.2 4.1–6.1 3.2–6.2 1.7–3.5	Helvécia
	H-328 Kornik-21 S-298-8	Sand	Seasonal	n.d.	1.5 × 1.0 1.5 × 1.0 1.5 × 1.0	6667 6667 6667	5, 6, 7, 8 5, 6 5, 6	6.7–7.2 7.3–8.1 7.4–8.5	Tiszakécske
[37]	I-214	Loam	No	n.d.	1.5 × 0.5 1.0 × 1.0 2.0 × 2.0	13,333 10,000 2500	4 4 4	11.5 9.6 7.5	Hanságliget
	Agathe-F				1.5 × 0.5 1.0 × 1.0 2.0 × 2.0	13,333 10,000 2500	4 4 4	14.1 12.9 12.3	
	I 45/51				1.5 × 0.5 1.0 × 1.0 2.0 × 2.0	13,333 10,000 2500	4 4 4	11.6 8.7 6.0	
	Blanc du Poitou				1.5 × 0.5 1.0 × 1.0 2.0 × 2.0	13,333 10,000 2500	4 4 4	9.4 9.8 6.9	
****	Koltay I-214 Pannónia	Loam	No	No	3.0 × 0.4	8333	3	8.0 *** 5.9 *** 5.2 ***	Bajti (Sárvár)

* Calculated from fresh biomass weight, using an average water content of 55%. ** The original locations are unpublished. The most probable nearest location is shown. *** Average annual yield measured between 2011 and 2015. **** unpublished.

Three yield categories were created for further modelling:

- Low yield category: below 6 t_{OD}/ha/year;
- Average yield category: 6 t_{OD}/ha/year and above but less than 10 t_{OD}/ha/year;
- High yield category: 10 t_{OD}/ha/year and above.

3.2. Financial Model

The costs of the three yield categories of poplar SRCs are presented in Table 3. The establishment and liquidation of the plantation have the exact same costs in all categories, as site quality or the yield of the plantation have no influence on these operations. The maintenance costs decrease from high yield to low yield, while the harvesting costs per oven-dry matter increase in the same direction. Overhead costs also decrease toward lower yield categories due to the decreasing land rental fees.

Table 3. Financial model of poplar SRCs in three yield categories applied in this study [38,39].

Costs	Unit	High Yield	Average Yield	Low Yield
Total establishment costs		**726.3**	**726.3**	**726.3**
Site inspection		42.9	42.9	42.9
Planning	€/ha	42.9	42.9	42.9
Soil preparation		128.6	128.6	128.6
Propagation material		256.0	256.0	256.0
Planting		256.0	256.0	256.0
Total maintenance costs		**242.9**	**185.7**	**128.6**
Weed control		100.0	100.0	100.0
Plant protection	€/ha	28.6	28.6	28.6
Nutrient supply		114.3	57.1	0.0
Total harvesting costs		**11.4**	**14.3**	**17.1**
Cutting	€/t_{OD}	5.7	8.6	11.4
Transporting		5.7	5.7	5.7
Liquidation costs	€/ha	**257.1**	**257.1**	**257.1**
Total overhead costs		**200.0**	**171.4**	**142.9**
Rental fee	€/ha	171.4	142.9	114.3
Technical advisor		28.6	28.6	28.6

Bold rows represent cost-type-groups, which are the sum of the cost items below.

Ranging from 43.5% to 51.3%, overhead costs have the largest share in the total costs over the lifecycle of the poplar SRCs. Harvesting and transportation costs are the second largest contributors to total costs, and their share ranges between 24.0% and 26.4%. There is a larger difference in the maintenance cost distribution, as it decreases from 16.6% in the high yield category to 2.6% in the low yield category. Although the establishment and liquidation costs are the same in all yield categories, they play a less important role in the high yield category with only a 13.4% share compared to the 22.1% share in the low yield category. Table 4 summarizes the data above.

Table 4. The share of cost types within the total costs of the poplar SRCs yield categories in this study.

Yield Categories	Establishment and Liquidation	Harvesting and Transportation	Maintenance	Overheads	Total Costs
High yield	13.4%	26.4%	16.6%	43.6%	100%
Average yield	15.6%	26.1%	14.7%	43.5%	100%
Low yield	22.1%	24.0%	2.6%	51.3%	100%

The cash flow balance of each yield category is calculated every year and presented in Table 5. In all cases, the price of the wood chips delivered to the place of use is 60.0 €/t_{OD}. The MANI of the low yield category is −77.0 €/ha/year, which means that even if the

overhead costs are not entirely incorporated into the model, the cash flow balance over the lifecycle of the plantation is negative. As a result of this, there is no reason to consider the remaining financial parameters for this category. The average yield and high yield categories provide 44.9 €/ha/year and 201.4 €/ha/year MANI, respectively.

Table 5. The cash flow and the financial parameters of the poplar SRC yield categories in this study.

Parameters		Unit	High Yield	Average Yield	Low Yield
Reference yield		t_{OD}/ha/year	12	8	4
Rotation cycle		y	3	3	4
Interest rate		%		3.0	
Price of wood chips		€/t_{OD}		60.0	
Cash Flow	year 0	€/ha	−726.3	−726.3	−726.3
	year 1		−442.9	−357.1	−271.4
	year 2		−200.0	−171.4	−142.9
	year 3		1548.6	925.7	−142.9
	year 4		−442.9	−357.1	542.9
	year 5		−200.0	−171.4	−271.4
	year 6		1548.6	925.7	−142.9
	year 7		−442.9	−357.1	−142.9
	year 8		−200.0	−171.4	542.9
	year 9		1461.1	870.9	−271.4
	year 10		−442.9	−357.1	−142.9
	year 11		−200.0	−171.4	−142.9
	year 12		1373.7	816.0	508.6
	year 13		−442.9	−357.1	−271.4
	year 14		−200.0	−171.4	−142.9
	year 15		1029.1	504.0	62.9
Total Lifecycle Income		€/ha	10,152.0	6768.0	3480.0
Total Lifecycle Cost		€/ha	7131.4	6094.9	4634.9
Lifecycle Cash Flow Balance		€/ha	3020.6	673.1	−1154.9
Mean Annual Net Income (MANI)		€/ha/y	201.4	44.9	−77.0
Net Present Value (NPV)		€/ha	2238.9	314.0	−1114.0
Annuity (A)		€/ha/y	187.5	26.3	−93.3
Internal Rate of Return (IRR)		%	21.6	6.8	*

* Not calculable.

For the calculation of NPV, A, and IRR, a 3.0% reference net interest rate was applied, which is understood as an interest rate above inflation. The NPV of the high yield category is 2238.9 €/ha, which equals 187.5 €/ha/year annuity and 21.6% IRR. Average yield category provides 314.0 €/ha NPV, 26.3 €/ha/year annuity, and 6.8% IRR.

Although the cost structure in this calculation is incomplete, the break-even-point (BEP) can be calculated as identifying yield-price combinations that provide zero (or near zero) MANI. Tables 6 and 7 show the result of this calculation with constant cost structure both with and without a 75% plantation establishment subsidy, respectively.

Table 6. The MANI of poplar SRCs by yield and the price of the wood chips in this study (break-even-points marked with grey background).

Price (€/t_{OD})	Yield (t_{OD}/ha/Year)										
	Low Yield			Average Yield				High Yield			
	3	4	5	6	7	8	9	10	11	12	13
54	−135.8	−100.2	−64.6	−74.9	−37.6	−0.2	37.1	53.7	93.7	133.7	173.7
57	−127.1	−88.6	−50.1	−58.0	−17.8	22.3	62.5	81.9	124.7	167.5	210.4
60	−118.4	−77.0	−35.6	−41.1	1.9	44.9	87.8	110.1	155.7	201.4	247.0
63	−109.7	−65.4	−21.1	−24.1	21.6	67.4	113.2	138.3	186.7	235.2	283.7
66	−101.0	−53.8	−6.6	−7.2	41.4	90.0	138.6	166.5	217.8	269.1	320.3

Table 7. The MANI of poplar SRCs by yield and the price of the wood chips in this study (break-even-points marked with grey background) with 75% establishment subsidy.

Price (€/t$_{OD}$)	Yield (t$_{OD}$/ha/year)										
	Low Yield			Average Yield				High Yield			
	3	4	5	6	7	8	9	10	11	12	13
54	−99.5	−63.9	−28.2	−38.6	−1.3	36.1	73.4	90.0	130.0	170.0	210.0
57	−90.8	−52.3	−13.7	−21.7	18.5	58.6	98.8	118.2	161.0	203.8	246.7
60	−82.1	−40.7	0.8	−4.8	38.2	81.2	124.2	146.4	192.0	237.7	283.3
63	−73.4	−29.1	15.3	12.2	58.0	103.8	149.5	174.6	223.0	271.5	320.0
66	−64.7	−17.5	29.8	29.1	77.7	126.3	174.9	202.8	254.1	305.4	356.7

4. Discussion

SRCs have been on the agenda for decades. Biomass, and especially woody biomass, is a renewable resource that can provide a positive energy balance and a low carbon output. Furthermore, it can be produced and used locally, thereby avoiding the negative effects of long transport distances. It is also available on a scale that is sufficient to make a meaningful contribution to the total energy supply. From a producer perspective, this land utilization form is intended to be flexible in terms of converting arable lands and plantations back and forth according to the producer needs and market demands. Furthermore, it is intended to be suitable for low quality land that would not be utilized otherwise.

Despite the long history of such plantations, Hungary lacks well-recorded field experiments that would cover various combinations of sites and technologies for the whole lifecycle. It must be noted that a short rotation period makes the growth rate highly dependent on weather variables; therefore, experiments on the same site can show significantly varying results over different periods of time.

The profitability of poplar SRCs is highly dependent on subsidies. The availability and conditions of such financial sources change frequently in Hungary; however, there are three basic types: an establishment subsidy paid by area at a fixed rate; the EU Single Area Payments Scheme (SAPS); and the subsidies for energy producers paid by the volume of production. SAPS plays the most important role, as it is comparable to the overhead costs applied in the model, namely the land rental fee and the technical advisor cost. Since this subsidy is available in almost all forms of agricultural land-use, including the no-use option, it is a neutral factor in land utilization decisions. The subsidies on the energy producer side influence the purchase price of the wood chips; thus, there is no need to incorporate these into the model separately.

The financial analysis of a specific SRC investment must consider actual conditions including the site conditions; suitable poplar cultivars; available propagation material; machinery, especially harvesting machines; storage needs; transportation methods and distances; and potential buyer requirements such as delivery frequency, moisture content, chip size, quality, etc. These factors may greatly influence the financial results and the investment decision. The currently applied agro-technology at a specific farm may be suitable for SRC cultivation, and it is also possible that the wood chips produced could be utilized within the farm. In the latter case, the substitution of other energy sources on the farm can bring additional benefits. On the other hand, the technology applied in this calculation may not be feasible in some areas due to lack of harvesting capacity or due to the small scale of a specific SRC. In such cases, the production costs would be significantly higher.

Specific environmental conditions can dramatically influence SRC yield, even under optimal management decisions. For instance, water supply can greatly affect the growth rate. The site analysis and the subsequent poplar cultivar selection is based on long-term climatic data, while the weather during the production period may vary and significantly deviate from long-term observations.

All these individual circumstances influence the investment decision and shed a different light on the potential role of SRC as a land management option at a regional or

national level. This financial analysis was conducted to evaluate the financial performance of poplar SRCs under a common framework incorporating best practices.

Site quality has a moderate influence on the cost structure. Establishment and liquidation costs are the same in each yield category; maintenance costs decrease, while harvesting costs slightly increase as they move from the high yield category to the low yield category. The total lifecycle cost in the high yield category is 7131.4 €/ha, which drops to 4634.9 €/ha for the low yield category, signifying a 35% cost decrease. The yield, however, has a great impact on the total lifecycle income, which drops from 10,152.0 €/ha in the high yield category to 3480.0 €/ha in the low yield category, for a decrease of 65.7%. According to the financial model, it can be concluded that the lower yield of low-quality sites and the lower income is not compensated by lower costs.

The results show that poplar SRCs reach the BEP at approximately 7 t_{OD}/ha/year under current financial conditions and the presented cost structure. Since the cost structure in the model excludes substantial cost items such as business administration, infrastructure maintenance, etc., the real BEP is assumed to be significantly higher. This means that plantations on lower-average and low-quality sites are not financially viable without subsidies. In the case of a 75% establishment subsidy, BEP is approximately 5 to 6 t_{OD}/ha/year.

It is evident that the subsidy system influences the financial performance of short rotation poplar plantations considerably. Alternative land-use forms compete for land. In the European Union, agricultural policy is one of the highest priorities and is empowered by a massive subsidy system. In Hungary, the proportion of direct subsidies in traditional agricultural crop production is above 60% [41] (p. 39). Land-use forms also include wilderness, sanctuaries, and many other areas for nature conservation and recreational purposes, which further increases land-use competition, especially on low-quality lands where poplar SRCs were primarily meant to be grown.

This result also challenges the former claim that poplar SRCs would be suitable for the utilization of low-quality land. It reflects the fact that poplar hybrids are capable of high-rate biomass production, but are susceptible to natural conditions, especially to temperature and water supply, the latter of which is a more critical limiting factor in Hungary. However, higher-average and high-quality poplar growing sites are more suitable for industrial wood production, where the main product is veneer log coupled with pulp wood and wood chips as side products. Such industrial wood plantations have a 12–25-year lifecycle, which is comparable to that of short rotation plantations.

One of the most important comparative advantages of SRC is that its production technology is less sophisticated, and fewer operations are needed; therefore, less experienced farmers can manage them. Since quality requirements in wood chip production do not play a major role, technological failures or damage from natural disasters or damaging agents do not result in significant income loss. The shorter rotation period also decreases the risk of damage and provides a more balanced income-flow.

Due to legal restrictions, the plantation lifecycle in our model is 15 years. Extending the lifecycle with a few more rotations to 20–25 years could increase the net income and, consequently, the return on investment. Nevertheless, this is severely limited by the gradual decrease of yield over time and depends on the health condition of the individual plantation.

This paper concluded that short rotation poplar plantations in Hungary have an approximate BEP of 7 t_{OD}/ha/year, which is only possible in above average, good quality poplar sites in which veneer production is also an option. Subsidies and extended rotation periods could lower BEP significantly, but both would also require changes in the current related policies.

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References

1. Aylott, M.J.; Casella, E.; Tubby, I.; Street, N.R.; Smith, P.; Taylor, G. Yield and spatial supply of bioenergy poplar and willow short-rotation coppice in the UK. *New Phytol.* **2008**, *178*, 897. [CrossRef]
2. Vanbeveren, S.P.; Ceulemans, R. Biodiversity in short-rotation coppice. *Renew. Sustain. Energy Rev.* **2019**, *111*, 34–43. [CrossRef]
3. Štochlová, P.; Novotná, K.; Costa, M.; Rodrigues, A. Biomass production of poplar short rotation coppice over five and six rotations and its aptitude as a fuel. *Biomass Bioenergy* **2019**, *122*, 183–192. [CrossRef]
4. Busch, G. A spatial explicit scenario method to support participative regional land-use decisions regarding economic and ecological options of short rotation coppice (SRC) for renewable energy production on arable land: Case study application for the Göttingen dist. *Energy. Sustain. Soc.* **2017**, *7*, 372. [CrossRef]
5. McKenney, D.W.; Yemshanov, D.; Fox, G.; Ramlal, E. Cost estimates for carbon sequestration from fast growing poplar plantations in Canada. *For. Policy Econ.* **2004**, *6*, 345–358. [CrossRef]
6. Updegraff, K.; Baughman, M.J.; Taff, S.J. Environmental benefits of cropland conversion to hybrid poplar: Economic and policy considerations. *Biomass Bioenergy* **2004**, *27*, 411–428. [CrossRef]
7. Ceulemans, R.; Deraedt, W. Production physiology and growth potential of poplars under short-rotation forestry culture. *For. Ecol. Manag.* **1999**, *121*, 9–23. [CrossRef]
8. Faasch, R.J.; Patenaude, G. The economics of short rotation coppice in Germany. *Biomass Bioenergy* **2012**, *45*, 27–40. [CrossRef]
9. Miller, R.O. Financial modeling of short rotation poplar plantations in michigan, USA. *Conf. Short Rotat. Woody Crop. Oper. Work. Gr.* **2016**, *2016*, 1–12.
10. Christersson, L. Poplar plantations for paper and energy in the south of Sweden. *Biomass Bioenergy* **2008**, *32*, 997–1000. [CrossRef]
11. Manzone, M.; Airoldi, G.; Balsari, P. Energetic and economic evaluation of a poplar cultivation for the biomass production in Italy. *Biomass Bioenergy* **2009**, *33*, 1258–1264. [CrossRef]
12. Manzone, M.; Bergante, S.; Facciotto, G. Energy and economic evaluation of a poplar plantation for woodchips production in Italy. *Biomass Bioenergy* **2014**, *60*, 164–170. [CrossRef]
13. El Kasmioui, O.; Ceulemans, R. Financial analysis of the cultivation of poplar and willow for bioenergy. *Biomass Bioenergy* **2012**, *43*, 52–64. [CrossRef]
14. El Kasmioui, O.; Ceulemans, R. Financial Analysis of the Cultivation of Short Rotation Woody Crops for Bioenergy in Belgium: Barriers and Opportunities. *Bioenergy Res.* **2013**, *6*, 336–350. [CrossRef]
15. Mitchell, C.P.; Stevens, E.A.; Watters, M.P. Short-rotation forestry-Operations, productivity and costs based on experience gained in the UK. *For. Ecol. Manag.* **1999**, *121*, 123–136. [CrossRef]
16. Hauk, S.; Knoke, T.; Wittkopf, S. Economic evaluation of short rotation coppice systems for energy from biomass-A review. *Renew. Sustain. Energy Rev.* **2014**, *29*, 435–448. [CrossRef]
17. Gasol, C.M.; Martínez, S.; Rigola, M.; Rieradevall, J.; Anton, A.; Carrasco, J.; Ciria, P.; Gabarrell, X. Feasibility assessment of poplar bioenergy systems in the Southern Europe. *Renew. Sustain. Energy Rev.* **2009**, *13*, 801–812. [CrossRef]
18. Allen, D.; McKenney, D.W.; Yemshanov, D.; Fraleigh, S. The economic attractiveness of Short Rotation Coppice biomass plantations for bioenergy in Northern Ontario. *For. Chron.* **2013**, *89*, 66–78. [CrossRef]
19. Schweier, J.; Becker, G. Economics of poplar short rotation coppice plantations on marginal land in Germany. *Biomass Bioenergy* **2013**, *59*, 494–502. [CrossRef]
20. Csiha, I.; Rásó, J.; Keserű, Z.; Kamandiné Végh, Á.; Kovács, C. A termőhelyi változások hatása a nemesnyár klónok produktumára. In Proceedings of the Alföldi Erdőkért Egyesület Kutatói Nap, Püspökladány, Hungary, 9 November 2012; Volume 1, pp. 19–27.
21. San Miguel, G.; Corona, B.; Ruiz, D.; Landholm, D.; Laina, R.; Tolosana, E.; Sixto, H.; Cañellas, I. Environmental, energy and economic analysis of a biomass supply chain based on a poplar short rotation coppice in Spain. *J. Clean. Prod.* **2015**, *94*, 93–101. [CrossRef]
22. Wolbert-Haverkamp, M.; Musshoff, O. Is short rotation coppice economically interesting? An application to Germany. *Agrofor. Syst.* **2014**, *88*, 413–426. [CrossRef]
23. UN FAO. *Global Forest Resources Assessment 2020 Report Hungary*; UN FAO: Rome, Italy, 2020.
24. National Food Chain Safety Office. *Forest Resources and Forest Management in Hungary 2015*; National Food Chain Safety Office: Budapest, Hungary, 2016.
25. Mátyás, C. Forecasts needed for retreating forests. *Nature* **2010**, *464*, 1271. [CrossRef] [PubMed]
26. Hirka, A.; Csóka, G.; Koltay, A.; Janik, G. A nyárak és füzek biotikus és abiotikus kárai. *Erdészeti Kut.* **2008**, *93*, 258–280.
27. Koltay, A. Az energetikai faültetvények növényvédelmi vonatkozásai. *Mezőgazdasági Tech.* **2010**, *51*, 66.

28. Führer, E. A klímaértékelés erdészeti vonatkozásai. *Erdészettudományi Közlemények* **2018**, *8*, 27–42. [CrossRef]

29. Führer, E.; László, H.; Anikó, J.; Machon, A.; Ildikó, S. Application of a new aridity index in Hungarian forestry practice. *Időjrás* **2011**, *115*, 205–216.

30. Gálos, B.; Ernő, F. A klíma erdészeti célú előrevetítése. *Erdészettudományi Közlemények* **2018**, *8*, 43–55. [CrossRef]

31. Norbert, M.; Tibor, T.; Kitti, B.; András, S.; Ervin, R.; Zoltán, G. Groundwater uptake of forest and agricultural land covers in regions of recharge and discharge. *iForest* **2016**, *9*, 696–701.

32. András, S.; Zoltán, G.; Tibor, T. Erdők hatása a talaj és altalaj sóforgalmára, valamint a talajvíz szintjére. *Agrokémia és Talajt.* **2012**, *61*, 195–209.

33. Szajkó, G.; Mezősi, A.; Pató, Z.; Orsolya, S.; Sugár, A.; András Istvá, T. *Erdészeti és Ültetvény Eredetű fás Szárú Energetikai Biomassza Magyarországon*; Regionális Energiagazdasági Kutatóközpont: Budapest, Hungary, 2009.

34. Heilig, D.; Heil, B.; Kovács, G. A növőtér-szabályozás hatása fás szárú nemesnyár ültetvény dendromassza-hozamára. *Erdészettudományi Közlemények* **2018**, *8*, 51–59. [CrossRef]

35. Kondor, A. A Földhasználat Átalakításának Lehetősége az Energiafűz (*Salix viminalis* L.) Termesztésbe Vonásával SZABOLCS-Szatmár-Bereg Megyében. Ph.D Thesis, Debreceni Egyetem, Debrecen, Hungary, 2015.

36. Marosvölgyi, B.; Halupa, L.; Wesztergom, I. Poplars as biological energy sources in Hungary. *Biomass Bioenergy* **1999**, *16*, 245–247. [CrossRef]

37. Szendrödi, L.B. Growing space-age related three-dimensional modeling of biomass production of hybrid poplar. *Biomass Bioenergy* **1996**, *10*, 251–259. [CrossRef]

38. Agrárminisztérium. Erdészeti Árstatisztikák. Available online: https://agrarstatisztika.kormany.hu/erdogazdalkodas2 (accessed on 20 October 2020).

39. Vass, J.; (Celldömölk, Hungary); Falvay, S.; (Szigetszentmiklós, Hungary); Hegedűs, A.; (Mogyoróska, Hungary); Barkóczy, Z.; (Sopron, Hungary). Personal communication, 2020.

40. Posavec, S.; Kajba, D.; Beljan, K.; Boric, D. Economic analysis of short rotation coppice investment. *Austrian J. For. Sci.* **2017**, *134*, 163–176.

41. Keszthelyi, S.; Kiss Csatári, E. *A Tesztüzemi Információs Rendszer Eredményei 2018*; Nemzeti Agrárkutatási és Innovációs Központ: Budapest, Hungary, 2020.