Economic assessment of forest plantations with short rotation: Russia and Serbia experience

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Abstract. The article presents the economic aspects of growing poplar on plantations in Russia and Serbia. For Russia, the cultivation of poplar on forest plantations with a short turnaround is a promising activity which enables to get NPV 7 202 €/ha, taking into account the risks of forest plantations. In the creation of plantation crops the fundamental role is played by their density. To get timber the density of plantation should be from 3.0 to 5.0 thousand plants per 1 ha. Plantations with a 20-year rotation and planting density of 3.0 thousand plants per 1 ha are the most profitable and less risky ones. Similar results have been obtained on poplar plantations in Serbia. NPV revenues are in a range 11 088 to 13 676 €/ha when growing poplar plantations in Serbia. It is advisable to get not only industrial wood chips, but also wood assortment during the cultivation of poplar plantations with 20-year rotation in the conditions of Serbia. Positive financial effect can be reached in future by lowering the costs of poplar plantations establishing. Costs can be also reduced by finding out the solution in the field of soil preparation for afforestation, working operations which will show the higher level of economic efficient.

1. Introduction

Forest business is quite widespread in Europe and Russia, as forest resources satisfy multiple economic needs. Sustainable forest management (SFM) is a concept in continuous development, the interpretation of which varies over time, as well as among countries, regions and even local landscapes in Europe [1].

In recent years, in the works of researchers, the development of forest business through the cultivation of forest plantations, of various types, is given great attention. There is great potential for increased output since only one-tenth of potentially arable land is cultivated [2].

The importance of growing energy forest plantations is noted in the work [3]. Within the international community there is considerable interest in the socio-economic implications of moving society towards the more widespread use of renewable energy resources [4].

In the study by Thomberlin, D. & J. Buongiorno, the cultivation of forest on plantations with short rotation is suitable for the production of paper and cardboard, wood-flakes, veneer, plywood, wood chips [5].
Forest plantations in Africa are mainly used for the production of charcoal [6].

In many tropical and temperate countries, wood production is now largely plantation-oriented (according to FAO, 95 per cent of all forest products are harvested in Chile, 93 per cent in New Zealand, 60 per cent in Brazil and Argentina, 50 per cent in Zambia and Zimbabwe) [7].

The Finnish nature centre Haltia and Keipi made calculations, according to which the cultivation of forest plantations of eucalyptus globulus and *Pinus radiata* in Chile was more lucrative than breeding cattle, and ranged from 2-20% [8].

Forestry plantations in South America are strongly supported. The economic benefits of forest plantations in these countries are associated with the ability to increase forest productivity and reduce the age of wood cultivation, through intensive methods of forest cultivation and use of introduced species. In conditions of increasing wood consumption and demand in the world, the aim of the majority of national economies is to intensify local resource production. Due to the fact that poplar rotation is one of the shortest in forestry, and as production of poplar wood requires rational and well-planned management, the potentials of sites and species must be maximally used [9].

In 1999, the Australian Bureau of Agricultural and Resource Economics published a report entitled "Global outlook for plantations", authored by Pöyry [10].

In 2000, forest plantations accounted for 3 per cent of the total forest area, but by 2005, forest plantations accounted for 7 per cent of the world's total forest area, or about 271 million hectares, and accounted for up to 35 per cent of the world's roundwood [11].

The short cutting age, the uniformity of the obtained wood grades, the ability to create and maintain an efficient transport infrastructure due to the fast payback - all this reduces the costs of wood production plantation and increases the efficiency of management [12]. At the same time, the priority for the forest business in plantation cultivation is not technical, but economic indicators [13]. For example, conventional poplar growing in Serbia is characterized by high costs of plantation establishment, as it is common to use the technology of full ground and soil preparation with a lot of working operations [14].

A number of researchers (Beattie, Nery) have noted the key role of government support for the private sector in the development of forest plantations and called these measures contributing to a favorable economic environment of the country as a whole [15,16].

In 2000, C. Brown conducted an extensive study to assess the current state and forecast the development of forest plantations in three scenarios until 2050 [17].

The work analyzed economic and political issues related to the creation and development of forest plantations, the forecast of demand and supply for wood, including the one harvested on forest plantations.

The study predicted an increase in the volume of industrial timber harvested on forest plantations in the range of 19.7-29.6% to 48.4-64.0% (depending on the scenario) of the global volume of timber harvesting.

In 2008, Carle and colleagues published the forecast of the volumes of timber harvesting and forest plantation. According to the scenarios, the volume of harvested wood on industrial plantations will increase to 1 897 million m$^3$ by 2030 (depending on the scenario). Industrial timber will account for 85% of the total timber harvested in forest plantations [18].

In 2014, a study was published under the auspices of the United Nations FAO to collect statistics on the assessment of the current volume and forecast of timber harvesting on forest plantations. The study uses mathematical modeling to estimate the volume of wood harvested in the countries for which data are not publicly available and to calculate the world volume of harvested wood in 2012: 54% of business wood is harvested in natural forests (913 million m$^3$), 33% - in forest plantations (562 million m$^3$), 12% - in semi-natural forests.

Based on these studies, it can be concluded that by 2030 up to 50% of the harvested volume of industrial timber in the world will be produced on forest plantations.

The process of investing in poplar cultivation in Serbia includes financial investments in the present period aimed at realisation of economic benefits or effects in a future period, of a seasonal...
character. This implies a significant problem in the process of predicting and determining investments in fixed assets, engagement of human and machine resources, etc. The main characteristics of the procedure of investment in poplar cultivation, is the fact that the conditions for the beginning of production and their exploitation are not created simultaneously. The advantage of plantations over classical forestry is that the production scope and structure can be relatively quickly adapted to market requirements.

The total area of these poplar plantations is about 48.0 ha, which is about 2.1% of the forest areas in Serbia [19].

Unfortunately, in Russia, due to the numerous reserves of natural forests, the issues of planted forest cultivation remained in oblivion for many years. The area of timber plantations in Russia does not exceed 160.0 ha [20]. However, the interest in planted cultivation of the wood species increased significantly in recent years. First of all, due to the reduction of economically available wood in the European part of the country. This actualizes the issues of economic evaluation of the cultivation of plantations with short rotation. Since the early 80s of the XXth century about 36.0 hectares of poplar plantations have been established as a raw material base for pulp and paper mills in the European part of the country. The issues of using forest plantations as a source of raw materials in the development of the pulp and paper industry in Russia are the studied tasks [21]. The questions of ecological efficiency of growing poplars on forest plantations in Russia are investigated [22]. Some progress has been made in these studies, but a number of unresolved and controversial issues related to predicting the performance of fast-growing plantations, depending on the density of risk-based activities, still remain.

2. Materials and methods

The research methodology is based on the hypothesis that from the perspective of the forest business, growing timber on plantations should be economically justified, and the risks of such activities should be taken into account.

The process of growing wood on forest plantations is laborious and includes soil preparation, planting, agricultural techniques during the operation of plantations.

Forest Management Plans prescribe rotation period in plantations of poplar on 25 years in Serbia, and thus a certain time major harvest - the main income in the cultures of clone poplars. Major cuts in plantations of clone poplars belong to the group of clean felling i.e. removing all trees from the selected area. Marking of trees for cutting in restoration is carried out along the border line that is included in the area of clean cut. Harvesting is realized at a time when there is no risk of sudden arrival of high water, to effectively protect produced assortments during floods. When performing cuts must be taken into account that felled trees not intersect and the stump height does not exceed ¼ of diameter. Cutting of felled timber is adapted to market conditions, to achieve maximum financial effects (greater participation of technical wood in relation to the physical, waste is minimized) and performed by a qualified person [23].

Costs and revenues in poplar plantations are presented using the analysis of their dynamics in selected forest compartments of Ravni Srem (Forest Estate “Sremska Mitrovica”, P.E. “Vojvodinašume”, Republic of Serbia). The stands which are analyzed are grown on different soil types and are of different age, while their initial planting density is the same 6 × 6 m. Also revenues from the analysed compartments are presented. The main task of this production is to provide high yields (per unit area) of certain assortments and low production costs. The goal of the article is to research costs and revenues of 4 study plots in poplar plantations in Ravni Srem and to point out the cost effectiveness using full ground and soil preparation in them.

The investigated sample plots were established from Populus x Euramericana cl. I-214, with planting spacing 6 x 3 m (555 trees per ha), for technical wood production, in the Northern province of Vojvodina. 4 study plots were investigated there, aged 24-42 years, with a total area of 45.35 ha (Table 1). Soil type in the plots is alluvial semigley. The research was carried out in plantations of poplar, in the area of the river Sava, in the period 2002 – 2013. Data pertaining revenues at the end of
rotation period were obtained from the archives of the forest enterprise which managed the studied plantations, and also the data from material books.

Since all studied stands are state-owned and managed by the Public Forest Enterprise “Vojvodinašume”, the value (cost) of the land (land rent) did not enter into the calculations. All income at the end of analyzed rotation (24, 26, 37 and 42 years) is presented through: the value of F—veneer and L—peeling logs, timber wood class I and II, and pulpwood and income from schematic thinning.

Table 1. Structure of costs in major felling in sample plots [23].

| Study plot | Harvested wood | Costs of felling and work up | Costs of extraction of assortments | Total costs of major felling |
|------------|----------------|-----------------------------|-----------------------------------|-----------------------------|
|            | Timber | Cordwood | Σ | Fuel and lubricants | Amortization of chainsaws | Consumption of spare | Costs of labor | Mechanized works | Labor force | Compensation for felled wood | The cost of the drive overheads | Fuel and lubricants | Amortization of chainsaws | Consumption of spare | Costs of labor | Mechanized works | Labor force | Compensation for felled wood | The cost of the drive overheads |
| Age | [m³] | [m³] | [m³] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] | [€] |
| 1 | 26 | 2139 | 727 | 2867 | 100 | 42 | 38 | 1330 | 1822 | 158 | 364 | 2195 | 6053 |
| 2 | 24 | 6713 | 1529 | 8243 | 88 | 35 | 32 | 829 | 1614 | 97 | 332 | 1483 | 4514 |
| 3 | 37 | 2845 | 426 | 3271 | 147 | 57 | 52 | 1733 | 2791 | 19 | 710 | 3087 | 8601 |
| 4 | 42 | 2207 | 351 | 2559 | 101 | 39 | 36 | 1114 | 1872 | 59 | 503 | 1994 | 5722 |

Revenues are present during the schematic thinning and at the end of the rotation in 4 sample plots. The highest revenue is in the sample plot 2 (24 years stand, alluvial semigley) (Table 2).

The income from growing timber on the plantations has been determined taking into account the rotation. Researchers linked the rotation with wood species and cultivation targets of wood or biomass [24].

To study the growth and development of forest plantations, we set up experimental poplar objects in the Voronezh region of Russia in 1990. During the study period, 720 model trees have been cut down and analyzed; 53 thousand plants have been measured in height and diameter.

The results of testing of plantations with different cutting speeds have been carried out in Russia. Poplar plantations were laid on an area of 2.2 hectares with different planting densities (3.0 thousand plants per 1 ha, 5 thousand plants per 1 ha, 8 thousand plants per 1 ha, 10 thousand plants per 1 ha). On the plantations, measurements were made of the height and diameter of the cultivated poplars with a logging turn of 10, 20, and 30 years [20]. Studies of soil composition have been made and records of the damage of plants by phyto-diseases and insect pests have been kept.
Table 2. Structure of revenues in major felling in sample plots [13].

| Sample plot 1 | Sample plot 2 | Sample plot 3 | Sample plot 4 |
|---------------|---------------|---------------|---------------|
| Assortment    | Quantity      | Value of assortments by price list of PE | Quantity | Value of assortments by price list of PE | Quantity | Value of assortments by price list of PE | Quantity | Value of assortments by price list of PE |
| F             | 470.7 m³      | 59.4 €/m³     | 3264.8 €/ha   | 984.8 m³ | 39.4 €/m³     | 1665.5 €/ha   | 1329.9 m³ | 229.3 €/m³     | 12611.2 €/ha   | 1329.9 m³ | 186.6 €/m³     | 10262.9 €/ha   |
| L             | 425.7 m³      | 53.7 €/m³     | 2415.8 €/ha   | 1207.9 m³ | 48.3 €/m³     | 2174.3 €/ha   | 680.5 m³ | 117.3 €/m³     | 5280.2 €/ha   | 456.8 €/m³     | 69.0 €/m³     | 3105.5 €/ha   |
| I             | 612.9 m³      | 77.3 €/m³     | 2705.2 €/ha   | 2419.0 m³ | 96.8 €/m³     | 3386.6 €/ha   | 438.2 m³ | 75.6 €/m³     | 2644.6 €/ha   | 315.8 €/m³     | 47.7 €/m³     | 1669.8 €/ha   |
| II            | 630.2 m³      | 79.5 €/m³     | 2185.4 €/ha   | 2101.8 m³ | 84.1 €/m³     | 2311.9 €/ha   | 396.4 m³ | 68.3 €/m³     | 1879.3 €/ha   | 199.8 €/m³     | 30.2 €/m³     | 830.2 €/ha   |
| p.w. v.m'     | 400.2 m³      | 50.5 €/m³     | 865.0 €/ha    | 614.9 m³ | 35.9 €/m³     | 1173.3 €/ha   | 248.8 m³ | 37.6 €/m³     | 644.2 €/ha    |               |              |             |
| p.w. m³       | 327.6 m³      | 17.1 €/m³     | 708.1 €/ha    | 633.1 m³ | 25.3 €/m³     | 329.7 €/ha    | 3271.8 m³ | 564.1 €/m³     | 23676.5 €/ha   | 103.1 €/m³     | 15.6 €/m³     | 266.8 €/ha   |
| Σ             | 2867.4 m³     | 361.6 €/m³    | 12144.2 €/ha  | 1243.5 m³ | 329.7 €/ha    | 11088.3 €/ha | 3271.8 m³ | 564.1 €/m³     | 23676.5 €/ha   | 2559.6 €/m³    | 386.6 €/m³     | 16779.5 €/ha |

We have taken the term of maximum exploitation of plantations of 60 years as a basis. Three periods of wood growing on plantations – 10, 20 and 30 years were considered. During this period, you can get six rotations at a turn of 10 years of cutting, 3 rotations at a turn of 20 years of cutting and 2 rotations at a turn of 30 years of cutting.

Another important factor is the density of plantation crops, by analogy with the first factor affecting the biomass yield. It is known that it is possible to create plantations with a density of 1 to 10 thousand plants/ha [25].

It is obvious that the decision to choose the density of plantation crops is also an optimization task for the maximum biomass yield with the maximum added value (profit). The degree of the density affects the biomass yield in the form of chips or wood assortments:

- Chips for cellulose, plate production, alcohols, etc.
- Industrial timber for the production of various wood assortments.

The calculations were performed for poplar plantations grown in Russia for four variants with a density of 3.0 thousand plants per 1 ha, 5 thousand plants per 1 ha, 8 thousand plants per 1 ha, 10 thousand plants per 1 ha.

We determined the costs of creating and maintaining forest plantations. The following factors were included in the calculations: the system of the used equipment, wood species, natural and climatic conditions of the area of wood cultivation, production rates, tariff categories of work and tariff rates, labor costs of workers in man-days, the need for fuel and electricity, as well as the density of plant planting.

The costs for the creation and operation of the plantations included [26]:
- The costs for the initial establishing of the plantation;
- The costs for the care and maintenance of plantation crops;
- The costs for cutting, primary processing and delivery to customers or to places of future processing.
The decision on the choice of the type of plantations is the optimization problem for the maximum profit from the sale of wood grown on plantations, depending on the rotation period, the density of plants and cultivation technology of wood.

The profit gained from the wood growing activity on the forest plantations depends on four components:
- Rotation, (years);
- Plantation density, (thousand plants / ha);
- Wood prices.

For the present study poplar was used as a type of wood species.

The risks of wood growing on forest plantations were taken into account in determining the profit:

\[ PR = f(P) - g (R), \]

\[ g(R) \text{ is a random function of risk losses,} \]
\[ f(P) \text{ is a non-random profit function depending on the income and costs of forest plantations.} \]

The discount rate was taken at the rate of 6%.

The greatest damage to forest plantations is caused by natural and climatic risks [27]. The consequences of the occurrence of individual types of risk at two levels of significance were taken into account: more than 50% of the plantations were destroyed due to the extensive risk occurrence or less than 50% of the area of plantations as a result of the local risk occurrence.

The Bernoulli equation was used to determine the probability of the occurrence of risk events:

\[ np^o - q^o \leq m_0^o \leq np^o + q^o \]
\[ np^{no} - q^{no} \leq m_0^{no} \leq np^{no} + q^{no}, \]

\[ n = 60 \text{ is the total number of tests,} \]
\[ q^o = 1 - p^o \text{ - the probability of non-occurrence of an extensive risk event,} \]
\[ q^{no} = 1 - p^{no} \text{ - probability of occurrence of a local risk event,} \]
\[ m_0^o, m_0^{no} - \text{is the most probable number of extensive and local risk events respectively for the 60-year cycle.} \]

The probability of such a number of risky events is determined by the formula:

\[ P_n(m_0) = \frac{C^m_n p^m q^{n-m}}{m_0!}, \]
\[ C^m_n = \frac{n!}{m_0!(n-m_0)!}, \quad n! = 1 \cdot 2 \cdot 3 \cdots n, \]

For each probability, the expected losses for each of the three types of plantations – mini-rotational, mid-rotational and maxi-rotational - were calculated [28].

3. Results

The volume of wood harvested on plantations with a short rotation depends on the wood species, the age of cutting and the density of plants.

For the 60-year-old life of the plantations, Russian business can harvest poplar wood on the mini-rotational plantations with a 10 year rotation age, for six cycles. If the rotation age is 20 years, the plantations will have three cycles and the rotation age of 30 years will have two cycles.

Our studies have shown that the income of the forest business in Russia from the harvesting and sale of poplar wood and poplar biomass will be different.

The income from the exploitation of poplar plantations is generated from the sales of biomass and wood assortment. To determine the income, the actual harvested volume and the price of poplar wood were taken into account.

The wood produced on mini-rotational plantations with a 10-year rotation will be small, and can be used exclusively for the production of industrial chips. With the increase of the rotation period to 20
years, the wood texture on mid-rotational plantations will be the following: 60% of medium-sized industrial wood, 8% of large and 31% of small one.

At 30-year rotation, the proportion of large and medium-sized wood will be 90%, small 10%, of the volume of industrial wood.

The lowest income from growing timber on plantations will be 2100 €/ha for mini-rotational plantations with planting density 3 thousand plants per 1 ha. The maximum income from growing timber on plantations will be 12510 €/ha for mid-rotational plantations with planting density of 8 thousand plants per 1 ha (Table 3).

**Table 3.** Profit from wood growing on plantations with different planting density and rotation in Russia.

| Rotation, years | Planting density, thousand plants per 1 ha | Costs per rotation | Total costs for 60 years, €/ha | Income, €/ha | Income for 60 years, €/ha | Profit for 60 years, €/ha |
|----------------|-------------------------------------------|--------------------|-------------------------------|-------------|--------------------------|--------------------------|
|                |                                           | Cutting, €/ha      | Planting and plant care, €/ha |             |                          |                          |
| mini-rotational (10 years) | 3                                          | 357.1              | 1130                          | 3272.9      | 350                      | -                        |
|                  | 5                                          | 428.5              | 1320                          | 3891.4      | 560                      | -                        |
|                  | 8                                          | 428.5              | 1512                          | 4083.4      | 560                      | -                        |
|                  | 10                                         | 457.1              | 1640                          | 4382.9      | 910                      | 5460                     |
| mid-rotational (20 years) | 3                                          | 642.8              | 1138                          | 3066.6      | 3446                     | 10338                    |
|                  | 5                                          | 642.8              | 1328                          | 3256.6      | 3810                     | 11430                    |
|                  | 8                                          | 685.7              | 1520                          | 3577.4      | 4170                     | 12510                    |
|                  | 10                                         | 685.7              | 1648                          | 3705.4      | 3990                     | 11970                    |
| maxi-rotational (30 years) | 3                                          | 828.5              | 1149                          | 2806.4      | 4390                     | 8780                     |
|                  | 5                                          | 828.5              | 1339                          | 2996.4      | 4605                     | 9210                     |
|                  | 8                                          | 885.7              | 1531                          | 3302.4      | 4280                     | 8560                     |
|                  | 10                                         | 885.7              | 1659                          | 3430.4      | 4100                     | 8200                     |

To predict the profit from growing timber on plantations with different planting density and rotation, the costs of soil preparation, plant planting, tending of plantations and cutting were determined.

Previously, we found that the number of plant care on plantations depends on the soil and climatic conditions of the region, the biological characteristics of trees and planting density.

It was determined that the implementation of the complex of works on the afforestation and tending of plantations will be from 1130 €/ha to 1659 €/ha, depending on the rotation and planting density.

The cost for cutting wood or biomass is between 15% and 50% of the production cost.

According to the results of the modeling income from growing timber plantations it was found that with the 20-year rotation and the planting density of 8.0 thousand plants per 1 ha the profit will be the maximum.

However, during the years of exploitation of plantations the probability of risks is not excluded. With the assistance of experts, we have established the probability of risk occurrence leading to
significant losses. Such risks are forest fires. Forest plantations are not forests, they are subject to the destructive impact of biological factors such as insects and fungus.

When simulating losses from the risk occurrence, it was believed that with local risks, half of the income could be lost, and with extensive ones, all the income would be lost. For each of the forest management options described above, a profit distribution function was built. The results of the calculations are presented in Table 4.

Table 4. The profits of the plantations, taking into account risks according to Russia.

| Rotation, years | Planting density, thousand plants per 1 ha | Number of risks in 60 years | Lost income, €/ha | Costs of reforestation of the plantation, €/ha | Probability of risk occurrence, P | Risk losses, €/ha |
|-----------------|-------------------------------------------|----------------------------|-------------------|-----------------------------------------------|-------------------------------|------------------|
|                 | local risks | wide risks | local risks | wide risks | local risks | wide risks |                  |                  |                   |
| mini-rotational (10 years) | 3          | 10         | 2           | 175         | 350         | 565         | 1130          | 0.6              | 1332             |
|                  | 5          | 11         | 3           | 280         | 1008        | 660         | 1320          | 0.52             | 1699             |
|                  | 8          | 13         | 4           | 280         | 1344        | 756         | 1512          | 0.35             | 1362             |
|                  | 10         | 15         | 4           | 455         | 792         | 820         | 1640          | 0.35             | 1297             |
| mid-rotational (20 years) | 3          | 10         | 2           | 1723        | 3446        | 569         | 1138          | 0.01             | 68               |
|                  | 5          | 11         | 3           | 1905        | 3810        | 664         | 1328          | 0.37             | 2851             |
|                  | 8          | 13         | 4           | 2085        | 4170        | 760         | 1520          | 0.33             | 2816             |
|                  | 10         | 15         | 4           | 1995        | 3990        | 824         | 1648          | 0.34             | 2875             |
| maxi-rotational (30 years) | 3          | 10         | 2           | 2197        | 4345        | 575         | 1149          | 0.38             | 3141             |
|                  | 5          | 11         | 3           | 2302        | 4605        | 670         | 1339          | 0.36             | 3209             |
|                  | 8          | 13         | 4           | 2140        | 4280        | 766         | 1531          | 0.33             | 2876             |
|                  | 10         | 15         | 4           | 2050        | 4100        | 830         | 1659          | 0.35             | 3023             |

The results of the simulations of income from growing timber on mini-rotational, mid-rotational and maxi-rotational plantations, taking into account the probability of risk occurrence, it was identified that the most profitable and less risky are mid-rotational plantations (Figure 1).
MRP|3 - mini-rotational, density of plantation is 3.0 thousand plants per 1 ha, MRP|5 - mini-rotational, density of plantation is 5.0 thousand plants per 1 ha, MRP|8 - mini-rotational, density of plantation is 8.0 thousand plants per 1 ha, MRP|10 - mini-rotational, density of plantation is 10.0 thousand plants per 1 ha;
MdRP|3 - mid-rotational, density of plantation is 3.0 thousand plants per 1 ha, MdRP|5 - mid-rotational, density of plantation is 5.0 thousand plants per 1 ha, MdRP|8 - mid-rotational, density of plantation is 8.0 thousand plants per 1 ha, MdRP|10 - mid-rotational, density of plantation is 10.0 thousand plants per 1 ha;
MaRP|3 - maxi-rotational, density of plantation is 3.0 thousand plants per 1 ha, MaRP|5 - maxi-rotational, density of plantation is 5.0 thousand plants per 1 ha, MaRP|8 - maxi-rotational, density of plantation is 8.0 thousand plants per 1 ha, MaRP|10 - maxi-rotational, density of plantation is 10.0 thousand plants per 1 ha.

Figure 1. Income from poplar plantations, taking into account risks according to Russia.

At the same time, the maximum profit can be obtained by growing wood on poplar plantations with a 20-year rotation and a density of 8.0 thousand plants per 1 ha. In many ways, similar results were obtained when studying poplar plantations in Serbia.

By applying the method of NPV (investment appraisal) it can be observed at the end of rotation (production cycle), i.e. different age, revenues were in a range 11 088 to 23 676 €/ha, respectively. The values for NPV at a discount rate of r=12 % were negative in all studied plots, and ranged from −1 743.02 to −2 161.99 €/ha (Table 5). Applying sensitivity analysis for NPV it is observed positive NPV values for p= 4% for all studied plots. At a discount rate of 4%, NPV ranged from 310 to 2 054 €/ha [14].

Table 5. Revenues and costs, NPV and the $NPV_s$ at discount rate 12% in the 4 studies plots according to Serbia.

| Study plot no. | Year | $C$ | $R$ | $C_t$ | $R_t$ | $C_r$ | $R_r$ | $\sum R_t - \sum C_t = NPV$ |
|----------------|------|-----|-----|-------|-------|-------|-------|----------------------------|
| 1              | 26   | 3857.77 | 12144.08 | 202.61 | 637.82 | 3 015.57 | 1176.97 | −1.838.60 |
| 2              | 24   | 3031.75 | 11 088.3 | 199.74 | 730.52 | 3 012.70 | 1269.68 | −1.743.02 |
| 3              | 37   | 5513.48 | 23 676.36 | 83.25 | 357.48 | 2 896.20 | 896.63 | −1.999.57 |
| 4              | 42   | 3727.64 | 16 779.22 | 31.94 | 143.75 | 2 844.90 | 682.91 | −2.161.99 |

C – costs; R – revenues, $C_t$ – discounted cost, $R_t$ – discounted revenue, $C_r$ – average relative cost (divided by age of plantation), $R_r$ – average relative revenue, $NPV$ – net present value, $NPV_s$ – average net present value (divided by age of plantation).
NPV depends on the actual investments in plantations, the height and arrangement of annual cash receipts and annual cash issuance during the use of plants, the length of the period of use for the time being, the height of calculative interest rate [29].

The internal rate of return (IRR) for 4 studied plots was found to be in the range 4.32 to 5.84%. The IRR values higher than 12% were not found in researched framework of cost-revenues changes rate. Priority in investment, have the stands with higher IRR. Average IRR is 5.22 for four studied plots. IRR values are higher for plantations that are up to habitats that are more appropriate for poplars (alluvial semigley), as well as shorter rotation and vice versa [30].

Pay back period (PBP) method predict the degree of economic effectiveness of investments in poplar cultivation. The most favourable situation for investments is the discount rate of 2%, where the period ranges between 14-20 years (Table 6).

| Study plot no. | 1  | 2  | 3  | 4  |
|----------------|----|----|----|----|
| p(%) year      |    |    |    |    |
| 6              | 33 | 29 | 41 | 80 |
| 4              | 21 | 19 | 22 | 38 |
| 2              | 15 | 14 | 14 | 20 |

B/C varied in the range 0.42 – 0.24 (average 0.34%) at a discount rate of 12%.

4. Conclusion
Growing poplar wood on forest plantations with a short rotation is a promising activity. For Russia, the switch to growing timber on plantations can reduce the environment pressure on natural forests.

According to the study of poplar plantations cultivation in Russia, it was established that it is possible to profit from the sale of biomass and the production of industrial chips by reducing the growing period of poplar wood up to 10 years.

The cultivation of poplar plantations with 20-year rotation is advisable to get not only industrial wood chips, but also wood assortment.

According to a study of poplar plantations cultivation in Russia, it was established that the cultivation of poplar wood in terms of mid-rotational plantations allows you to profit 7202 €/ha. In the creation of plantation crops the fundamental role is played by their density. To get timber the density of plantation should be from 3.0 to 5.0 thousand plants per 1 ha.

Plantations with a 20-year rotation and planting density of 3.0 thousand plants per 1 ha are the most profitable and less risky ones according to the research at the territory of Russia.

The most important factor in forest plantation management is the rotation age. Forest plantations with 30-year rotation or more, are able to provide environmental benefits specific for the forests with natural reforestation processes managed for the production of wood. In order to create forest plantations, preference should be given to lands not previously occupied by forests. This reduces the risk of damage to wood caused by diseases and harmful insects.

When designing forest plantations, it is necessary to take into account that the main costs are connected with soil maintenance and biological protection of trees from pests and diseases. Principally, modern plantation cultivation is carried out by analogy with the technologies of cultivation of agricultural plants.

From the conducted analysis in Serbia the following can be concluded:
- Costs are present in the first six years of establishment of plantation,
- Revenues are present during the schematic thinning and at the end of the rotation,
- Revenues were in a range 11 088 to 13 676 €/ha by applying the method of NPV.
Positive financial effect can be reached in the future by lowering the costs of establishing of poplar plantations. Costs can also be reduced by finding out the solution in the field of soil preparation for afforestation, working operations which will show the higher level of economic efficient. To find out the optimal solution in the framework of the enterprise management to aim financial resources to reduce the costs or increase the revenues, by finding optimal solution and direct and advise the forestry practice to reduce the costs of production (in production phases, reduce the costs of ground and soil preparation, advance the working organization in the forest).

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