Betula pendula Roth. survival and growth on mine sites of the Kursk Magnetic Anomaly

E Treschevskaya*, I Golyadkina and S Treschevskaya

Abstract. The study sites is located in an iron-mining district of European part of Russia, called The Kursk Magnetic Anomaly. Birch tree (Betula pendula Roth) plantation was created in 1972 in two different types of heap dumps (hydraulic-mine dumps and mining dumps). Afforested dumps are mainly consisted of cenomanian and aptian sands with the admixture of mesozoic carbonate rocks. In particular hydraulic-mine dumps are formed with sand material and mining dumps are formed with sandy-lime material. For improving poor properties of sand substrate before the planting birch trees on hydraulic-mine dumps were used the technique of soil transfer. The re-spreading fertile layer of soil varies from 30 to 80 cm. Substrate quality varied considerably. Long-term growth and survival of birch tree were analyzed and volume per ha were calculated in different slope parts. Study results show that double-layer substrate with fertile layer (30-40 cm) on the top would not appear to be the best way to rehabilitate mine ecosystems and it has significant disadvantages. At the age of 38 years, common birch is characterized by sufficiently high growth parameters, but low survival.

1. Introduction

Every year over two thousands ha of land are allocated for waste storage, including valuable agricultural lands which also affect the environmental situations of regions in Russia [1]. This problem is urgent for Belgorod region where there is situated a number of the Kursk Magnetic Anomaly deposits (KMA, Russia). A great amount of waste is produced at Lebedinsky and Stylensky minings, where tens of millions of cubic meters of technogenic raw are generated every year [2].

Essential part of technogenig raw is mechanogenic raw material presented by clay and sand. These materials of mechanogenic origin are stored in dumps (hydraulic-mine dumps and mining dumps). Variety of mine soil materials are characterized by vastly different physical and chemical properties and have lower nutrients than native top soils.

The formation of the mining landscape with heap dumps and heaps of different heights and shapes increases metabolism and energy. Nonclosure of energy flows in such ecosystems determines their instability. Artificially created meso- and micro-relief with steep unvegetated slopes strengthens the role of abiotic factors, which in time form a hydrographic network with its own micro water-shed areas and special aerodynamic conditions [3].

The negative impact of mining disturbance on the surrounding area exceeded 10-15 times the area of mine sites. Tree planting remains one of the most effective strategies in re-establishing ecosystems.
in areas affected by industrial disturbance [4-8]. Forest reclamation and restoration of mine sites helps to prevent erosion and to return the land to productive capability [9].

The natural revegetation of mine sites is a long process and it has been recommended to wait a certain time (several hundred years) studying the natural dynamics before adopting management measures if sites are to be rehabilitated [10-12]. However, spontaneous restoration is not foreseeable in the context of global change. It is therefore not considered an acceptable rehabilitation strategy. One of the most important condition for vegetation re-establishment is soil amendment and even reconstructing is thus necessary [13,14].

After soil engineering operations follows vegetation restoring of technogenic ecosystems. Over 50 different species of trees, shrubs and grasses were tested to reduce the negative impact of mine sites in Russia and abroad. Common birch (Betula pendula Roth.) is important deciduous species for mine sites rehabilitation. Danko [15] shows that for better growth and survival birch tree needs sandy-loam texture of parent material. Andryuschenko emphasized that sandy lime mixture have more favorable properties for birch tree on mine dumps of the Kursk Magnetic anomaly [16]. Jonash recommends on clay parent material before planting common birch to create temporary black alder (Alnus glutinosa) plantations for soil properties improvement [17].

The aim of the current study was to determine the common birch long-term survival and growth in different treatments on mine sites of the Kursk magnetic anomaly. The selection of tree species for a reclamation purposes should consider the influence of substrate material, topography, and local climate.

2. Materials and methods

Common birch (Betula pendula Roth.) is deciduous tree that belongs to the family Betulaceae. Betula pendula are rapidly growing, undemanding trees, which after about 50 years have reached their final height of about 25 m. It is found in sparse deciduous, coniferous and mixed forests and is native to almost all of Europe and central Russia. Birch tree is often used for ecosystems rehabilitation as fast-growing pioneer species.

Studied birch tree plantation were created at post-mining sites located in the northeastern part of Belgorod region in an iron-mining district of European part of Russia, called The Kursk magnetic anomaly (KMA). KMA is one of the largest territories rich in iron ores on Earth. Reserves of iron ores are presently estimated at 200-210 billion tons about 50% of iron reserves on the planet. The boundaries of reserves extend to 160 thousand square km. Underground ore mining methods are used [18]. Essential part of technogenic raw is mechanogenic raw material presented by siltstones and sandstones. This material of mechanogenic origin is stored in dumps.

Pure stands of birch tree were created in 1972 in two different types of dumps (hydraulic-mine dumps and mining dumps). The slopes degree varies from 25° to 38°. The height of heaps reached 50-100 m with 3-4 terraces. Afforested dumps are mainly consisted of cenomanian and aptian sands with the admixture of mesozoic carbonate rocks, forming so-called sandy-lime substrate. In particular hydraulic-mine dumps are formed with sand material and mining dumps are formed with sandy-lime material. For improving poor properties of sand substrate before the planting birch trees on hydraulic-mine dumps were used the technique of soil transfer. The re-spreading fertile layer of soil varies from 30 to 80 cm.

All plantations were established by hand-planting bare root common birch seedlings. Within each plantation, a fixed area plot between 0.02 and 0.04 ha was randomly established. Plot size varied so as to ensure uniform site conditions across each plot. On each plot all trees were tallied and total height, breast height diameter were recorded. Also on each plot the percent survival and volume per ha was calculated and resulting in growth class of studied plantations [19].

For each substrate three replicates of soil samples were taken from the top 0-10 cm bellow the litter layer. Soil samples were crushed, transported to the laboratory and after that sieved, air-dried and analyzed. The pH value of a 1:2.5 water suspension was determined potential measurements. Extraction of labile fractions of soil phosphorus and potassium was carried out by Machigin’s method.
by solution of carbonate ammonium \((\text{NH}_4)_2\text{CO}_3\) (1wt.% concentration) at ratio of soil to solution 1:20). Cations and anions contents of water soluble compounds were determined in water extract from the soils. Exchangeable cations composition was investigated in 0.1 N \(\text{NH}_4\text{Cl}\)-ethanol extract after leaching of water-soluble compounds. Total nitrogen content was determined by Kornfeld method with hydrolysis of organic compounds of the soil with 1N \(\text{NaOH}\) solution. The content of organic carbon was determined using the modification of the Tyurin method (dichromate oxidation). Hydrolytic acidity was determined by Kappen method. Particle size distribution was determined by the Kachinskii method with sodium pyrophosphate.

3. Results and discussion

3.1. Soil physical and chemical properties

Parent material and its chemical and physical properties directly effects on such important soil processes as nutrient accumulation, humus formation and interaction between mineral and organic part of the soil. Sand and sandy-lime mixture are common parent material of technogenic ecosystems in Europe and central Russia. In these particular researches hydraulic-mine dumps are formed with sand material and mining dumps are formed with sandy-lime material.

For improving poor properties of sand substrate before the planting birch trees on hydraulic-mine dumps were used the technique of soil transfer. The re-spreading fertile layer of soil varies from 30 to 80 cm.

As shown in table 1 studied mine dumps are characterized by different properties of substrates. One of the most important properties is soil particle size distribution. According to our data, the content of small particles (less than 0.01 mm) is higher in sandy-lime substrate compare to sand. Transfer fertile layer are characterized by maximum content of small particles.

Sand substrates are characterized by lack of vital chemical elements. Sands more than 96 % consists of silicon dioxide, just in case of admixture carbonates in sands increase the content of such biologically important elements as potassium and phosphorus. NKP content significantly higher in transfer fertile layer (1.9; 10.3 and 1.0 mg/100 g respectively).

Soil physical and chemical properties of substrates strongly vary. The value of pH ranged between 7.2 and 7.6. The highest rate of organic matter content in transfer fertile layer (3.5 %), then sandy-lime (0.27) and the lowest in sand (0.1). Substrate moisture characteristics shows that sandy-lime substrate have higher reserves of productive water.

Double-layer substrate with the fertile layer on the top had higher content of organic matter and nutrients. Our results show that in the long term, transfer fertile layer had poor physical properties such as low porosity and high compaction causes low aeration, less water infiltration, more runoff.

| Physical and chemical properties | Sandy-lime substrate | Transfer fertile layer | Sand Substrate |
|---------------------------------|----------------------|-----------------------|---------------|
| Particle size distribution: <0.01 mm (%) | 10.67 | 54.51 | 3.22 |
| > 0.01 mm (%) | 89.33 | 45.49 | 96.78 |
| Bulk density, g cm\(^{-3}\) | 1.47 | 1.40 | 1.54 |
| Hardness at a depth 20-25 cm, kg cm\(^{-2}\) | 11 | 30 | 11 |
| Porosity, % | 47 | 45 | 44 |
| \(p\text{H}_{\text{KCl}}\) | 7.5 | 7.2 | 7.6 |
| Organic matter content, % | 0.27 | 3.50 | 0.10 |
| Nitrogen (N), mg/100 g | 0.03 | 1.90 | 0 |
| Phosphorus (P), mg/100 g | 0.75 | 1.00 | 0.70 |
| Potassium (K), mg/100 g | 5.0 | 10.3 | 2.8 |
| Hygroscopic moisture, % | 2.3 | 8.5 | 0.9 |
| Wilting moisture, % | 3.5 | 12.8 | 1.4 |
As a result of poor infiltration and physical properties of double-layer substrate after re-spreading of fertile layer intensive erosion processes occurred. This led to the loss of nutrients and overall fertility of topsoil. In dry periods moisture of the upper layer (0-10 cm) decreased up to the wilting moisture.

3.2. Birch tree survival and growth

Pure stands of birch tree were created in 1972 on two different dumps. The first plantation was on sandy-lime substrate, and the second one on the double-layer substrate with transfer fertile layer on the top.

Birch tree grew well on the sandy-lime substrate of the mining dump (see table 2). The results for volume roughly paralleled those of height and DBH (diameter at breast height). The birch tree average of 198 m$^3$/ha on the bottom part of dump compared to the upper and the middle part – 107 and 93 m$^3$/ha respectively. On the bottom of the dump stems are characterized by the biggest DBH in spite of average height.

At the age of 38, the birch tree growth class is high (II) in all the parts of the dump slope, the highest survival (40%) was on the top and middle of the slope. The bottom part is characterized by the lowest survival (30%). Survival values for the common birch after 38 years were very poor on steep slopes of sandy-lime dumps. Our results show low survival of birch largely due to high amounts of limestone in overburden. Thus birch tree plantation could not protect steep slopes from soil erosion, flushing of topsoil layer which is demonstrated on figure 1.

Figure 1. Bare roots of birch tree (38-age) planted on double-layer substrate of hydraulic-mine dump site.
Table 2. Birch tree (38 age) survival and growth on different mine dumps substrates.

| Dump type      | Substrate     | Part of slope | Survival percent | Height, m | Height growth, cm | DBH, cm | Growth class | Volume per ha, m³ |
|----------------|---------------|---------------|------------------|-----------|-------------------|---------|--------------|------------------|
| Mining Sandy-lime | bottom       | 30.0         | 14.9             | 39.2      | 21.23 ± 0.42      | II      | 198          |
|                | middle        | 40.0         | 14.1             | 37.1      | 12.51 ± 0.47      | II      | 93           |
|                | top           | 40.0         | 14.0             | 36.8      | 13.34 ± 0.77      | II      | 107          |
| Hydraulic-mine  | Double-layer substrate bottom | 34.0 | 15.5             | 40.79     | 13.50 ± 0.39      | I       | 115          |
|                | middle        | 33.0         | 15.3             | 40.26     | 13.24 ± 0.41      | I       | 101          |
|                | top           | 33.0         | 15.3             | 40.26     | 13.22 ± 0.42      | I       | 101          |

On double-layer substrate of hydraulic-mine dump birch trees are characterized by high survival which is ranged between 75-87 % in the first years after planting. But after 38 years survival values was very poor (33-34 %). The survival and growth rate were higher on the bottom part of the dump. It was similar to that described for mining dump.

The main factor which is limited birch tree growth on mine sites is moistening. Table 3 shows birch tree survival and growth from 1977 to 2013 depending on annual precipitation. Three types of hydrothermal conditions in different slope parts were clearly distinguished: optimal, medium and unfavorable. Optimal conditions are formed with the amount of precipitation more than 600 mm and their steady distribution over months. It is also characterized by the good moisture recharge of the fertile layer since the autumn of the previous year.

The second (medium type) includes years with precipitation of 500-600 mm, but with unsteady distribution by month, resulting in periods of not only atmospheric, but also soil drought. The third type of hydrothermal conditions is characterized by low amount of precipitation (less than 500 mm).

It should be noticed that maximum of height growth were observed not only in the years with optimal hydrothermal conditions, but also in those years, which are preceded them. Thus, the high growth rates of birch in 1983 are due to the optimal hydrothermal conditions of the previous year. However, in the years with a optimal type of hydrothermal conditions (1980, 1982), the height growth reached its maximum.

Table 3. Birch tree survival and growth from 1977 to 2013 depending on precipitation (hydraulic-mine dump).

| Year | Age | Precipitation, mm/year | Survival percent | Height, m | Height growth, cm | Diameter BH, cm |
|------|-----|------------------------|------------------|-----------|-------------------|-----------------|
| 1977 | 3   | 644                    | 85.6             | 0.41±0.01 | 19.6±0.25         | 0.52±0.01       |
| 1978 | 4   | 534                    | 75.5             | 0.90±0.09 | 31.3±0.32         | 1.03±0.01       |
| 1979 | 5   | 592                    | 70.0             | 1.23±0.01 | 18.4±0.17         | 1.85±0.02       |
| 1980 | 6   | 799                    | 70.0             | 1.77±0.02 | 40.4±0.44         | 2.36±0.03       |
| 1981 | 7   | 600                    | 69.8             | 2.20±0.03 | 43.3±0.46         | 3.28±0.03       |
| 1982 | 8   | 675                    | 69.0             | 2.65±0.03 | 50.7±0.46         | 4.60±0.03       |
| 1983 | 9   | 497                    | 69.0             | 3.20±0.05 | 60.6±1.50         | 5.60±0.05       |
| 2010 | 35  | 400                    | 35.0             | 15.00±0.06| 42.9±0.87         | 13.00±0.08      |
| 2013 | 38  | 550                    | 33.0             | 15.37±0.11| 30.4±0.77         | 13.32±0.40      |

The survival of birch tree varied from 85 to 69 % during the first seven years after planting. It was almost stable at the age of 5-9 years. It had dropped sharply up to 35 % by the age of 35. Changes in survival over the years are mainly due to the environmental conditions. So, sharp decrease in survival of a birch tree was established in the first years when optimal hydrothermal conditions changing on medium or even unfavourable.
4. Conclusions
This study shows that at the age of 38 years, common birch is characterized by sufficiently high growth parameters at the bottom part of the slope, resulting in the 2nd growth class of birch on sandy-lime mixture and the 1st growth class on double-layer substrate.

Inspite of high initial survival after 38 years birch trees had the low survival which could be explained by poor water and physical properties of studied substrate. Thus, birch tree plantation doesn’t provide stabilization of steep slope and potential economic returns.

Our findings for the Kursk magnetic anomaly indicate that 1) double-layer substrate with fertile layer (30-40 cm) on the top would not appear to be the best way to rehabilitate mine ecosystems and it has significant disadvantages. The presence of fertile layer was insignificant in survival and growth of birch tree, mostly because of poor water infiltration and aeration.

Based on our results birch tree is not recommended for tree planting during land reclamation on mine sites of the Kursk magnetic anomaly, Central Russia.

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