Plant species selection and biomass nutrient content on post-mine sites of the Kursk magnetic anomaly, Russia

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Abstract The article presents data on the assessment of the different tree and shrubs species for a reclamation of the hydraulic dump of the Kursk Magnetic Anomaly, Russia. The purpose of the work is to identify highly productive tree and shrub species with the maximum content of nitrogen and ash elements in the biomass. The objects of research are protective plantations of Robinia pseudoacacia L., Caragana arborescens L., Betula pendula L., Hippophae rhamnoides L., Pinus sylvestris L., Populus balsamifera L. Under the influence of different type of vegetation, the fertility of the dump substrates increases and the initial substrates gradually turns into soil. The rate of formation of primary soils depends on the biomass of plantations and the content of chemical elements in it. The article analyzes data on the content of the main chemical elements in different parts of plants aged 8-9 years. Trees and shrubs are arranged in sequential rows in terms of nitrogen accumulation, ash elements and overall biological productivity. The authors identified sea-buckthorn and robinia pseudoacacia, which, already at a young age, are characterized by high productivity (146.2 and 118.0 dt/ha) and have a positive effect on the fertility of the dump substrates.

1. Introduction
As a result of the use of natural resources, there is a significant anthropogenic impact on natural landscapes [1]. One of the reasons for the violation of the Earth's surface and the emergence of man-made landscapes is open-source mining. Such deposits are available in almost all regions of our country and abroad.

More than 2,000,000 ha of land have been violated in the Russian Federation. The Kursk magnetic anomaly (KMA) is the largest and richest iron ore basin in the world. It is located in the Central Federal district. The area of disturbed lands of the KMA is about 40,000 ha [2].

In the extraction of minerals by open method destroys all the biological components of the landscape. The geological foundation is being rebuilt, the ground water level is changing, and the soil and vegetation cover is being disturbed. There are man-made landscapes that dramatically worsen the environmental situation in the region.

The overburden rocks are stored in dumps and form unstable artificial geosystems. The limiting factor in man-made landscapes is moisture. A small amount of moisture and nutrients in the dumps'
substrates contribute to a long period of self-healing of phytocenoses. For many decades, most of these territories have retained the appearance of man-made wastes. Assessing the prospects for its restoration is an urgent problem of our time.

Reclamation is used to restore disturbed land and return it to economic circulation. The most affordable and cheap direction of reclamation is forestry. In different regions of Russia and countries of the near and far abroad, about 50 species of tree and shrub species were tested during forest reclamation [3-5]. Not all of it correspond to the forest-growing conditions of the disturbed lands.

The sand and sand-chalk mixtures occupy a leading position among overburden rocks in many mineral deposits. It is characterized by low-favorable agrochemical and water-physical properties. According to GOST 17.5.1.03-83 sands and sand-chalk mixtures are considered to be unsuitable rocks for forest reclamation [6].

One of the ways to increase the fertility of substrates and improve the forest growing conditions of industrial dumps is the re-spreading of fertile layer [7]. A fertile layer of zonal soils is used. However, the formation of two-component soil not solve the whole problem of the cultivation in it of protective plantations. It is necessary to aspire to the transformation of layers in the soil. This occurs under the influence of tree and shrub species [8]. The rate of formation of primary soils depends on the biomass of plantings and the content of chemical elements in it. It improves the physical condition of the applied fertile layer and generally increase the fertility of the dumps' substrates.

The aim of the current study was to identify highly productive tree and shrub species with the maximum biomass nutrient content and assess the possibility of using the most perspective plants for forest reclamation on post-mine sites in central forest-steppe zone, Russia.

2. Methods and material

The objects of research were protective plantings of the following tree and shrub species: Robinia pseudoacacia L., caragana tree (Caragana arborescens L.), birch (Betula pendula L.), sea-buckthorn (Hippophae rhamnoides L.), common pine (Pinus sylvestris L.), balsamic poplar (Populus balsamifera L.). The plantations were created on the dump called “Birch log” Kursk magnetic anomaly. The dump was formed by the hydraulic method. The total area of the dump at the end of its formation was 1241.3 ha, height – 40-46 m, slope steepness – 6-30°. The dump was located in the North-Eastern part of the Belgorod region, which belongs to the Central Federal district.

The dump was composed of a sand-chalk mixture. In order to improve the forest growing conditions on the surface of the hydraulic dump, land use was carried out. Vehicles applied a fertile layer with a capacity of 30-80 cm, which was removed during the development of the quarry.

Forest reclamation of the dump began in 1976. Trial plots were laid in the different type of vegetation, taking into account modern taxation requirements. Determination of the plant biomass for different plant species was carried out by the method of model trees, the number of which and the fractional composition (leaves, branches, trunk, roots) of the phytomass were determined. Determination of the fractional composition of phytomass was carried out directly by weighing all model trees in steps of different diameters on breast height. In most cases 3-5 tree models were taken on each of sample plots. Then samples were taken from each phytomass fraction to obtain the dry matter content, the results were extended to a tree level.

Biomass nutrient content was determined in the State Agrochemical Laboratory «Voronezh» to the following ISO standards: phosphorus (P) – according to ISO 6491:1998 "Animal feeding stuffs – Determination of phosphorus content – Spectrometric method", IDT; calcium (Ca) and magnesium (Mg), potassium (K) – according to ISO 27085:2009 "Animal feeding stuffs – Determination of calcium, magnesium, potassium by ICP-AES", IDT; nitrogen (N) – ISO 5983-2:2009 "Animal feeding stuffs – Determination of nitrogen content and calculation of crude protein content – Part 2: Block digestion and steam distillation method", IDT [9-11]. The determination of silicon (Si³⁺), iron (Fe³⁺) and aluminum (Al³⁺) in different phytomass fraction was carried out using an atomic adsorption spectrophotometer AAS 703 (Perkin-Elmer, USA) in the Department of physical and chemical research of the Institute of non-infectious animal diseases (Voronezh, Russia).
3. Results and discussion

Vegetation is one of the important factors of soil formation. Protective forest plantations, created in the conditions of dump-quarry complexes, contribute to the restoration of overburden rocks and mixtures and accelerate the formation of primary soils [12-14]. At the same time, according to many authors, green parts of plants have the greatest positive effect on the safety and fertility of substrates on the slopes of dumps in technogenic landscapes [15-17].

The approaches to the selection of tree and shrub species for forest reclamation are different. For example, in the USA, the basis for the use of a particular species is the observation of the natural regeneration (local species). In our practice, primary attention is paid to the species that are most resistant to difficult environmental conditions and low soil fertility.

For reclamation of post-mine sites of the Kursk magnetic anomaly were selected six different species such as robinia pseudoacacia, caragana arborea, birch, sea-buckthorn, common pine and balsamic poplar. The chemical composition of which is presented in table 1. It follows from the tabular data that the biomass nutrient content in different species is not the same.

Table 1. Biomass nutrient content in different tree and shrubs species on post-mine sites of the Kursk magnetic anomaly.

| Part of tree | Content of chemicals, kg/ha |
|--------------|-----------------------------|
|              | N   | Ca   | K    | Mg   | P    | Si   | Fe   | Al   | Sum    |
| Aboveground  | Robinia pseudoacacia, 9 years | 188.30 | 162.31 | 23.85 | 15.19 | 32.46 | 9.96 | 5.80 | 3.10 | 440.97 |
| Underground  | 59.68 | 44.98 | 16.16 | 9.75 | 10.69 | 3.79 | 2.22 | 1.05 | 148.32 |
| Total        | 247.98 | 207.29 | 40.01 | 24.94 | 43.15 | 13.75 | 8.02 | 4.15 | 589.29 |
| Aboveground  | Caragana arborea, 8 years | 40.08 | 22.31 | 3.04 | 5.74 | 3.73 | 1.37 | 1.09 | 0.62 | 77.98 |
| Underground  | 36.56 | 4.82 | 2.42 | 1.53 | 2.49 | 2.48 | 0.79 | 0.57 | 51.66 |
| Total        | 76.64 | 27.13 | 5.46 | 7.27 | 6.22 | 3.85 | 1.88 | 1.19 | 129.64 |
| Aboveground  | Betula pendula, 9 years | 35.48 | 26.94 | 6.79 | 7.41 | 15.33 | 4.23 | 1.97 | 1.32 | 99.47 |
| Underground  | 3.94 | 6.06 | 1.79 | 0.93 | 2.37 | 0.68 | 0.55 | 0.24 | 16.55 |
| Total        | 39.42 | 33.00 | 8.58 | 8.34 | 17.70 | 4.91 | 2.52 | 1.56 | 116.02 |
| Aboveground  | Hippophae rhamnoides, 9 years | 128.00 | 39.28 | 20.50 | 21.92 | 26.65 | 4.83 | 7.39 | 1.65 | 250.22 |
| Underground  | 91.19 | 15.26 | 6.26 | 6.23 | 7.34 | 2.43 | 3.69 | 1.69 | 134.09 |
| Total        | 219.19 | 54.54 | 26.76 | 28.15 | 33.99 | 7.26 | 11.08 | 3.34 | 384.31 |
| Aboveground  | Pinus sylvestris, 9 years | 23.01 | 10.48 | 3.79 | 2.32 | 6.88 | 2.61 | 0.79 | 0.45 | 50.33 |
| Underground  | 3.56 | 2.92 | 3.97 | 0.81 | 2.14 | 1.29 | 0.78 | 0.75 | 16.22 |
| Total        | 26.57 | 13.40 | 7.76 | 3.13 | 9.02 | 3.90 | 1.57 | 1.20 | 66.55 |
| Aboveground  | Populus balsamifera, 9 years | 20.73 | 39.69 | 10.74 | 2.13 | 9.08 | 7.65 | 1.03 | 0.73 | 91.78 |
| Underground  | 7.50 | 29.78 | 10.82 | 3.99 | 6.10 | 5.81 | 0.96 | 0.72 | 65.68 |
| Total        | 28.23 | 69.47 | 21.56 | 6.12 | 15.18 | 13.46 | 1.99 | 1.45 | 157.46 |

The maximum reserves of nutrients, including nitrogen, are concentrated in the cultures of sea-buckthorn and robinia pseudoacacia, the minimum reserves are typical for the common pine, birch and poplar. In the plantations of robinia, the amount of nitrogen in the underground and aboveground biomass is 247.98, in sea buckthorn – 219.19, while in the plantations of pine, birch and poplar this figure does not exceed 39.42 kg/ha.
A similar trend is observed in the content of calcium in the phytomass of the species - the highest values were recorded in poplar, robinia, and sea-buckthorn. Thus, the maximum calcium content was noted in robinia - 207.29 kg/ha, which is several times higher than in other plants. The minimum calcium content was noted in pine - 13.40 kg/ha, and from deciduous, in caragana and birch - 27.13 and 33 kg/ha, respectively. In total, the plantations of robinia and sea-buckthorn have maximum values - 589.29 and 384.31 kg/ha, respectively. Further in the descending sequence are poplar, caragana and birch - 157.46; 129.64 and 116.02 kg/ha. The minimum value is typical for the plantation of common pine – 66.55 kg/ha.

Based on table 1, in the roots of nitrogen-accumulating plants, the reserves of chemical elements are about 25-35%, in particular nitrogen - 24-48% of the total content. Moreover, more than half of the total amount of nitrogen is accumulated in small roots, 25% of which die off annually and serve as one of the sources of nitrogen enrichment of substrates [18].

The most interesting, from the point of view of soil formation, are the green parts of plants. Leaves biomass is the most important link in the exchange between vegetation and soil. When decomposing, it replenishes the resources of mineral food of plants in the substrate, affects the microbiome of primary soils, and participates in the formation of humus. The study of the nitrogen content of the biomass showed that the assimilation parts of plants on disturbed lands contain 30-40% of nutrients from their total stock. Thus, the maximum amount of nutrients is returned to the soil with leaf and needle fall.

Among the mineral elements in both conifers and deciduous plants, calcium predominates, the next element in terms of the intensity of accumulation is potassium and phosphorus. In the green phytomass of perennial grasses (without dividing them by species), potassium is in the lead in the intensity of accumulation, which accounts for about 50% of the total amount of chemical elements. Calcium and silicon are further accumulated. The content of iron and aluminum in tree and shrubs on post-mine sites is insignificant (up to 5% of the total amount of nutrients).

Table 2 shows the contribution of various parts of robinia to the accumulation of the chemical elements. Thus, the highest values of nitrogen, potassium and phosphorus concentrated mostly in aerial parts - leaves, branches and trunk, and the main part of nitrogen is accumulated in the perennial part - the trunk and amounts to 114.6 kg/ha. The main part of phosphorus is accumulated in foliage and trunk - 80.29 and 74.19 kg/ha, respectively. The main part of potassium is accumulated in the trunk (13.91 kg/ha).

Table 2. Biomass nutrient content in structural parts of robinia pseudoacacia.

| Part of tree         | N    | Ca   | K    | Mg   | P    | Si   | Fe   | Al   | Sum  |
|----------------------|------|------|------|------|------|------|------|------|------|
| Leaves               | 61.10| 80.29| 7.91 | 6.20 | 14.41| 4.96 | 2.17 | 0.93 | 177.97|
| Branches             | 12.60| 7.83 | 2.03 | 1.04 | 1.49 | 0.36 | 0.32 | 0.18 | 25.85 |
| Trunk                | 114.60|74.19|13.91|7.95 |16.56|4.64 |3.31 |1.99 |237.15 |
| Total: branches and trunk | 127.20|82.02|15.94|8.99 |18.05|5.00 |3.63 |2.17 |263.00 |
| Roots little         | 18.43| 6.02 |1.75 |1.57 |1.20 |1.17 |0.58 |0.40 |31.12 |
| Roots large          | 41.25|38.96|14.41|8.18 |9.49 |2.62 |1.64 |0.65 |117.20 |
| Total: roots         | 59.68|44.98|16.16|9.75 |10.69|3.79 |2.22 |1.05 |148.32 |
| Total                | 247.98|207.29|40.01|24.94|43.15|13.75|8.02|4.15 |589.29 |

In the underground biomass (fraction of small and large roots), the total amount of nutrients is 88.64 kg/ha, and the nitrogen content is 59.68 kg/ha, which is 2-3 times lower than in the aboveground biomass. In terms of the intensity of accumulation in the roots of robinia, calcium is in the lead, followed by potassium and phosphorus.
Based on the obtained material, the order of accumulation of nutrients in the biomass of the studied tree and shrub species in absolute terms can be represented by the following series: pseudoacacia robinia > sea-buckthorn > poplar > caragana > birch > common pine (figure 1).

The total biological productivity is directly related to the accumulation of nitrogen and other elements in the biomass and changes with the age of the plantations. The phytomass reserves of the main tree and shrub species are not the same, they are presented in table 3.

The maximum biological productivity is typical for the cultures of robinia pseudoacacia and sea-buckthorn, in the stand of which the total phytomass reserves are 146.2 and 118.0 dt/ha, respectively.

Table 3. Biomass reserves in 9-year-old plantings, centners per ha (dt/ha).

| Fraction of biomass | Robinia pseudoacacia | Caragana arborescens | Betula pendula | Hippophae rhamnoides | Pinus sylvestris | Populus balsamifera |
|---------------------|----------------------|----------------------|----------------|----------------------|-----------------|-------------------|
| Leaves (needle)     | 18.4                 | 4.8                  | 7.5            | 19.1                 | 6.3             | 3.5               |
| Trunk, branches     | 91.8                 | 8.4                  | 27.3           | 60.4                 | 11.2            | 29.4              |
| Total aboveground   | 110.2                | 13.2                 | 34.8           | 79.5                 | 17.5            | 32.9              |
| Roots               | 36.0                 | 5.9                  | 8.2            | 38.5                 | 3.4             | 22.9              |
| Total underground   | 36.0                 | 5.9                  | 8.2            | 38.5                 | 3.4             | 22.9              |
| Total biomass       | 146.2                | 19.1                 | 43.0           | 118.0                | 20.9            | 55.8              |

At the same time, the share of perennial parts of plants (trunk, branches) has the highest values - 91.8 and 60.4 dt/ha, respectively. The biomass of the underground part of robinia and sea-buckthorn also gives the maximum values among other species – 36.0 and 38.5 dt/ha.

The rest of the tree and shrub species according to the total biological productivity of the studied species can be arranged in the following series: poplar (55.8 dt/ha) > birch (43.0 dt/ha) > common pine (20.9 dt/ha) > caragana (19.1 dt/ha).

4. Conclusion
For the first time in this scientific work, a comparison was made of six potentially suitable species of trees and shrubs for purposes of forest reclamation of post-mine sites of the Kursk magnetic anomaly. Based on the results of the work, the following conclusions were obtained.

In 9-year-old plantings, a significant part of the chemical elements is concentrated in the aboveground biomass in the green parts of plants. Sea-buckthorn and robinia pseudoacacia are of significant reclamation importance, because of foliage biomass is 19.1 and 18.7 dt/ha, respectively. Birch, caragana, pine and poplar are significantly inferior to them.
According to the total amount of nitrogen and other nutrients in the biomass, the studied tree and shrub species can be arranged in the following series: pseudoacacia robinia (589.29 kg/ha) > sea-buckthorn (384.31 kg/ha) > balsamic poplar (157.46 kg/ha) > caragana (129.64 kg/ha) > birch (116.02 kg/ha) > common pine (66.55 kg/ha). According to the total biological productivity, the studied tree and shrub species can be arranged in the following series: pseudoacacia robinia (146.2 dt/ha) > sea-buckthorn (118.0 dt/ha) > balsamic poplar (55.8 dt/ha) > birch (43.0 dt/ha) > common pine (20.9 dt/ha) > caragana (19.1 dt/ha).

Robinia pseudoacacia and sea-buckthorn are the most perspective species for reclamation of post-mine sites. Already at a young age, the plantings of sea-buckthorn and robinia are characterized by high productivity (146.2 and 118.0 dt/ha) and have a positive effect on increasing the fertility of the dump substrates.

In further work, it is necessary to assess the durability and stability of sea-buckthorn and robinia plantations, as well as the erosion protection value of these species on post-mine sites of the Kursk magnetic anomaly.

References
[1] Food and Agriculture Organization [FAO] 2015 Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/3/a-bc600e.pdf
[2] State Report 2017 ‘The state and protection of the environment of the Russian Federation in 2016’ [in Russian]
[3] Treschevskaya E, Golyadkina I and Treschevskaya S 2019 Betula pendula Roth. survival and growth on mine sites of the Kursk Magnetic Anomaly IOP C. Ser. Earth Env. Sci. 392 012022 doi:10.1088/1755-1315/392/1/012022
[4] Banik M, Sarkar A, Ghatak P, Ray R and Patra S 2018 Reclamation of waterlogged lowland in indo-gangetic alluvial plains using some biodrainage species. Int. J. Curr. Microbiol. Appl. Sci. 7 1028 doi:10.20546/ijcmas.2018.702.127
[5] Prach K and Tolvanen A 2016 How can we restore biodiversity and ecosystem services in mining and industrial sites. Environ. Sci. Pollut. R. 23 13587 doi: 10.1007/s11356-016-7113-3
[6] GOST 17.5.1.03-83 1984 Nature protection. Lands. Reclamation general requirements. Available at: https://docs.cntd.ru/document/1200003393
[7] Treschevskaya E, Tichonova E, Golyadkina I and Malinina T 2019 Soil development processes under different tree species post-mining sites IOP C. Ser. Earth Env. 226 012012 doi:10.1088/1755-1315/226/1/012012
[8] Macdonald S, Landhausser S, Skousen J, Franklin J, Frouz J, Hall S, Jacobs D and Quideau S 2015 Forest restoration following surface mining disturbance: challenges and solutions. New Forests 46 703 doi: 10.1017/s11056-015-9306-4
[9] ISO 6491:1998 Animal feeding stuffs. Determination of phosphorus content. Spectrometric method, IDT. Available at: https://docs.cntd.ru/document/1200141724
[10] ISO 27085:2009 Animal feeding stuffs. Determination of calcium, magnesium, potassium by ICP-AES. Available at: https://docs.cntd.ru/document/1200098799
[11] ISO 5983-2:2009 Animal feeding stuffs. Determination of nitrogen content and calculation of crude protein content. Part 2: Block digestion and steam distillation method. Available at: https://docs.cntd.ru/document/1200140571
[12] Sroka K, Chodak M, Klimek B and Pietrzykowski M 2018 Effect of black alder (Alnus glutinosa) admixture to Scots pine (Pinus sylvestris) plantations on chemical and microbial properties of sandy mine soils. App. Soil Ec. 124 62 doi:10.1016/j.apsoil.2017.10.031
[13] Brunori A, et al. 2017 Carbon balance and Life Cycle Assessment in an oak plantation for mined area reclamation. *J. Clean. Prod.* **144** 69 doi: 10.1007/s00468-017-1592-9

[14] Borišev M, Pajević S, Nikolić N, Pilipović A, Arsenov D and Župunski M 2018 Mine site restoration using silvicultural approach. *Bio-Geotechnology for Mine Site Rehabilitation* **7** 115 doi:10.1016/B978-0-12-812986-9.00007-5

[15] Dedenko T, Tikhonova E and Malinina T 2019 Forest growing conditions of chalk marl rocks in the Central forest steppe neo-landscapes. *IOP C Ser. Earth Env.* **392** 012027 doi:10.1088/1755-1315/392/1/012027

[16] Dedenko T and Navalikhin S 2019 Ecological aspect of the industrial soils' penetration resistance in wood recultivation of Kursk Magnetic Anomaly. *IOP C Ser. Earth Env.* **226** 012024 doi:10.1088/1755-1315/226/1/012024

[17] Pietrzykowski M 2019 Tree species selection and reaction to mine soil reconstructed at reforested post-mine sites: Central and eastern European experiences *Env. Sci.* **3** 100012 doi:10.1016/j.ecoena.2019.100012

[18] Poorter H, et al. 2015 How does biomass allocation change with size and differ among species? An analysis for 1200 plant species from five continents *New Phytologist.* **208** (3) 13571 doi: 10.1111/nph.13571