Assessment of phytoremediation potential of some cereals under the action of mine wastewater of a mining enterprise

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Abstract. The article presents data on the accumulation of pollutants in the green vegetative mass of four cereal species, *Festuca arundinacea Schreb.*, *F. rubra* L., *Lolium perenne* L. and *Poa pratensis* L. under regular exposure to mine wastewater of a mining enterprise. The changes in the morphological and physiological parameters of plant development were assessed using the PlantEye F500 installation. The most informative parameters were: digital biomass and normalized chlorophyll index (NPCI). It was noted that at the initial stages of exposure to wastewater, growth processes are activated, which decreases after 21 days of plant cultivation. Photosynthetic activity was maintained at a high level throughout the experiment. The most promising species with a high ability to accumulate pollutants and resistance to technogenic impacts were identified, which can be recommended for the creation of phytopurification systems.

1 Introduction

Mine wastewater from mining enterprises poses a danger to the environment due to the oxidation of iron sulfides and non-ferrous metals, which increases their overall mineralization [1]. One of the most common treatment methods used at many Russian enterprises is settling of discharged wastewater in settling ponds. In some cases, settling is the only stage of treatment if there are no special requirements for the quality of water that subsequently enters natural ecosystems [2].

To reduce the settling time of wastewater, many countries use phytoremediation units that include various combinations of phytoremediant plants that take an active part in the biogenic migration of elements [3-4]. In this regard, the so-called hyperaccumulator plants of toxic pollutants are especially promising [5]. They are selected based on the ability of different species to selectively absorb a specific group of pollutants. The main requirements for such plants include: increased accumulative capacity to absorb pollutants whose MPC exceeds permissible standards, adaptability to growing conditions, high degree of renewal, resistance to pests and diseases, rapid growth of vegetative mass. Finding plants that meet

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these requirements is one of the key tasks, the solution of which will allow the implementation of these technologies in the conditions of the Russian Federation.

The aim of the work: to study the degree of accumulation of pollutants in green mass and changes in the morpho-physiological parameters of some cereals under conditions of regular exposure of wastewater from a mining enterprise to the growth and development of plants.

2 Materials and methods

The study was conducted using equipment of a unique scientific installation (UNI "Botanical Garden of the Belgorod State National Research University", https://ckp-rf.ru/usu/200997/).

The plants were sown in a greenhouse complex and cultivated on phytoracks with LED lamps for 24 days. After that, the first scanning of the studied plants was carried out. Every three days, the experimental group of plants was watered with mine wastewater from a mining enterprise to assess their morphophysiological state in the following combinations: 1. Control plants of *Festuca arundinacea*; 2. Experimental group of plants of *Festuca arundinacea*; 3. Control plants of Festuca rubra; 4. Experimental group of plants of *Festuca rubra*; 5. Control plants of Lolium perenne; 6. Experimental group of plants of *Lolium perenne*; 7. Control plants of *Poa pratensis*; 8. Experimental group of *Poa pratensis* plants.

The content of pollutants in plants was assessed using an AVIO 220 Max optical emission spectrometer after the end of the experiment. The results are presented as % of the dry weight of the sample.

The change in morphological and physiological parameters of plants was assessed using a PlantEye F500 3D scanner based on the following characteristics:

- Digital biomass, cm^3 [6].
- Normalized chlorophyll index (NPCI), range of values from -1 to 1 [7].

The growth rate of digital biomass and the growth rate of the normalized chlorophyll index were calculated using the basic method according to the following formulas:

$$\Delta TR = (Pk - Pn) / Pn \times 100\% \quad (1)$$

Where Pk is the final values of the indicator; Pn is the initial values of the indicator); TR = (Pk – Pn)1/n (where Pk is the final values of the indicator; Pn is the initial values of the indicator; n is the number of days of the experiment.

3 Results

The experimental results on the accumulation of K, Mg, Ca, Sr, Ba, As, Sb, Mn, Fe and Zn in the green vegetative mass of *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne* and *Poa pratensis* plants growing under the conditions of constant exposure to mine wastewater of a mining enterprise are presented in Table 1. The accumulation level for each element is visualized in a row from the lowest (highlighted in red) to the highest value (highlighted in green) (Table 1). The numbers are indicated according to the experimental variants during the experiment.

Table 1. The level of accumulation of pollutants in the green vegetative mass of plants when exposed to mine wastewater.

No. p/p	K, %	Mg, %	Ca, %	Sr, %	Ba, %	As, %	Sb, %	Mn, %	Fe, %	Zn, %
1	1.158	0.032	1.645	0.044	0.006	0.001	0.005	0.005	0.228	0.010
2	2.287	0.158	9.582	0.182	0.036	0.058	0.032	0.013	1.274	0.108
3	4.408	0.147	9.167	0.165	0.040	0.006	0.017	0.031	1.649	0.025
4	8.435	0.252	12.736	0.454	0.060	0.059	0.061	0.033	3.443	0.035
5	6.988	0.161	7.366	0.213	0.027	0.000	0.027	0.031	1.230	0.043
6	3.087	0.147	9.900	0.165	0.034	0.065	0.028	0.020	2.035	0.094
7	2.068	0.066	4.530	0.121	0.016	0.015	0.017	0.006	0.759	0.006
8	2.615	0.131	7.292	0.161	0.036	0.029	0.018	0.010	2.550	0.026

From the data presented in Table 1 it follows that all four studied cereal species have accumulative capacity to absorb mine wastewater pollutants. The highest degree of their accumulation in comparison with the control of other species for all elements except Zn was noted in *Festuca rubra*.

During the experiment, it was found that the accumulation of pollutants in the green mass of *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne* and *Poa pratensis* affects the morphophysiological features of plant growth and development. Digital biomass reflects the intensity of plant growth, since its calculation takes into account the height and area of leaves, which allows for an objective assessment of plant development [6]. Figures 1-4 show the dynamics of changes in this parameter in the studied species.

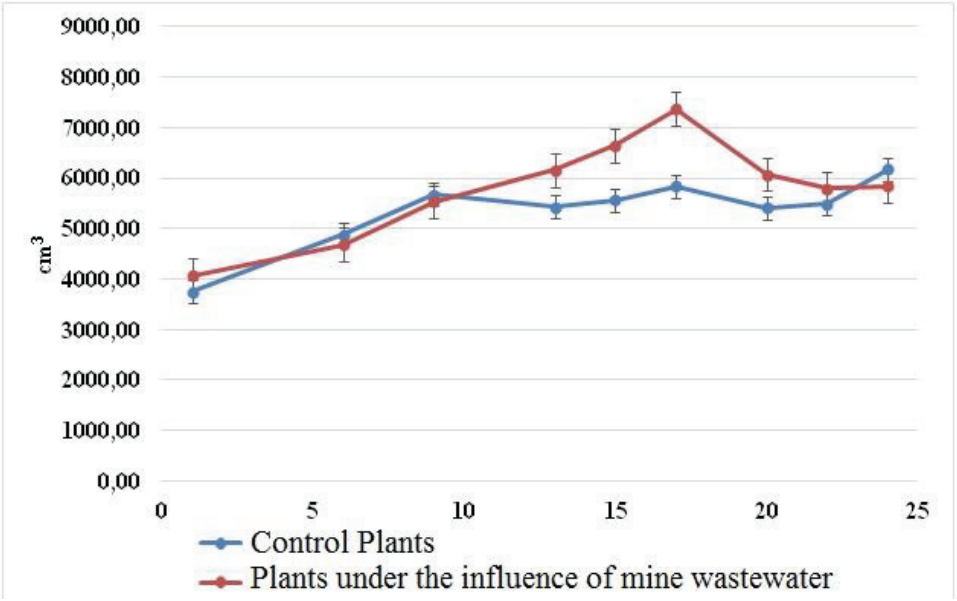

Fig. 1. Changes in digital biomass of *Festuca arundinacea* plants.

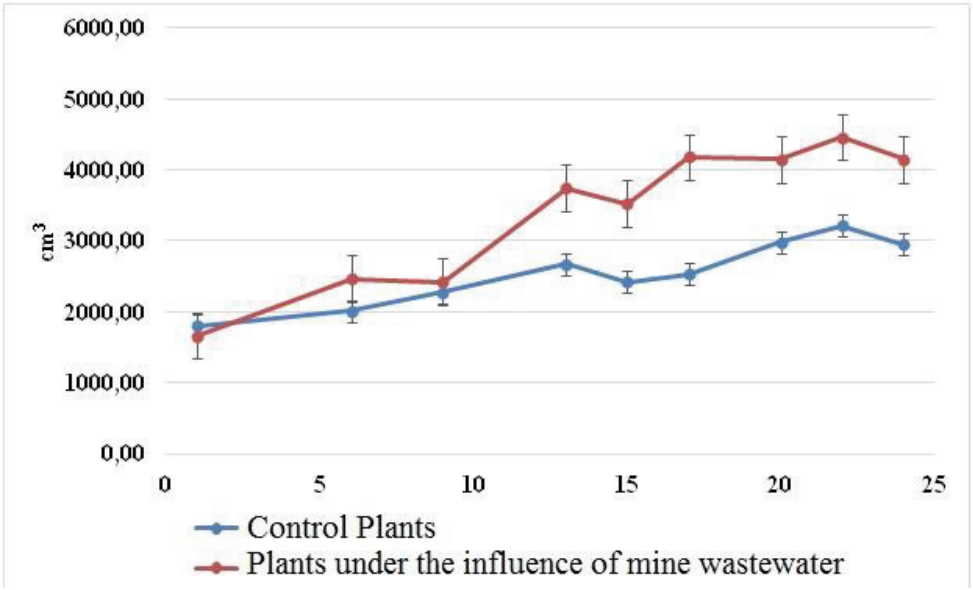

Fig. 2. Changes in digital biomass of *Festuca rubra* plants.

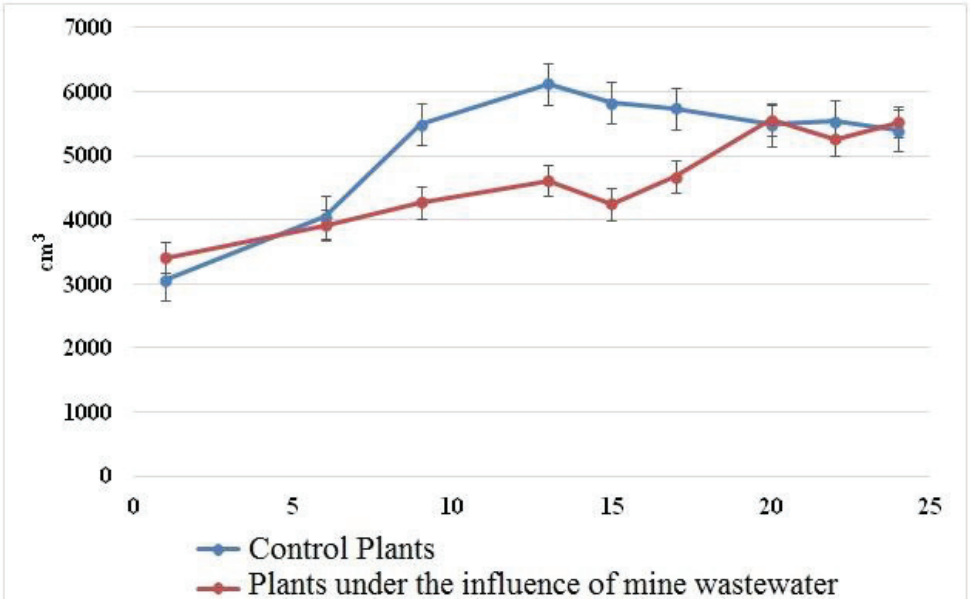

Fig. 3. Change in digital biomass of *Lolium perenne* plants.

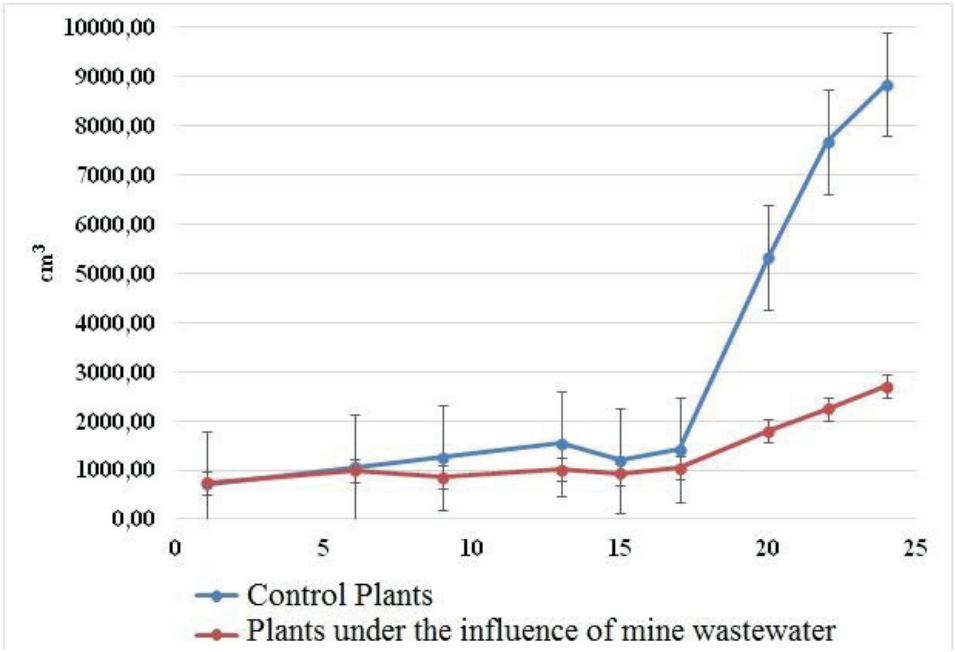

Fig. 4. Change in digital biomass of *Poa pratensis*.

The Normalized Chlorophyll Ratio Index (NPCI) value is an index measured at the fluorescence wavelength excited in blue light (UV rays). It is compared with the fluorescence wavelength excited in red light. Chlorophyll fluoresces at both wavelengths. Based on previously obtained experimental data, it was concluded that using the difference between these two wavelengths according to the formula:

$$(RED - BLUE)/(RED + BLUE) \quad (2)$$

It is possible to calculate values that correlate with the chlorophyll content in plants [7-8].

Table 2 shows the changes in the NPCI index in *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne* and *Poa pratensis* plants in the experiment and the growth rate for each variant. The numbers are indicated according to the experimental variants.

Table 2. Dynamics of changes in the NPCI index in the studied plants.

No. p/p	Days of measurements									Rate of increase
	1	6	9	13	15	17	20	22	24	
1	0.07	0.11	0.11	0.12	0.13	0.13	0.14	0.15	0.15	97.84%
2	0.09	0.11	0.11	0.13	0.13	0.13	0.14	0.15	0.15	105.90%
3	0.05	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.11	106.22%
4	0.00	0.02	0.02	0.06	0.05	0.07	0.08	0.09	0.10	110.26%
5	0.10	0.14	0.15	0.15	0.17	0.16	0.17	0.17	0.18	107.57%
6	0.09	0.13	0.12	0.13	0.14	0.13	0.15	0.15	0.16	106.54%
7	-0.01	0.01	0.03	0.06	0.03	0.01	0.03	0.07	0.08	109.10%
8	0.01	0.05	0.04	0.07	0.07	0.08	0.09	0.09	0.10	109.67%

During the experiment it was found that the effect of wastewater from the mining enterprise in all variants slightly increased the NCPI values in the experimental plants. Only in the case of *Lolium perenne* was this parameter in the experimental group lower than the values in the control group of plants.

4 Discussion

The conducted study shows that mine wastewater of the mining enterprise at the first stages of plant cultivation acts as a source of valuable microelements that can activate the processes of growth and increase in vegetative mass. The growth rate of digital biomass of *Festuca arundinacea* plants on the 17th day of the experiment was 81.14% compared to the control (55.54%). At the same time, by the end of the experiment, the growth rate in the control decreased to 64.57%, and in the experimental group of plants to 43.44%. The use of a closely related species *Festuca rubra* demonstrated a completely different dependence in the growth of digital biomass. Despite the decrease in the growth rate of plants at the end of the experiment, it was noted that the values in the experimental group by the end of the experiment were 148.89%, and in the control 63.63%. The revealed differences in the reactions of closely related plants to the impact of a technogenic factor can be explained by physiological characteristics. The differences are due to a greater accumulation of anti-stress secondary metabolites (anthocyanins) in *Festuca rubra* plants [9]. The change in digital biomass in *Lolium perenne* occurs in the same way as in *Festuca arundinacea* plants. The growth rate of plants by the end of the experiment in the control is 76.33%, and in the experimental group - 61.95%. The fourth species, *Poa pratensis*, during the experiment demonstrated, like the previous species, positive dynamics of growth of digital biomass, both in the control and in the experimental group. Moreover, on the twentieth day of the experiment, the plants in the control group significantly increased their digital biomass, while in the experimental group such a sharp jump in this indicator was not observed. This, apparently, indicates some suppression of the intensity of growth processes in this species.

The values of the normalized chlorophyll index increased steadily in all species, both in the control and experimental groups of plants. This indicates that during 24 days of exposure to mine wastewater from a mining enterprise, despite the accumulation of pollutants, there is no change in the activity of the functioning of the photosynthetic systems of plants.

The accumulation of pollutants in the green vegetative mass allows us to identify species with high selective accumulation capacity for certain groups of toxic elements. This makes it possible to recommend them as effective phytoremediant plants that can be successfully used to purify mine wastewater from mining enterprises.

5 Conclusion

The ability to effectively accumulate pollutants in the vegetative mass of the studied plants is confirmed by the results of experiments obtained using the AVIO 220 Max optical emission spectrometer. The most effective accumulators of toxic substances from the cereals studied during the experiment include *Festuca rubra* plants.

During the experimental study, it was found that under the influence of mine wastewater from mining enterprises, growth processes in plants are activated, but subsequently there is a decrease in growth rates, which is due to the negative long-term impact of pollutants. Photosynthetic systems of plants (assessed through the NCPI index) in

the experiment maintained their activity throughout the entire experiment, which is confirmed by the results obtained on the PlantEye F500 3D scanner.

Plants that should be considered when selecting objects for phytoextraction and phytoremediation in mine wastewater treatment systems at mining enterprises may show promise in species with increased anthocyanin content in their vegetative mass. These species are capable of accumulating significant amounts of pollutants while maintaining high growth rates. The next stage of research into the use of these species for phytoextraction is the creation of symbiotic plant-microorganism complexes, which, as previous studies show, can significantly increase the adaptive potential of species and enhance the accumulation of pollutants.

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