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ADAPTABLE PLANTS FOR ACIDIC WASTEWATER SEDIMENT OF COPPER SULFIDE MINES

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Abstract

The treatment of acidic wastewater of copper sulfide produces a huge amount of sediment, which can be processed into the planting matrix for ecological restoration of mines. This paper attempts to screen out the plants suitable for the acidic wastewater sediment, laying the basis for ecological restoration of mines. Therefore, 14 plant species were selected for preliminary tests on survival rate and growth tests in sediment pond. The survival rates and growth conditions of each plant species in the sediment (planting matrix) were observed and recorded, and subjected to comparative analysis of planting data of test plots. The results about 14 plant growth data show that *Dracocephalum moldavica*, *Lolium perenne L.*, *Photinia fraseri Dress*, *Ligustrum compactum (Wall. ex G. Don) Hook. F*, *Robinia pseudoacacia* and *Populus tomentosa* boast high survival rate, fast growth and good greening effect. These species can be used as the pioneer plants adaptable to acidic wastewater sediment.

Keywords: acidic wastewater sediment, adaptable plants, ecological restoration, screening

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1. Introduction

At present, the acid waste water generated during the copper sulfide mining process produces a large amount of sediment, which includes the main components such as calcium sulfate, iron hydroxide, etc., as well as the copper, lead, zinc and other metals lower than the primary standard (GB8978-1996). Such sediment belongs to the Class I industrial solid waste (AIS, 2006a, 2006b; Li et al., 2010). The current disposal method is to pile it up in the waste-rock yard directly or after filter pressing, which occupies valuable mine space and is prone to secondary environmental pollution. The acid wastewater sediment of the copper sulfide mine contains microbial indicators, constant nutrient and organic matter indexes required for the growth of various plants, but these indicators are extremely low, the crystal moisture content is high, and the sediment is severely hardened. Thus, it must be repaired by fertilization before being applied to the ecological restoration of the mining area, thereby realizing the minimization and recycling of solid waste. Based on this, it is an urgent issue to screen the adaptable plants to the matrix environment of acid wastewater sediment.

As a bioremediation technology with great potential, good effect and low cost, phytoremediation technology is widely recognized in the research of contaminated soil remediation and ecological restoration of mining areas (Liu, 2018; Marques et al., 2009; Rascio and Navari-lzzo, 2011; Zhu et al., 2011). According to the pollution degree, pollution categories and site conditions in different regions, it has always been a hot and difficult point to screen the adaptable plants in phytoremediation research. For instance, Li

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et al. (2017) found through the field investigation that *Bobboschoenus planiculmis*, *Ruppia maritima*, *Paspalum vaginatum Sw*., and *Sesuvium portulacastrum (L.) L.* boast the salt-tolerant, water-resistant and sewage-purifying ability, and can be used for phytoremediation in high-salt wastewater. Zhang et al. (2014) compared the purification ability of four dominant plants to COD, NH^4+-N and TP, and finally screened out the *Scirpus validus Vahl* and *Clinopodium urticifolium (Hance) C. Y. Wu et Hsuan*. Li et al. (2015) conducted a pot experiment to compare the survival rate, plant height, biomass and remediation ability of four forage plants, and concluded that *Dracocephalum moldavica* and *Sudan grass* are more suitable for the restoration of oil-contaminated soil in North China Oilfield. De Campos et al. (2019) analysed the morphological changes and biochemical reactions of *Pistia stratiotes* in water with different concentrations of As^{III}, and concluded that *Pistia stratiotes* can be used in the aquatic environment with As^{III} concentration of10 μM for plant restoration. In the screening study of mine ecological restoration vegetation, the researchers mostly focused on the screening of adaptable plants for different tailings ponds and waste dump. Yan et al. (2011) planted 6 plants species in the experimental area of iron tailings and analysed their growth of the 6 plants, finding that *Populus xiaozhuanica*, *Hedysarum mongolicum Turez*, and *Elaeagnus angustifolia Linn*, and *Caragana korshinskii*are more suitable for growth under iron tailings conditions. Tang et al. (2019) by adding different proportions of peat in lead-zinc tailings, compared the growth conditions of 15 plants and their ability to absorb Pb/Zn, concluding that *Swida wilsoniana (Wanger.) Soja*, *Apocynum venetum*, *Ricinus communis L.*, *Salix matsudana var. matsudana f. pendula Schneid*., *Populus nigra* have higher Pb/Zn tolerance and are more suitable for growth under the lead-zinc tailings conditions. Li (2010) compared the growth of six different plants and their configuration in the iron ore dump, and finally screened five pioneer plants such as *Robinia pseudoacacia*, *Forsythia suspensa (Thunb.) Vahl*, and *Amorpha fruticosa Linn.*asthe pioneer plants. Fu et al. (2019) through comparative analysis for the barite enrichment characteristics of nine dominant plants, found that *Clerodendrum bungei Steud*, *Dicranopteris dichotoma (Thunb.) Berhn.*, *Pinus massoniana Lamb*, and *Litsea pungens Hemsl* are more suitable as the repairing plant for heavy metal contaminated soil in lead-zinc tailing dump.

At present, there has been no studies at home and abroad on the screening test of adaptable plants for ecological restoration using the repaired acid wastewater sediment as the plant matrix. In view of this, 4 kinds of herbaceous plants, 3 species of gramineous plants, 3 kinds of shrubs, and 4 kinds of arbor trees were selected for small-scale preliminary test on plant survival rate and growth test of various plants in sediment pond. The survival rates and growth conditions of each plant species were observed and recorded, and subjected to comparative analysis, in order to screen out the suitable plant species for the acidic wastewater sediments, and then form an ecologically reclaimed plant system with scientific and rational distribution of grasses, shrubs and trees. This shall provide a scientific basis for the plant-diverse ecological restoration of mines in the acidic wastewater sediment environment.

2. Test material and methods

2.1. Test material

The test material was taken from the sediments produced by the acidic water treatment plant of one copper sulfide mine. Because the acidic water sediments not suitable for plant growth, so it must be repaired by adding organic matter and fertilizer before it can be used. Besides, a self-invented conditioner specifically for fertilization and repair of acidic wastewater sediment of copper sulfide mine was used to improve the physicochemical properties of the sediment and fertilize the sediment, and the main components include: peat, medical stone, calcite, frankincense, organic fertilizer, straw, water retention agent, and binder.

2.2. Test design

(1) Preliminary selection of adaptable plants

The key to the successful plant restoration in acidic wastewater sediment is to select the right plant species. Therefore, according to the site conditions near the mine, 14 plant species with strong stress resistance were selected for the small-scale preliminary test on the survival rate of plants in sediments. The test was conducted near the Fujiawu Road under the hillside of Baitai Company of Dexing Copper Mine. The sediment was piled into earthwork block or small mounds, and then mixed with loess of 10% and 20% or so, for planting a variety of plants. Table 1 shows the planting methods. Next, the 14 plants growth were observed, so as to make preliminary screening of eugenic plants according to survival rate. The 14 plant species include: herbaceous plants such as *Kochia scoparia (L.) Schrad.*, *Dracocephalum moldavica*, *Plantago depressa Willd.*, *Sorghum sudanense (Piper) Stapf*; Gramineous plants such as *Pennisetum sinese Roxb*, *Lolium perenne L.*, *Arundo donax*; Shrubs such as *Photinia fraseri Dress*, *Ligustrum compactum (Wall. ex G. Don) Hook. f*, *Ligustrum quihoui Carr.*; arbor trees such as *Robinia pseudoacacia*, *Cycas revoluta*, *Populus tomentosa*, and *Pinus elliottii Engelm*

(2) Small-scale growth teston various plants in the sediment pond

Based on the results of preliminary test above, the 2,600 square meters site of the Yangtaowu waste dump was selected for the test, in the specific steps as follows: in late June 2017, 2,600 square meters of test site was prepared; in early July 2017, according to the conditioner composition for the sediment repair, the proportion of the components, and preparation technology, the conditioners were prepared, and then fermented for 15 days; in late July 2017, the fermented conditioner was applied to the sediment ditch with a distance of 30 cm and a depth of 15 cm, and also covered. After the sediment in the test area of the Yangtaowu dumping site was conditioned, fertilized and repaired, the plant species that have been initially screened were planted according to the planting season of each plant species, and the growth of various plants was observed.

The observation period of herbaceous plants and gramineous plants was 90 days after sowing, and the observation period of shrubs and arbor trees was 180 days after transplanting. Further, the adaptable plants were screened.

Table 1. Planting methods of 14 planting plants

Plant	*Planting method*
Kochia scoparia (L.) Schrad.	Seeding
Dracocephalum moldavica	Seeding
Plantago depressa Willd	Seeding
Sorghum sudanense (Piper) Stapf	Seeding
Pennisetum sinese Roxb	Seeding
Lolium perenne L.	Seeding
Arundo donax	Transplanting
Photinia fraseri Dress	Cutting
Ligustrum quihoui Carr.	Transplanting
Ligustrum compactum (Wall. ex G. Don) Hook. f	Transplanting
Robinia pseudoacacia	Cutting
Cycas revoluta	Transplanting
Populus tomentosawere	Cutting
Pinus elliottii Engelm	Transplanting

2.3. Test items and methods

For the acidic wastewater sediment of the copper sulfide mine, the moisture content was determined according to *Soil-determination of dry matter and water content-gravimetric method* in HJ613-2011 (NEPS, 2011); the organic matter was based on NY/T1121.6-2006 (2006); the total nitrogen was based on NY/T 53-1987 *Method for the determination of soil total nitrogen (Semi-micro Kjeldahl method)* (NS,1987); total phosphorus was based on NY/T 88-1988 *Method for determination of soil total phosphorus* (NS, 1988); total potassium was based on LY/T 1234-2015 (FIS, 2018); the pH of the copper sulfide ore acidic wastewater sediment was based on NY/T 1121.2-2006 (AIS, 2006b).

2.4. Data analysis and processing

The test was performed using Excel for 14 plant growth statistics and Origin 9.1 software for drawing of plant growth chart.

3. Results and analysis

3.1. Basic physiochemical properties of the sediment

The basic physiochemical properties of the sediment are shown in Table 2. The test results show that the sediment was weakly acidic, and the phosphorus and potassium required for plant growth in the sediment were in the normal range, but the nitrogen content was very small; the organic matter needed for plant growth is only 4.01 *g/kg*, the sediment contained 63.76% of water, but the crystal water content was high, and the sediment was easy to be hardened, which can inhibit the growth and expansion of plant root systems, and further influence plant growth.

3.2. Survival condition of preliminarily selected plants

The survival rate of 14 plants in the small-scale preliminary test is shown in Fig. 1 and Fig.2.

Table 2. Basic physical and chemical properties of acidic wastewater sediments

Material type	*Total nitrogen/%*	*Total phosphorus/%*	*Total potassium/%*	*Organic matter/g/kg*	*Water content/%*	*pH*
Acidic Wastewater Sediment	0.26	0.038	0.33	4.01	63.76	6.55

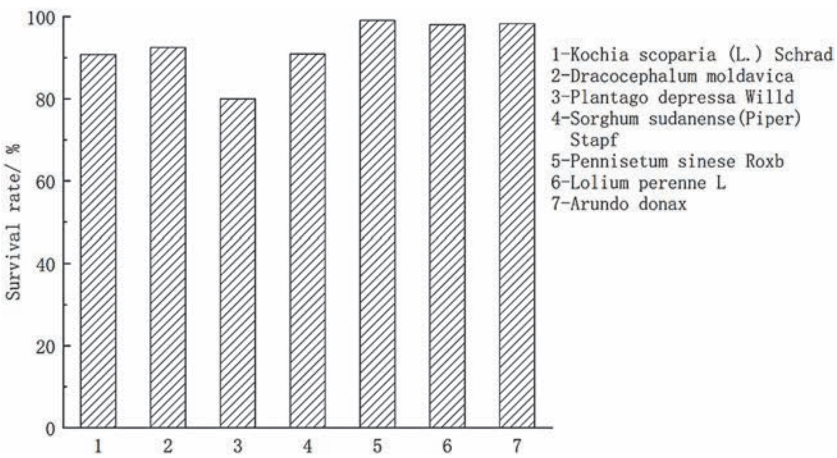

Fig. 1. The survival of herbaceous plants and gramineous plants

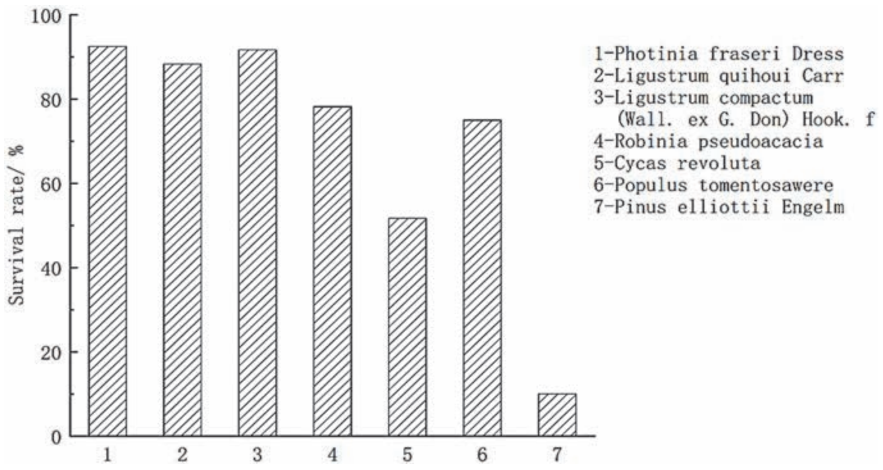

Fig. 2. Survival of shrubs and trees

It's found that the survival rates of the four herbaceous plants and the three gramineous plants were higher, and the survival rates of *Dracocephalum moldavica*, *Pennisetum sinese Roxb*, *Lolium perenne L.* and *Arundo donax* were over 90%, which are more suitable for growth on the tested acid sediments compared with *Kochia scoparia (L.) Schrad.*,*Plantago depressa Willd, and Sorghum sudanense (Piper) Stapf*; the survival rate of the three shrubs were high, which are more suitable for survival on acid wastewater sediments; among the four species of trees, the survival rates of *Robinia pseudoacacia*, and *Populus tomentosa*were significantly higher than *Pinus elliottii Engelm,* and *Cycas revoluta*, so they are more suitable for survival on the acidic wastewater sediments tested.

In summary, by comparing the survival rates of various plants in the sediment pond, the preliminarily screened plants include *Dracocephalum moldavica*, *Pennisetum sinese Roxb*, *Arundo donax*, *Photinia fraseri Dress*, *Ligustrum quihoui Carr.*, *Ligustrum compactum (Wall. ex G. Don) Hook. f*, *Robinia pseudoacacia*, and *Populus tomentosa*.

3. 3. Growth of plants in the sediment pond

All those screened plant species in the sediment pond of Yangtaowu grew well (Table 3).

(1) Growth of herbaceous and gramineous plants

Fig. 3 shows the growth of herbaceous plants and gramineous plants observed for 90 days. The *Dracocephalum moldavica* grew well; in the same experimental area with sediment conditioners, the diameter of a single plant was up to 2 cm, and the average height was 1.2 m; the leaf was wide, covering a large area; the root system was developed, i.e., the longest main root was 62 cm, and the root cover area was 50 cm in diameter. Its developed root system has greatly improved the sediment hardening, and the secretion of its developed root system has also effectively promoted the biological activity of the sediment and further the self-remediation of the sediment. Under the action of sediment conditioners, the *Lolium perenne L.* had sufficient nutrients, and grew well: the average height of single plants was 80 cm; the root system was developed, the main root was up to 37 cm, and the root cover area was 60 cm in diameter; there were as many as 12 roots for the smallest plant; the physical structure of the sediment gradually became granular from the original plate shape, so that the hardening condition of the sediment could be greatly improved; a large number of hyphae appeared in the sediment, which improves the microbial environment.

For the *Pennisetum sinese Roxb*, its growth rate at the early stage was second only to *Lolium perenne L.*; the average height of the plant was 91.3 cm, and the diameter of the single plant was 1.6 cm; its growth condition was good on the sediment. For *Arundo donax*, the average height was 104.7 cm, but its growth rate on the sediment was slow, and its growth ability is the weakest on the test sediment.

Table 3. Growth of plants in sediment reservoir

Number	***Plant species***	***Planting method***	***Growth***
1	*Dracocephalum moldavica*	Seeding	Growing more than 120cm
2	*Pennisetum sinese Roxb*	Seeding	Growing more than 90cm
3	*Lolium perenne L.*	Seeding	Growing more than 80cm
4	*Arundo donax*	Transplanting	Growing more than 100cm
5	*Photinia fraseri Dress*	Transplanting	Growing more than 170cm
6	*Ligustrum quihoui Carr.*	Transplanting	Growing more than 110cm
7	*Ligustrum compactum (Wall. ex G. Don) Hook. f Hook. f*	Transplanting	Growing more than 130cm
8	*Robinia pseudoacacia*	Cutting	Growing more than 410cm
9	*Populus tomentosawere*	Cutting	Growing more than 430cm

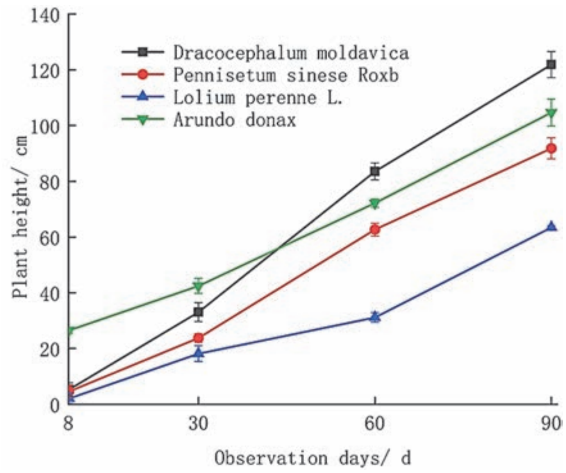

Fig. 3. Growth situation of herbaceous plants and gramineous plants

In general, *Dracocephalum moldavica*, *Pennisetum sinese Roxb* and *Lolium perenne L.* are more suitable for growth on the sediment in the test, but the *Dracocephalum moldavica* and *Lolium perenne L.* were finally screened out, in order to achieve the acidic wastewater sediments physicochemical properties of vegetation restoration and the free maintenance effect of ecological restoration.

(2) Growth of shrubs

Fig. 4 shows the growth of the three shrubs *Photinia fraseri Dress*, *Ligustrum compactum (Wall. ex G. Don) Hook. f*, and *Ligustrum quihoui Carr.* in the test sediments within 180 days. In the first 30 days the three plants grew relatively smoothly. For *Photinia fraseri Dress*, the growth rate increased from 30th days, and the average height of the plants at the 180 day was 176.5 cm, which was much higher than the other two shrubs, with good landscape effect. The *Ligustrum compactum (Wall. ex G. Don) Hook. f* boasted good survival rate and continued to increase during the observation period, and the average height of the plants reached 135.5 cm at 180 days. *Ligustrum quihoui Carr.* Started to grow fast from the 90th day, later than the other two, and the average height of the final plant was 112.6 cm. Through comprehensive comparison of the growth conditions of the three shrubs for 180 days, *Photinia fraseri Dress* and *Ligustrum compactum (Wall. ex G. Don) Hook. f*, are significantly superior to *Ligustrum quihoui Carr.* The two plants are more suitable for growth on the test sediment, and have better viewing.

(3) Growth of trees

Fig. 5 shows the growth of the two trees such as *Robinia pseudoacacia* and *Populus tomentosa* in the test sediments within 180 days. The two plants had a high survival rate and good growth condition on the test sediment. The observations showed that the growth rate of the *Robinia pseudoacacia* was fast before 120 days, but began to slow down after 120 days; the average plant height reached 412.3 cm at 180 days. The growth rate of *Populus tomentosa* was relatively slow in the first 120 days, but increased from 120 days, and the average plant height reached 437.5 cm at 180 days. For the *Robinia pseudoacacia*, considering its fast growth rate in the early stage, the root nodule root, and strong nitrogen fixation ability, it can be used as a pioneer species; for *Populus tomentosa*, it has fast high growth rate in the later stage, great height, and developed root systems which can effectively improve the sediment hardening. In the reclamation process of acid wastewater sediment, the mixed use of two plants can be considered for the ecological restoration of the mining area.

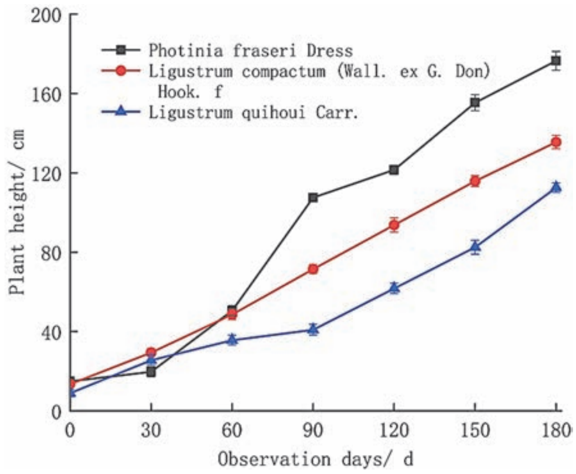

Fig. 4. Shrub growth situation

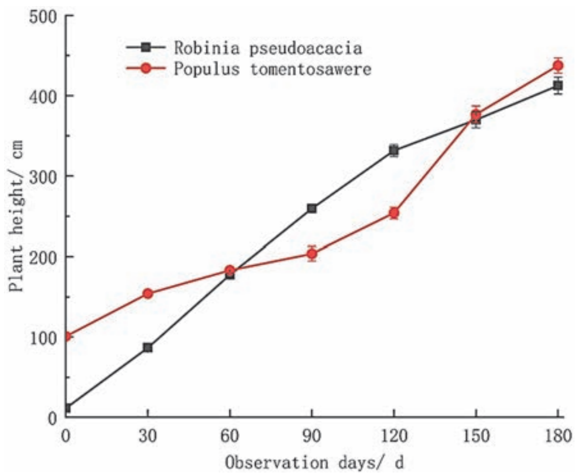

Fig. 5. Trees growth situation

4. Conclusions

In this study, the small-scale preliminary test on the survival rate of various plants and the growth tests of various plants were carried out in the sediment pond. The comparison results showed that among the selected seven herbaceous and gramineous plants, *Dracocephalum moldavica* and *Lolium perenne L.* had high survival rate and good growth condition, and they also can improve the physical and chemical properties of the sediment well, making it more suitable for plant growth under the conditions of the test sediment. Among the selected three species of shrubs, *Photinia fraseri Dress* and *Ligustrum compactum (Wall. ex G. Don) Hook. f*, had high survival rate and good growth conditions, and the two also had good landscape effects. Among the selected trees, the survival rate of *Robinia pseudoacacia* and *Populus tomentosa*was higher than that of *Cycas revoluta* and *Pinus elliottii Engelm*, and the plant was taller and covered a wider area.

Finally, *Dracocephalum moldavica*, *Lolium perenne L*, *Photinia fraseri Dress*, *Ligustrum compactum (Wall. ex G. Don) Hook. f*, *Robinia pseudoacacia,* and *Populus tomentosa* were selected as adaptable plants from the 14 plants. In addition, *Dracocephalum moldavica*, *Lolium perenne L.* and *Robinia pseudoacacia*can be considered as pioneer plants for the ecological restoration of sediment because they are fast-growing in the early stage, and the developed root systems are beneficial to improve the physical and chemical properties of the sediment. At the same time, the growth of plants also promoted the improvement of the physical and chemical structure and the regulation of the microbial community of the sediment. Different plants have different effects on adjusting sediment, Robinia pseudoacacia has a good nitrogen fixation effect, Ryegrass and corngrass have high organic matter content, which is of great help to improve the organic matter content of sediment.

This paper studies the screening of adaptable plants under the conditions of acid wastewater sediment in copper sulfide mine, and achieves some preliminary results. In this study, only the survival rate and growth of plants were compared, but without considering the interspecific differences between plants. In the future, it's necessary to focus on how different plants remove heavy metals from the acid wastewater sediment of copper sulfide mine and affect the microbial activity of the sediment, so as to analyse the action mechanism of phytoremediation on acidic wastewater sediments.

Acknowledgments

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