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On Selection of Remediation Plants for Heavy Metal Polluted Soil

Zhaofang Chen

Yellow River Engineering Consulting Co., Ltd., Zhengzhou 450003, China
86964783@qq.com

In this paper, in order to address the common serious soil pollution by heavy metal in the surroundings of coal and copper mines in China, we select heavy metal accumulating plants suitable for remediation of copper and coal mine soil, measure the contents of heavy metal elements in the plants and analyze the enrichment and transfer of heavy metal in plants to study the potentials of different plants to remediate heavily polluted soils in coal and copper mines. The study on phytoremediation of heavy metal polluted soil surrounding coal mines shows that the contents of the same heavy metal are different in five different plants, and the aerial and underground parts of the same plant absorb different amounts of the metal. All these plants show strong accumulation of Ni, Cr, Pb and Cd. The transfer coefficients of most heavy metal elements to Jerusalem artichoke and Erigeron annuus are greater than 1, which make them hyperaccumulating plants. The results of the study on remediation plants for heavy metal polluted soil in coal mines show that, with the increase in the proportion of copper slag in the soil, the germination rate, root length and seedling growth height of clovers, alfalfa and amorpha fruticosa increase first and then decrease, i.e. “low-promoting and high-repressing”. The three kinds of plants with content of copper from high to low are amorpha fruticosa, clover and alfalfa, and those with an increase in copper absorption compared with a copper concentration of 0% are clover, amorpha fruticosa and alfalfa from large to small. Clover absorbs a larger amount of copper in the copper-contaminated soil and when the concentration of copper in the soil is high, it is the least inhibited in growth, so it is an ideal choice of remediation plant for the copper-contaminated soil around copper mines.

1. Introduction

In recent years, in order to maintain sustainable development in China, the demands for heavy metal have been growing. The excessive exploration of heavy metal mines has caused serious pollution to the ecological environment around the mines, especially the soil pollution by heavy metal. Traditional physical and chemical remediation technologies for heavy soil pollution are not only costly, but they may also bring secondary pollution, and the treatment results are hardly satisfactory.

Recently, phytoremediation of soil pollution by heavy metal has attracted more and more attention from scholars (Xing et al., 2008). The current research hotspot and challenge is selecting appropriate hyperaccumulating plants according to the characteristics of heavy metal pollution in different soils to transfer the heavy metal from the soil to the plants so that the heavy metal pollution can be treated ecologically (Turgut et al., 2004; Wang et al., 2011). At present, the phytoremediation of soil pollution by heavy metal mainly includes plant extraction technology (Baker et al., 1994; Chen et al.,2000), heavy metal passivation or fixation technology (Pulford and Watson, 2003; Dushenkov et al., 1995; Vangronsveld et al.,2009), plant volatilization technology, plant rhizofiltration technology (Lin and Terry, 2003), plant-assisted remediation techniques (Ma et al., 2009) and remediation of soil heavy metal pollution by hyperaccumlating plant. The above methods have all achieved some results in specific mines and heavy metal polluted soil.

In this paper, in order to address the common serious soil pollution by heavy metal in the surroundings of coal and copper mines in China, we select heavy metal accumulating plants suitable for remediation of copper and coal mine soil, measure the contents of heavy metal elements in the plants and analyze the enrichment and transfer of heavy metal in plants to study the potentials of different plants to remediate heavily polluted soils in coal and copper mines.

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2. 2 Plant remediation of heavy metal pollution in the surrounding soil of coal mines

2.1 Sampling and data processing

The sampling points are set in the subsided reclamation region of a coal mine. In this region, a total of 50 samples are collected, involving 5 plants, namely Jerusalem artichoke, artemisia lavandulaefolia, erigeron annuus, Sonchus oleraceus and Artemisia sacrorum. For each plant, collect 2kg of sample from the aerial part and about 1.5kg from 0-20cm of the root underground. Remove the soil on the root of the plant, clean and sterilize it, dry it in the 55℃ thermostatic drier box to constant weight, grind and screen it and then store it in a sealed bag.

When measuring the content of heavy metals in plants, we adopt the HCl-HNO_3 method to digest the sample and extract the dry-ashed test sample with hydrochloric acid solution. The heavy metals tested are mainly 7 elements, namely Cd, Zn, Cr, Ni, Cu, Pb and Mn. Zn, Cr, Ni, Cu and Mn in plants are tested by flame atomic spectrophotometry. The contents of Cd and Pb in plants are measured by the graphite furnace method. Data post-processing are mainly completed by software Matlab, Origin and SPSS.

Usually enrichment coefficient (EC) and transfer coefficient (TC) are used to evaluate the contents of heavy metals in plants. The expressions of EC and TC are as follows:

$$EC = \frac{(HM)_{pl-ag}}{(HM)_{soil}} \tag{1}$$

$$TC = \frac{(HM)_{pl-ag}}{(HM)_{un-g}} \tag{2}$$

Where, $(HM)_{pl\text{-}ag}$ is the content of heavy metal in the aerial part of the plant; $(HM)_{soil}$ is the content of heavy metal in the soil; $(HM)_{un\text{-}g}$ is the content of heavy metal in the underground part of the plant.

2.2 Analysis on absorption of heavy metals by different plants

Table 1 lists the contents of heavy metals in aerial parts and roots of 5 plants namely Jerusalem artichoke, artemisia lavandulaefolia, erigeron annuus, sonchus oleraceus and artemisia sacrorum. From the table, we can see that, on the whole, the same type of heavy metal have different contents in 5 different plants; the amount of the same heavy metal absorbed is also different in the aerial and underground parts of one plant. For the element of Zn, the content is the highest in the aerial part of artemisia sacrorum, which is 52.4mg/kg; in artemisia lavandulaefolia, the root absorbs the largest amount of Zn, which is up to 70.77mg/kg; the aerial part of artemisia lavandulaefolia absorbs the largest amount of Mn, which is up to 85.26mg/kg; in erigeron annuus and artemisia lavandulaefolia, the roots absorb almost the same amount of Mn – above 150mg/kg; for the element of Cu, the root of artemisia lavandulaefolia absorbs the largest amount, which is 36.74mg/kg; aboveground, sonchus oleraceus absorbs the largest amount, which is 27.03mg/kg; for Cr, the root of artemisia sacrorum absorbs 60.36mg/kg, but the aerial part absorbs a relatively small amount; aboveground, the largest absorbed amount is 19.62mg/kg in artemisia sacrorum; 5 plants all absorb small amounts of Cd – aboveground, artemisia lavandulaefolia absorbs the largest amount, which is 1.68mg/kg, and in the root, artemisia lavandulaefolia absorbs the largest amount, too, which is 2.26mg/kg; both the aerial part and root of erigeron annuus absorb the largest amount of Pb, which is respectively 12.38mg/kg and 25.47mg/kg; sonchus oleraceus absorbs the largest amount of Ni, and the absorptions of the two parts are 60.68mg/kg and 25.63mg/kg, respectively.

It can also be seen from Table 1 that the average contents of the elements Zn and Mn in the five plants are much higher than those of other elements. The contents of Zn, Mn, Cu and Cd absorbed in Artemisia lavandulaefolia are the highest among the five plants; in Artemisia sacrorum, the contents of Cr and Ni are relatively high; in Erigeron annuus, the contents of Mn and Pb are relatively high; in Sonchus oleraceus, the content of Ni is relatively high; and in Jerusalem artichoke, the contents of Mn, Cu, Cr and Ni are the lowest among the five plants and much lower than those in other plants.

The aerial parts and roots of the 5 plants also show different heavy metal absorption capacities. For most heavy metal elements, artemisia lavandulaefolia, artemisia sacrorum, erigeron annuus and sonchus oleraceus absorb more in the root than in the aerial part, but Jerusalem artichoke is the opposite. Zn, Mn and Cu are the elements essential to plants, and appropriate concentrations can contribute to the plant growth; Cd and Pb are not essential to plants, and high content of Cd and Pb in the soil can inhibit the plant growth and even kill them. From the table, we can see that all these five kinds of plants can accumulate large amounts of Ni, Cr, Pb and Cd.

Table 1: The heavy metal content in aerial part of plants and root zone

Plant	Position	Heavy metal content of different plants(mg/kg)						
		Zn	Mn	Cu	Cr	Cd	Pb	Ni
Jerusalem	Root	24.4	39.79	7.11	8.22	0.37	4.41	7.38
artichoke	Aerial part	42.72	68.17	7.59	3.58	0.79	6.71	4.07
Artemisia	Root	70.77	152.98	36.74	22.94	2.26	21.07	30.13
lavandulaefolia	Aerial part	45.99	85.26	15.97	10.49	1.68	8.63	15.85
Erigeron	Root	37.55	155.47	13.99	57.9	1.11	25.47	57.83
annuus	Aerial part	46.34	69.55	16.89	12.16	1.46	12.38	8.33
Sonchus	Root	40.22	137.92	24.59	30.15	0.99	11.25	60.68
oleraceus	Aerial part	28.18	66.35	27.03	14.88	0.39	8.47	25.63
Artemisia	Root	37.55	112.66	22.31	60.36	1.19	9.02	50.23
sacrorum	Aerial part	52.4	63.85	16.93	19.62	1.01	8.15	20.18

2.3 Hyperaccumulation of heavy metal elements in different plants

Plant hyperaccumulation of heavy metal elements means that the cumulative absorption of one or more heavy metal elements in a plant is much greater than that in a non-hyperaccumulator, and the plant itself is not seriously damaged. By calculating the enrichment coefficients and transfer coefficients of heavy metals in plants, we can effectively select the plants with strong soil remediation capabilities as the dominant plants. Table 2 and Table 3 lists the enrichment and transfer coefficients of the 5 plants, respectively.

Table 2: Enrichment coefficients of 5 kinds of plants

Plant	Position	Enrichment coefficient						
		Zn	Mn	Cu	Cr	Cd	Pb	Ni
Jerusalem	Root	0.07	0.10	0.17	0.05	0.46	0.07	0.23
artichoke	Aerial part	0.12	0.17	0.18	0.02	1.01	0.11	0.13
Artemisia	Root	0.45	0.35	0.92	0.15	3.23	0.33	0.94
lavandulaefolia	Aerial part	0.29	0.19	0.40	0.07	2.40	0.14	0.50
Erigeron	Root	0.11	0.32	0.31	0.33	1.19	0.57	1.81
annuus	Aerial part	0.13	0.14	0.38	0.07	1.57	0.25	0.26
Sonchus	Root	0.07	0.40	0.82	0.10	0.82	0.24	1.44
oleraceus	Aerial part	0.05	0.19	0.90	0.05	0.32	0.17	0.61
Artemisia	Root	0.10	0.24	0.57	0.29	1.38	0.17	1.52
sacrorum	Aerial part	0.14	0.13	0.43	0.10	1.17	0.16	0.61

Table 3: Transfer coefficients of 5 kinds of plants

Plant	Transfer coefficient						
	Zn	Mn	Cu	Cr	Cd	Pb	Ni
Jerusalem artichoke	1.75	1.71	1.07	0.44	2.22	1.52	0.55
Artemisia lavandulaefolia	0.65	0.56	0.43	0.46	0.74	0.41	0.53
Erigeron annuus	1.23	0.45	1.21	0.21	1.32	0.45	0.14
Sonchus oleraceus	0.70	0.48	1.10	0.49	0.39	0.72	0.42
Artemisia sacrorum	1.40	0.57	0.76	0.33	0.85	0.90	0.40

It can be observed from Table 2 that different plants and even different parts of one plant have greatly different enrichment capacities of heavy metals. Except for Sonchus oleraceus, the enrichment coefficients of Cd in the aerial parts of all the plants are greater than 1, which are -1.01 for Jerusalem artichoke, -2.4 for artemisia lavandulaefolia, -1.57 for Erigeron annuus, and -1.17 for Artemisia sacrorum, and at the same time, the enrichment coefficients of Cd in the roots of artemisia lavandulaefolia, erigeron annuus and artemisia sacrorum are also greater than 1. The enrichment coefficients of Ni in the roots of Euminon annuus, Sonchus oleraceus and Artemisia sacrorum are all greater than 1, and those of the elements Zn, Mn, Cu, Cr and Pb are less than 1 in both the roots and aerial parts of the 5 plants.

As shown in Table 3, the transfer coefficients of 7 heavy metal elements to artemisia lavandulaefolia are all less than 1, indicating that artemisia lavandulaefolia is poor at transferring heavy metal elements in the soil and cannot remediate the soil effectively. The transfer coefficient of Zn to Artemisia sacrorum is greater than 1, but those of the other 6 elements to this plant are less than 1; the transfer coefficient of Cu to sonchus oleraceus is 1.10, and those of the other six elements to this plant are less than 1. It can be seen that sonchus oleraceus and artemisia sacrorum can only transfer specific heavy metal elements, that is, they can only remediate soil in specific environments. The transfer coefficients of most heavy metal elements to Jerusalem artichoke and erigeron annuus are greater than 1, indicating that the two can well transfer the heavy metal elements from the soil and remediate the soil. According to the calculation results of enrichment coefficients, Jerusalem artichoke and erigeron annuus are hyperaccumulators for the element Cd, and can be grown at a large scale to remediate the contamination of soil by Cd.

3. Selection of remediation plants for heavy metal pollution in copper mine soil

Based on the above analysis, we further analyze the remediation potentials of plants for common heavy metal pollution in copper mine soil in West China.

3.1 Testing materials and methods

The soil samples for testing were collected from a large copper mine in Northwest China. The remediation plants studied are clover, alfalfa and amorpha fruticosa. We took some aerial parts and roots of the three types of plants on site. The seeds of the plants cultivated in the laboratory were from a large seed company. Seed germination and growth were carried out in a sterile environment. The seeds were stored at a constant temperature for 15 days and soaked in tap water for 24h before the test. 50 seeds were picked for each type of plant and planted at a certain interval. The experimental culture environment is sunlight at 25℃ and soil that is kept moist. The average dry weight of seedlings was recorded according to the germination and growth of seeds.

We added copper slag into the soil at a content of 15%, 20%, 25%, 35% and 50% and set up two control groups - pure soil and pure slag groups to analyze the growth status of the three plants at different copper concentrations and their absorption of the heavy metal Cu. When the seedlings were grown to a certain height, we dried, grinded, purified and diluted them and at last used the flame atomic absorption spectrometry to determine the contents of Cu in these plants.

3.2 Analysis of testing results

Figure 1 shows curves of the germination rates and seedling heights of the three plants at different copper slag concentrations in the soil. As can be seen from the figure, with the increase of the proportion of copper slag, the germination rates of the three plants increase first and then decrease, i.e. “low-promoting and high-repressing”. This is because appropriate copper concentration can supply necessary materials and energy for seed germination, but excessively high copper concentration affects the activity of the enzyme in the seed. Clover, amorpha fruticosa and alfalfa reach a maximum germination rate when the copper concentration is 95%, 25% and 15%, respectively, and the maximum rates are 95%, 99% and 80%, respectively. The maximum germination rates of clover, amorpha fruticosa and alfalfa are 4.13, 1.27 and 1.95 times those when the copper concentration was 0%, indicating that an appropriate copper concentration can significantly promote the seed germination. When the copper concentration exceeds 35%, with the increase of the copper concentration, the germination rates of the three plant seeds are inhibited and rapidly decreased. When the copper concentration is 100%, the germination rates of clover, amorpha fruticosa and alfalfa reach the minimum values. At this time, the germination rates are 0.23, 0.29 and 0.2 times of the respective maximum germination rates.

From the seedling height curves of the three plants shown in Figure 1, it can be seen that when the copper concentration is between 20%-50%, it can obviously promote the heights of clover and alfalfa seedlings. The average heights are 1.49 and 1.31 times those when the copper concentration is 0%. With the copper concentration gradually increasing, this promotion is gradually decreased. When the copper concentration reaches 100%, the heights of seedlings are almost no different than those when the concentration is 0%. For amorpha fruticosa, instead of promoting the growth of seedlings, the increase of copper concentration only rapidly decreases their growth rate. When the copper concentration reaches 100%, the seedling height is only 0.8cm.

Figure 2 shows the curves of the root lengths and dry weights of the three plants. With the increase of copper concentration, the root lengths of the three plants also increase first and then decrease, among which, the root length of amorpha fruticosa is decreased the most significantly. The increase of copper concentration has different effects on the dry weights of the three plants. The dry weight of alfalfa is not significantly affected at high concentration, while those of clover and amorpha fruticosa are significantly decreased when the copper concentration is increased.

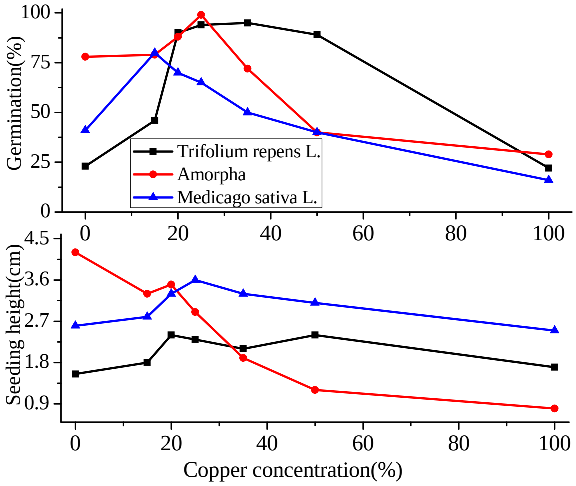

Figure 1: Germination and seeding height of 3 plants under different copper concentrations

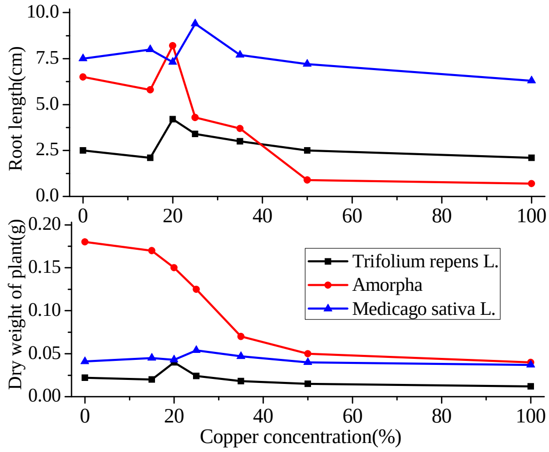

Figure 2: Root length and dry weight of 3 plants under different copper concentration

Figure 3 compares the copper absorption capabilities of the three plants. It can be seen from the figure that the copper absorption capabilities of the three plants are improved with the increase of copper concentration, and the absorbed amounts also increase gradually. When the concentration of copper is 100%, the plants with the content of copper from large to small are amorpha fruticosa, clover and alfalfa, and the plants with the amount of copper absorbed from large to small compared with that when the copper concentration is 0% are clover, amorpha fruticosa and alfalfa.
In summary, from the above analysis, we can see that clover absorbs the greatest amount of copper in the copper-contaminated soil, and when the copper concentration is high in the soil, the growth of this plant is the least inhibited. Therefore, it is an ideal plant for remediation of the copper contamination in the soil surrounding copper mines.

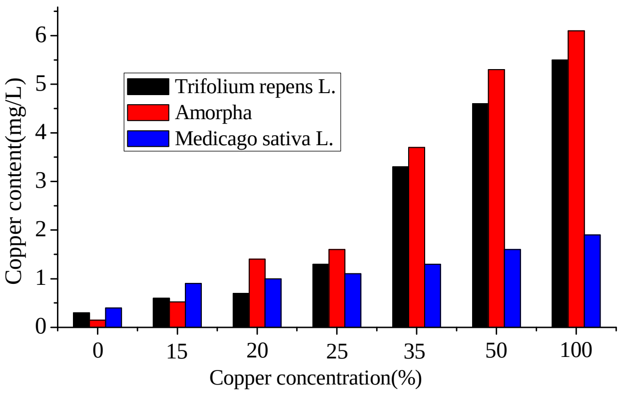

Figure 3: Copper enrichment content of 3 plants under different copper concentration

4. Conclusions

In this paper, in order to address the common serious soil pollution by heavy metal in the surroundings of coal and copper mines in China, we select heavy metal accumulating plants suitable for remediation of copper and coal mine soil, measure the contents of heavy metal elements in the plants and analyze the enrichment and transfer of heavy metal in plants to study the potentials of different plants to remediate heavily polluted soils in coal and copper mines. The conclusions are as follows:

According to the study on phytoremediation of heavy metal polluted soil surrounding coal mines: (1) The contents of the same heavy metal are different in five different plants, and the aerial and underground parts of the same plant absorb different amounts of the metal. The average contents of Zn and Mn in 5 kinds of plants are far higher than those of other elements. For most heavy metal elements, artemisia lavandulaefolia, artemisia sacrorum, erigeron annuus and sonchus oleraceus absorb more in the root than in the aerial part, but Jerusalem artichoke is the opposite. All these five kinds of plants can accumulate large amounts of Ni, Cr, Pb and Cd.

(2) Different plants and even different parts of one plant have greatly different enrichment capacities of heavy metals. Sonchus oleraceus and artemisia sacrorum can only transfer specific heavy metal elements, that is, they can only remediate soil in specific environments. The transfer coefficients of most heavy metal elements to Jerusalem artichoke and erigeron annuus are greater than 1, indicating that the two can well transfer the heavy metal elements from the soil and remediate the soil, and thus they are hyperaccumulating plants.

According to the study on phytoremediation of heavy metal polluted soil in coal mines:

(1) With the increase in the proportion of copper slag in the soil, the germination rate, root length and seedling height of clovers, alfalfa and amorpha fruticosa increase first and then decrease, i.e. “low-promoting and high-repressing”. When the copper concentration is between 20%-50%, it can obviously promote the heights of clover and alfalfa seedlings. With the copper concentration gradually increasing, this promotion is gradually decreased. For amorpha fruticosa, instead of promoting the growth of seedlings, the increase of copper concentration only make their growth rates rapidly decrease.

(2) The increase of copper concentration has different effects on the dry weights of the three plants. The dry weight of alfalfa is not significantly affected at high concentration, while those of clover and amorpha fruticosa are significantly decreased when the copper concentration is increased. The plants with the content of copper from large to small are amorpha fruticosa, clover and alfalfa, and the plants with the amount of copper absorbed from large to small compared with that when the copper concentration is 0% are clover, amorpha fruticosa and alfalfa. Clover absorbs the greatest amount of copper in the copper-contaminated soil, and when the copper concentration is high in the soil, the growth of this plant is the least inhibited. Therefore, it is an ideal plant for remediation of the copper contamination in the soil surrounding copper mines.

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