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Role of the different planting age of seabuckthorn forests to soil amelioration in coal mining subsidence land

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Abstract To investigate the effects of seabuckthorn (*Hippophae rhamnoides*) on soil amelioration, using the space replacement method, soil physical and chemical indexes as well as the microorganism quantity and soil enzyme activities were analyzed. The results showed that: the soil bulk density of surface soil decreased and soil porosity and field capacity increased after afforestation with seabuckthorn. The plant was found to effectively reduce the soil pH, increase the soil conductivity, soil organic matters and available nutrients. Soil microorganism quantity, soil enzyme activities were both higher in 0–20 cm layer than in 20–40 cm layer. With the increase years of remediation with seabuckthorn, the quantity of soil microorganism and enzyme activities were increasing to a higher level 5 to 8 years later. Our study indicates that seabuckthorn can effectively improve soil physical and chemical properties, increase the quantity of soil microorganisms and enzyme activities, which is of great significance for the ecosystem restoration in mining areas.

Keywords Coal mining subsidence land · Seabuckthorn plantation · Rhizosphere soil · Soil amelioration

1 Introduction

Coal is the main energy in China, accounting for over 70 % of energy consumption, and it will continue to occupy the dominant position in total energy consumption structure in the twenty-first century (Li 2011; Lin et al. 2014). Coal mining has made important contributions to economic development, however, with the expansion of the scale of coal mining, it has caused tremendous pressure and severe damage to the local ecological environment (Zang et al. 2010; Zhao et al. 2013). More than 95 % of coal production is from underground mining in China. Overlying strata will lost support and the overburden stress state of equilibrium is destroyed because of underground mining, which results the occurrence of mining subsidence (Li et al. 2011). In addition, coal mining has also caused land destructions, including decreased soil water content, increased soil permeability and erosion, intensified desertification (Zhang et al. 2003; Wang et al. 2008). The problem of ecological governance of wasteland in mining subsidence areas need to be addressed. Undoubtedly phytoremediation is one of the most important means of ecological restoration for the perturbed mining wasteland. *Hippophae rh*amnoides L., commonly known as seabuckthorn is a native tree species with characteristics such as rapid growth, quick adaptability and high economic and ecological value. The plant can grow on marginal land and is excellent for soil improvement (Ruan and Li 2002; Zhang and Chen 2007). It has been used for ecological restoration on coal mining subsidence land in recent years (Gao et al. 2009). In this paper, the effects of seabuckthorn plantation on soil environment after different periods were studied in attempt to provide new insights on land reclamation and ecological restoration on coal mining subsidence land.

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2 Material and methods

2.1 Study area

The Daliuta mining area is located in Shenmu County, Shaanxi Province in northwest China, at junction of northern Shaanxi plateau and Maowusu Desert. Mean elevation in the region is 1,334.1 m. The landscape is dominated by aeolian sands, sand dunes and sand ridges. The area has a typical continental semi-arid climate with long and cold winter, hot and short summer, frequent sandstorms and rainstorms, and higher diurnal temperature difference. The average annual temperature is about 8.4 °C with the highest temperature of 38 °C and the lowest of −28 °C. Mean annual precipitation is 441.2 mm, which is concentrated between June and September. Annual average evaporation is 2,211.2 mm. The site was chosen within the seabuckthorn planting area in the coal mining subsidence, where the terrain is relatively smooth and the soil is mainly barren sandy soil (Xu et al. 2008).

2.2 Soil samples selection

Seabuckthorn plantations of different planting years (1, 2, 5, 8 years) were selected and the bare sand was used as control. Underlying surface conditions of all the samples were the same.

In each quadrat area, 100 × 100 m^2 quadrat was selected and then 5 quadrats of 10 × 10 m^2 were selected in each big quadrat. After choosing standard plants in the each small quadrat and removing the surface litter around plant roots, the rhizosphere soil in depths of 0–20 cm and 20–40 cm were collected into sterile plastic bags, frozen and quickly transported back to the laboratory for analysis. The soil samples were divided into two parts, one was sieved through a mesh of <2 mm in diameter, and preserved at 4 °C for analysis of microbial quantity and enzymatic activity; the other was naturally air-dried, and sieved through a mesh of <1 mm in diameter for the analysis of soil physical–chemical properties.

2.3 Indexes measured

2.3.1 Soil physical and chemical indexes

Bulk density, porosity and field capacity were measured by the cutting ring method. Organic matters were determined by the external heating oxidation; nitrogen by the alkaline solution diffusion method; available phosphorus by the $NaHCO_3$ extraction colorimetric method and potassium by flame photometer. Soil pH value and electrical conductivity were measured by using pH and conductivity meters, respectively (Bao 2000).

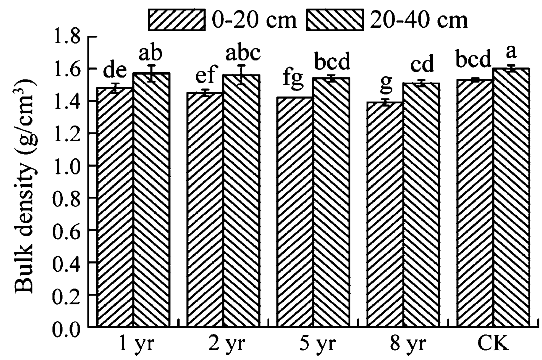

Fig. 1 Soil bulk density in seabuckthorn plantation area after different years of planting

2.3.2 Soil biological indexes

The microbial analysis was conducted by the dilution-plate method (Shen et al. 1999). The bacteria were incubated on beef extract peptone medium; actinomycetes were cultured on the modified Gao medium, fungi on the Rose Bengal Agar medium. Phosphatase activity was measured by the improved method of Tabatabai and Brimner (Phillips and Hayman 1970). In addition, invertase and urease activities were determined by using 3,5-dinitrosalicylic acid colorimetry and the modified phenol hypochlorite colorimetric method respectively (Du et al. 2013).

2.4 Data analysis method

The data were analyzed by using Excel 2007 software, and DPS7.05 software was used to test the significance of difference.

3 Results

3.1 Soil physical properties

Bulk density is an important physical property of the soil, which is an indicator to measure the degree of soil compaction (Sun et al. 2007). Soil bulk density changed between 1.39 and 1.60 g/cm^3, in 0–20 cm layer. After remediation for 5 and 8 years, the bulk density was significantly smaller than those in other years and the bare land ($P < 0.05$), indicating that planting seabuckthorn could decrease the soil bulk density (Fig. 1). In 20–40 cm layer, the bulk densities of all restoration years were not significantly as compared to 0–20 cm, however, the density decreased gradually with the increasing planting time.

Soil field capacity in 0–20 cm layer was higher than - that in 20–40 cm layer (Fig. 2). In 0–20 cm layer, the field capacities after 5 and 8 year of remedation were up to 24.12 % and 26.14 % respectively, significantly higher than those in other samples ($P < 0.05$). In 20–40 cm layer, the holding capacity in each quadrat at different restoration years was significantly higher than that in the bare land, except in quadrat of one year restoration. The results indicated that planting seabuckthorn could significantly improve soil water holding capacity, which is important for ecological restoration of mining subsidence.

The soil porosity showed in order of 8 years > 5 years > 2 years > 1 year > CK in 0–20 cm layer (Fig. 3). Compared with the other quadrats, the 5 and 8 year quadrats were significantly different. In 20–40 cm layer, the porosity after 8 year of restoration was the highest, and had increased 40.2 % compared with the control. Root growth of seabuckthorn is believe to loose the soil and improves the gas, thermal and fertilization conditions of the soil.

3.2 Soil chemical properties

With the increase in seabuckthorn plantation time, soil pH value decreased (Table 1), making the nutrient in soil to be released, resulting in better seabuckthorn growth. Soil electrical conductivity reflects the content of the main ion in the soil, and has an impact on the effectiveness of fertilizers. The results showed that the electrical conductivities in seabuckthorn planting quadrats were significantly higher than that in the bare land ($P < 0.05$). Additionally, with increasing restoration years, the electrical conductivity reached a maximum after 8 years, which were 104.9 %–211.6 % higher compared with the control.

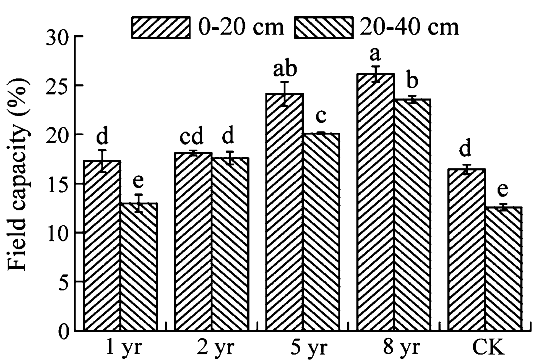

Fig. 2 Soil water holding capacity in seabuckthorn plantation area after different years of planting

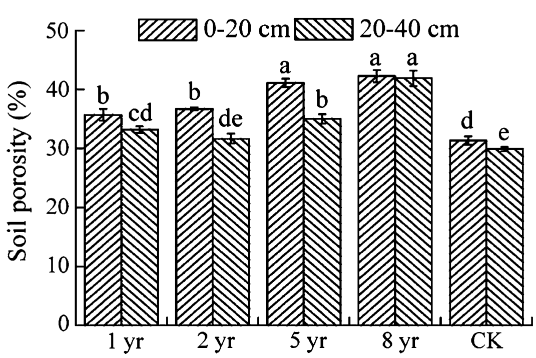

Fig. 3 Soil porosity in seabuckthorn plantation area after different years of planting

Soil organic matter is an important index to reflect the soil fertility. The difference in soil organic matter contents between seabuckthorn area and the bare land was not significant one and two years after planting ($P > 0.05$). With increasing plantation age, the soil organic matter content increased gradually, and began to show significant difference after 5 years ($P < 0.05$). The content reached the maximum after 8 years.

Available nutrients in soil are essential for normal growth of plant and are absorbed by the plant, meanwhile, the decomposition of plant litter will return nutrients back into the soil, which increases the soil fertility. Soil available nitrogen, available phosphorus and available potassium contents in the seabuckthorn area were higher than in the bare land, and were increased with the plantation age (Table 1), showing that the cultivation of seabuckthorn had certain stimulative effect on soil fertility.

3.3 Biological properties

3.3.1 Enzyme activity

Soil enzymes are active participants all biochemical processes in the soil and they are shown to be sensitive and reliable indicators of soil biological activity and soil fertility (Yang and Wang 2004). For example, the activity of phosphatase is related to many physiological and biochemical processes of cell and can be used to reflect the transformation status of soil organic phosphorus (Xie et al. 2013). The results showed that the activity of acidic phosphatases in rhizosphere of seabuckthorn plants began to be different after one year of growing ($P < 0.05$), which may be due to positive effects produced by the root activity and root exudates of seabuckthorn plants. With increasing growing time, the activitity of acid phosphatase showed an increasing trend and reached to a higher level after 5 and 8 years,when the activities in 0–20 cm and 20–40 cm soil layers increased by 102.88 %, 106.17 % and 87.88 %, 81.81 %, respectively, as compared with those in the bare land.

The invertase breaks down sucrose molecules in the soil into fructose and glucose, which is conducive to the uptake and utilization by plant and microbe. The activity of the enzyme may reflect the accumulation and decomposition of soil organic carbon (Zhao et al. 2014). Our data showed that

Table 1 Chemical comparisions of properties in seabuckthorn plantation area after different years of planting

Planting years (yr)	Soil depth (cm)	PH	Ec	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	Organic matter (g/kg)
1	0–20	7.87 ± 0.04b	57.63 ± 1.06de	16.92 ± 2.02de	1.09 ± 0.21bc	50.43 ± 1.77c	14.16 ± 0.41cd
	20–40	8.06 ± 0.13a	61.40 ± 1.01d	8.75 ± 3.50f	0.70 ± 0.01d	28.64 ± 0.62e	5.36 ± 0.88f
2	0–20	7.90 ± 0.03b	55.33 ± 2.15e	15.17 ± 1.01def	1.17 ± 0.04b	55.74 ± 4.08bc	14.85 ± 1.65c
	20–40	8.11 ± 0.05a	43.00 ± 1.73f	10.50 ± 1.75ef	0.50 ± 0.10d	36.99 ± 0.47d	5.87 ± 0.51f
5	0–20	7.58 ± 0.06c	86.60 ± 2.79b	25.08 ± 4.04bc	1.59 ± 0.22a	37.84 ± 0.56d	17.66 ± 1.88b
	20–40	7.66 ± 0.02c	74.50 ± 3.00c	21.00 ± 3.03 cd	1.68 ± 0.14a	39.25 ± 0.35d	8.86 ± 0.97e
8	0–20	7.46 ± 0.02d	88.17 ± 3.45b	36.75 ± 3.50a	1.41 ± 0.06ab	111.77 ± 3.55a	22.95 ± 1.66a
	20–40	7.42 ± 0.04d	95.57 ± 5.71a	32.08 ± 1.01ab	0.58 ± 0.04d	57.05 ± 0.84b	12.96 ± 1.15d
CK	0–20	7.90 ± 0.06b	43.03 ± 1.50f	13.18 ± 1.62ef	0.77 ± 0.11 cd	23.27 ± 1.15ef	14.34 ± 2.14cd
	20–40	8.01 ± 0.09a	30.67 ± 2.50g	7.58 ± 2.67f	0.57 ± 0.05d	20.37 ± 0.66f	5.57 ± 0.73f

Table 2 Rhizosphere enzyme activities in seabuckthorn plantation area after different years of planting

Planting years (yr)	Soil depth (cm)	Invertase activity (mg/g)	Urease activity (mg/g)	Acid phosphatase activity (umol/gsoil/h)
1	0–20	2.42 ± 0.10d	0.10 ± 0.01de	3.46 ± 0.12bcd
	20–40	0.81 ± 0.10 fg	0.10 ± 0.00de	3.06 ± 0.19d
2	0–20	3.83 ± 0.35c	0.16 ± 0.01cd	3.16 ± 0.20cd
	20–40	1.53 ± 0.21ef	0.13 ± 0.00de	2.48 ± 0.09e
5	0–20	5.10 ± 0.20b	0.24 ± 0.01c	4.93 ± 0.18a
	20–40	1.90 ± 0.20de	0.17 ± 0.02cd	3.72 ± 0.14b
8	0–20	13.70 ± 0.53a	0.96 ± 0.04a	5.01 ± 0.21a
	20–40	4.43 ± 0.23bc	0.47 ± 0.08b	3.60 ± 0.26bc
CK	0–20	2.13 ± 0.15de	0.05 ± 0.01e	2.43 ± 0.15e
	20–40	0.70 ± 0.10g	0.05 ± 0.00e	1.98 ± 0.10e

the invertase activity after different years of remediation were higher than that of the control, and after 2 years, the activity was significantly different from the control ($P < 0.05$), and at soil depths of 0–20 cm and 20–40 cm the activity increased by 79.8 % and 118.6 %, respectively as compared with that of the control. When restored for 8 - years, the soil enzyme activity reached the maximum, and at 0–20 cm and 20–40 cm, it was 13.70 and 4.43 mg/g, respectively, an increase of 543.2 % and 532.9 %, respectively, as compared with the control (Table 2).

Urease can hydrolyze organic urea compounds into ammonia nitrogen, making them available to plants. The activity of the enzyme has a close relationship with nitrogen transformation in soil. The results showed that in comparison with the control, the artificial seabuckthorn afforestation increased the urease activity in soil and the increase was bigger as the year of afforestation increased. Eight years after the planting, the activity was the highest and was 18.2 and 8.4 times than that of control at the two soil depths, respectively. Our findings clearly showed that the cultivation of seabuckthorn can greatly enhance the activity of metabolic enzymes in the soil, and are positive for improving soil fertility.

3.3.2 *The number of soil microorganisms*

Soil microorganism is an important part of soil biological characteristics, which is the embodiment of soil biological activity and can reflect the changes of soil environmental quality sensitively (Hu et al. 2006; Yang et al. 2013). The number of bacteria, actinomycetes and fungi are presented in Table 3. The numbers were higher in soil depth of 0–20 cm than in 20–40 cm (Table 3). Compared with bare soil, the number of microorganisms increased with the increasing planting years, suggesting that seabuckthorn plant had significant effect on microbial activity in the rhizosphere soil. Analysis of variance indicated that, compared with bare land, the numbers of bacteria and actinomycetes after five and eight years of remediation were significantly greater in the 0–20 cm layer ($P < 0.05$); the number of fungi was significantly higher ($P < 0.05$) after eight years. The data also showed that the microbial number was larger but not significantly larger after one and two years of afforestation as compared with control ($P > 0.05$).

Table 3 Number of rhizosphere microorganisms in seabuckthorn plantation area after different years of planting

Planting years (yr)	Soil depth (cm)	Bacteria/(10^5 cfu/g)	Fungi (10^3 cfu/g)	Actinomycetes (10^4 cfu/g)	The total (10^5 cfu/g)
1	0–20	56.18 ± 8.41c	9.54 ± 1.06cd	108.12 ± 5.61de	67.09 ± 7.91c
	20–40	28.26 ± 2.09de	3.49 ± 1.60d	99.08 ± 10.74efg	38.20 ± 2.92d
2	0–20	54.53 ± 3.35c	9.15 ± 2.76cd	151.52 ± 21.18c	69.78 ± 3.93c
	20–40	28.88 ± 1.59de	6.26 ± 3.76cd	69.60 ± 6.71fg	35.90 ± 0.98d
5	0–20	81.48 ± 6.17b	11.59 ± 2.79c	221.27 ± 10.54b	103.73 ± 6.10b
	20–40	53.51 ± 1.65c	6.11 ± 1.65cd	65.73 ± 7.07g	60.15 ± 1.65c
8	0–20	136.47 ± 16.35a	59.08 ± 3.61a	375.40 ± 24.27a	174.61 ± 14.35a
	20–40	46.97 ± 3.13cd	30.27 ± 4.78b	138.49 ± 3.52cd	61.13 ± 2.74c
CK	0–20	22.52 ± 3.23e	6.33 ± 1.0cd	105.93 ± 14.18def	33.18 ± 3.07d
	20–40	16.57 ± 2.66e	3.53 ± 1.62d	81.44 ± 7.99efg	24.75 ± 1.91d

4 Discussions

In the long run, phytoremediation is definitely a good choice for the land reclamation in coal mining subsidence. After planting seabuckthorn, the soil could become looser and the bulk density of surface soil also tended to decrease, and the porosity accordingly increased with the development of underground root systems. All these contributed to improve the structure of soil and the ability to hold water, which is of great significance for the subsidence land in the semi-arid and arid region in western China, as well as for subsequent ecological succession.

Seabuckthorn plantation was shown to play a role in reducing the soil pH, and improving soil electrical conductivity. This might be due to the accumulation of organic acids secreted or discharged from microorganisms, animals, plant roots and leaf litters on the surface soil. The improvement of soil's electrical conductivity might be resulted from the accumulation of K^+, Na^+ and Mg^{2+} ions released from the plant roots. Seabuckthorn can increase the content of nitrogen in soil, and improve soil fertility through nitrogen fixation by nitrogen-fixing bacteria Frankia in rhizosphere. In this study, in comparison with bare land, in the seabuckthorn woodland the content of soil available nitrogen content increased by 179 %–323 % after 8 years of remediation. Though the content is still low, it is useful for the sustainable development of the damaged ecosystem.

During the growth of plants mineral elements are absorbed and enriched in the surface in various forms. That is, the nutrients are absorbed by root systems, stored in the surface soil in the form of organic matters, and then quickly decomposed by microbes. The soil organic matter content in the early stage of study (one and two years after planting) and in bare sandy land were not different remarkably. However, with the rapid development of above-ground plants and underground roots, the roots of plants, the litters, the surface and underground secretions, such as the root residues all became important sources of soil organic matter.

Rhizosphere microorganisms are beneficial for plant, and their proliferation is supported by root extrudes from plants (Huang 2000). Enzymes in the soil mainly come - from the microbes, animals and plant roots, and the increase of their activity is an important indication of improvement in soil qualities such as physical and chemical properties physical and chemical properties (Liu et al. 2014). Our data showed that the growth of seabuckthorn helped to increase the amounts of microbes in rhizosphere soil, and that the number of bacteria, fungi, actinomycetes increased obviously as compared with bare land. An increase in the number of microorganism in coal mining subsidence land is conducive to soil metabolism and thereby speed up restoration of damaged ecosystem. Meanwhile, the activities of soil enzymes, such as acid phosphatase, urease and invertase activity were also sharply in the seabuckthorn area as growth time increased. The restoration was found to be proportional to the length of remediation. Increased activities of microorganisms and soil enzymes also indicated that the seabuckthorn plantation is effective in improving the soil quality and these activities can be used as important biological indicators to measure the restoration of damaged ecosystem.

5 Conclusion

Coal mining has caused serious damage for soil ecological environment in mining area, and reasonable planting of seabuckthorn ecological forest is ecologically beneficial. Our analysis of soil samples from the afforestation area showed that seabuckthorn plantation can improve soil structure and properties, reduce soil bulk density, increase soil porosity and field capacity as well as soil available nutrients significantly. Meanwhile the cultivation of seabuckthorn plants can effectively improve the activity of soil enzymes, such as invertase, urease, acid phosphatase. The forests could increase the number of soil microbes, which effectively promote the metabolic activity in the soil enzymes and material circulation. Because of physiology and growth characteristics of seabuckthorn, the growth of aboveground part and its root starts to speed up 2 years after planting. After 5 to 8 years, the seabuckthorn forest can generate remarkable ecological effect.

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