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Hua Li[1,2]
Hongbo Shao[2,3]
Weixiang Li[4,*]
Rutian Bi[4]
Zhongke Bai[5]

[1]College of Environment and Resources, Shanxi University, Taiyuan, P. R. China
[2]The CAS/Shandong Provincial Key Laboratory of Coastal Environmental Process, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (CAS), Yantai, P. R. China
[3]Institute for Life Sciences, Qingdao University of Science & Technology (QUST), Qingdao, P. R. China
[4]Shanxi Agricultural University, Taigu, P. R. China
[5]Department of Land Science Technology, University of Geosciences, Beijing, P. R. China

Short Communication

Improving Soil Enzyme Activities and Related Quality Properties of Reclaimed Soil by Applying Weathered Coal in Opencast-Mining Areas of the Chinese Loess Plateau

There are many problems for the reclaimed soil in opencast-mining areas of the Loess Plateau of China such as poor soil structure and extreme poverty in soil nutrients and so on. For the sake of finding a better way to improve soil quality, the current study was to apply the weathered coal for repairing soil media and investigate the physicochemical properties of the reclaimed soil and the changes in enzyme activities after planting *Robinia pseucdoacacia*. The results showed that the application of the weathered coal significantly improved the quality of soil aggregates, increased the content of water stable aggregates, and the organic matter, humus, and the cation exchange capacity of topsoil were significantly improved, but it did not have a significant effect on soil pH. Planting *R. pseucdoacacia* significantly enhanced the activities of soil catalase, urease, and invertase, but the application of the weathered coal inhibited the activity of catalase. Although the application of appropriate weathered coal was able to significantly increase urease activity, the activities of catalase, urease, or invertase had a close link with the soil profile levels and time. This study suggests that applying weathered coals could improve the physicochemical properties and soil enzyme activities of the reclaimed soil in opencast-mining areas of the Loess Plateau of China and the optimum applied amount of the weathered coal for reclaimed soil remediation is about 27 000 kg hm^{-2}.

Keywords: Mineland restoration and remediation; Physiochemical properties; *Robinia pseucdoacacia*; Soil quality indicators

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1 Introduction

The mining has caused large-scale destruction of the land in China and the world, which is a very serious issue and has been one of the biggest concerns. All countries in the world, in particular the major mining-industrial countries attach great importance to the land restoration devastated by the mining industry. In China there are more people with less land. Soil and environmental damage caused by human activities such as mining have reached a large amount and covered wide areas, which has repudiated numerous debts to the environment. According to statistics, more than 85% of China's annual industrial solid waste emissions have come from the mining. The national mining of China has accumulated an area of about 6 million hm^2, destroying nearly 2 million hm^2 of land and is still rising at a rate of 40 000 hm^2 annually [1–3]. It was reported that the land collapse and destruction and occupied land of coal-mining wastes in Shanxi coal industries have totally reached 66 700 hm^2, and are growing at a rate of 5000 hm^2 year^{-1}, 40% of which are arable land [4–6]. Soil food web structure is an integral component of ecosystem function, but there are few strategies orientated toward managing its development in restoration projects [7–10]. Therefore, rehabilitation and reconstruction of the degraded ecosystems in the mining-areas have become one of the research spots of the international soil restoration and remediation, land use, and soil conservation fields [11, 12].

Weathered coal, as waste coal of coal-mining production, widely exists in the mining-area, which has not been used as useful mineral resources at all times. The humic acid-type substances rich in it have a wide range of potential application prospects. In China humic acid content in weathered coal is more abundant, for instance Shanxi, Xinjiang, and some other places have abundant reserves of weathered coal with high quality [13–17]. From the angle of the rational use of available resources to solve environmental problems, there is a need to conduct in-depth study of humic acid materials in the weathered coal in a targeted manner. In this context, the specific questions we should to answer: (1) Do the application of weathered coal and planting *Robinia pseucdoacacia* affect physicochemical prop-

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Correspondence: Professor H. Shao, Institute for Life Sciences, Qingdao University of Science & Technology (QUST), Qingdao 266042, P. R. China
E-mail: shaohongbochu@126.com

[*]Additional corresponding author: H. Li, lihua@sxu.edu.cn

Table 1. Basic properties of soil in the experiment site

Parameter	Value	Parameter	Value
Bulk density (g cm^{-3})	1.50	Organic matter (g/kg)	0.32
pH value	8.49	Total N (g/kg)	0.20
Total carbon of humus (%)	0.04	Olsen P (mg/kg)	7.81

erties in Pingshuo Antaibao opencast-mining area of the Chinese Loess Plateau? (2) Are there any changes in soil enzyme activities related to weathered coal application?

2 Materials and methods

2.1 Case study area

The experiments were conducted in the black triangle zone bordering the Loess Plateau of Shanxi province, Shaanxi province, and Inner Mongolia within the border of Shuozhou City in the north of Shanxi Province. The geographical coordinates are E 112° 10′–113° 30′ and N 39° 23′–39° 37′. It belongs to a typical semi-arid temperate continental monsoon climate zone, with an average annual temperature of 4.8–7.8°C, average annual rainfall 428.2–449.0 mm, and annual evaporation amount 1786.6–2598.0 mm more than four times of the precipitation. Frost-free period is about 115–130 days. Geomorphology of the mining areas belongs to a gentle slope hilly region with widespread loess, sparse vegetation, serious water erosion, and wind erosion and an elevation of 1180–1500 m. Zonal soil of the mining area is transitional zone of the chestnut soil and chestnut cinnamon, and the zonal vegetation belongs to the type of arid grassland vegetation [18]. Due to the destruction of mining activities (stripping, transport, heaping and padding, and subsidence) for the mine surface, the original physical and chemical properties of the soil of mine district make fundamental changes, which are reflected mainly in severely damaged soil aggregates, loose soil, significantly decreased capability of corrosion resistance [3], decreased content of soil organic matter, and an extreme shortage of nutrients [18]. The pH value of weathered coal is 6.16 measured with H_2O. Total carbon of humus content is 44.64%. And basic properties of the soil in the experimental site are shown in Tab. 1.

2.2 Experimental design

The field experiment was conducted at the following application rates: 0, 13 500, 27 000, 40 500, and 54 000 kg hm^{-2}. Each treatment with an area of 30 m^2 had three replicates and was arranged in a randomized block design to investigate effects on physicochemical changes and soil enzyme activities.

The experiment was conducted on April 20, 2006 by applying weathered coal and planting *R. pseucdoacacia*. Soil samples with 0–20 and 20–40 cm depth were taken on July 20 (3 months) and September 20 (6 months) in 2006, respectively, and they were air-dried, then passed through 1.0 and 0.25-mm sieves for determination.

Detection steps: by adopting dry filtration method to determine the soil aggregates, and the method of water purifying to determine soil water-stable aggregates; by the potential method to measure pH value and the potassium dichromate-volumetric method to measure organic matter; determine humus with the method of the soil humus composition measure [19]; determine cation exchange capacity by ammonium acetate method [2]; adopt the method of permanganate titration to measure catalase, sodium phenoxide colorimetry for determination of urease, and colorimetric determination of invertase with 3,5-dinitrosalicylic acid [20].

The experimental data were arranged with Microsoft Excel. The analysis of variance (ANOVA) and the Duncan's multiple range tests (DMRT) procedure were applied with the statistical software SPSS13.0 for data analysis.

3 Results

3.1 Effects of weathered coal on soil physical and chemical properties

3.1.1 Structure of soil aggregates

Percentage of soil aggregates (Tabs. 2 and 3) in 0–20 cm soil layer was significantly higher than that of the control group ($p < 0.05$) with application of weathered coal, and reached a maximum of 89.22% when the application amount of weathered coal is 40 500 kg hm^{-2}. The content of soil aggregates decreased with the extension of remediation time. The quality percentages of all levels of soil aggregates in 20–40 cm depth were higher than those in 0–20 cm layer. Results showed that the proper application of the weathered coal could significantly increase aggregates content in arable soil and applying 40 500 kg hm^{-2} of the weathered coal achieved the best remediation for the soil aggregates. In this research the role of planting *R. pseucdoacacia* in the same year did not reached significant levels in terms of soil aggregates.

3.1.2 Soil organic matter content

Soil organic matter is not only the source of plant nutrition and mineral nutrition, but also the organic cement for formation of soil

Table 2. Effects of different weathered coal treatments on soil aggregates (%)

Dose of weathered coal (kg hm^{-2})	3 months		6 months	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
0	71.50 ± 1.98^{eB}a)	86.93 ± 1.02^{eA}	60.21 ± 2.01^{eD}	66.85 ± 1.09^{eC}
13 500	85.84 ± 4.01^{bD}	93.34 ± 2.03^{bA}	86.20 ± 1.32^{bC}	89.47 ± 1.42^{aB}
27 000	81.78 ± 2.03^{cD}	92.17 ± 0.97^{cA}	84.80 ± 1.36^{cC}	88.29 ± 2.03^{bB}
40 500	89.43 ± 2.10^{aB}	99.99 ± 0.12^{aA}	89.22 ± 2.31^{aB}	86.77 ± 2.01^{cC}
54 000	81.50 ± 2.32^{dB}	89.85 ± 3.01^{dA}	70.85 ± 2.34^{dC}	73.70 ± 1.05^{dC}

a) Mean of three replicated observations ± standard deviation. In a column, means followed by a common letter are not significantly different ($p < 0.05$) by Duncan's multiple range test (DMRT).

Table 3. Effects of weathered coal treatments on soil water stable aggregates (%)

Dose of weathered coal (kg hm^{-2})	3 months		6 months	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
0	$86.07 \pm 2.10^{\mathrm{dB}}$[a)]	$86.03 \pm 1.53^{\mathrm{aB}}$	$82.03 \pm 1.56^{\mathrm{eC}}$	$89.20 \pm 1.34^{\mathrm{cA}}$
13 500	$82.80 \pm 1.89^{\mathrm{eC}}$	$76.43 \pm 6.01^{\mathrm{eD}}$	$88.80 \pm 2.68^{\mathrm{aA}}$	$87.60 \pm 4.06^{\mathrm{dB}}$
27 000	$90.43 \pm 4.02^{\mathrm{bA}}$	$84.40 \pm 2.10^{\mathrm{bC}}$	$87.20 \pm 3.21^{\mathrm{bB}}$	$87.20 \pm 2.35^{\mathrm{eB}}$
40 500	$91.57 \pm 3.23^{\mathrm{aA}}$	$80.40 \pm 4.11^{\mathrm{dC}}$	$86.40 \pm 1.54^{\mathrm{cB}}$	$91.60 \pm 3.03^{\mathrm{aA}}$
54 000	$89.63 \pm 4.00^{\mathrm{cB}}$	$80.80 \pm 1.03^{\mathrm{cD}}$	$85.20 \pm 5.02^{\mathrm{dC}}$	$91.20 \pm 4.01^{\mathrm{bA}}$

[a)] Mean of three replicated observations ± standard deviation. In a column, means followed by a common letter are not significantly different ($p < 0.05$) by Duncan's multiple range test (DMRT).

Table 4. Effects of weathered coal treatments on soil organic matter (%)

Dose of weathered coal (kg hm^{-2})	3 months		6 months	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
0	$0.56 \pm 0.01^{\mathrm{dB}}$[a)]	$0.35 \pm 0.01^{\mathrm{cD}}$	$0.78 \pm 0.00^{\mathrm{dA}}$	$0.45 \pm 0.00^{\mathrm{aC}}$
13 500	$0.51 \pm 0.01^{\mathrm{eB}}$	$0.37 \pm 0.01^{\mathrm{cC}}$	$0.66 \pm 0.00^{\mathrm{eA}}$	$0.40 \pm 0.00^{\mathrm{bC}}$
27 000	$1.08 \pm 0.00^{\mathrm{cB}}$	$0.55 \pm 0.01^{\mathrm{aC}}$	$1.35 \pm 0.01^{\mathrm{bA}}$	$0.39 \pm 0.00^{\mathrm{bD}}$
40 500	$1.31 \pm 0.01^{\mathrm{aA}}$	$0.39 \pm 0.02^{\mathrm{cB}}$	$1.30 \pm 0.00^{\mathrm{cA}}$	$0.42 \pm 0.01^{\mathrm{abB}}$
54 000	$1.14 \pm 0.02^{\mathrm{bB}}$	$0.45 \pm 0.00^{\mathrm{bC}}$	$1.78 \pm 0.01^{\mathrm{aA}}$	$0.47 \pm 0.00^{\mathrm{aC}}$

[a)] Mean of three replicated observations ± standard deviation. In a column, means followed by a common letter are not significantly different ($p < 0.05$) by Duncan's multiple range test (DMRT).

structure. The content of organic matter is considered as an important indicator to measure soil fertility [21, 22]. Soil organic matter contents of 0–20 cm depth (Tab. 4) increased with the increase in the application amount of the weathered coal, which were all significantly higher than those before the reclamation ($p < 0.05$), and up to the maximum with an increase of 1.78% when the application amount of weathered coal was 54 000 kg hm^{-2}, followed by 1.35% when the application of weathered coal was 27 000 kg hm^{-2}, 1.7 times and 1.2 times of the control soil before reclamation, respectively. The soil organic matter content of 20–40 cm depth had no significant change with the increase in the application amount of weathered coal ($p > 0.05$). Soil organic matter contents of 0–20 cm depth in all the treatments were significantly increased ($p < 0.05$) except that applying 40 500 kg hm^{-2} of the weathered coal did not reach the significant level. For the same amount of weathered coal treatments, soil organic matter content in 0–20 cm depth was significantly higher than that in 20–40 cm depth. One of the reasons for that was related to the way of applying weathered coal. The other reason was that 0–20 cm depth was used as farming land, decomposition, and transition of the organic matter input into it occurred mainly in this depth. Thus, the different treatments have evident influence on the soil organic matter content in the layer [3, 23]. Soil organic matter composition was changed with NPK-fertilization [2, 24].

3.1.3 Soil humus

Humus is the basic material of soil fertility, and also the most active part of the soil, which has an important effect on the level of fertility [10, 11]. Soil humus content of 0–20 cm depth increased with the increase in the application amount of weathered coal (Tab. 5), which was up to a maximum of 0.15% and five times of the control group when 54 000 kg hm^{-2} of weathered coal was applied. Soil humus content of 20–40 cm depth showed no significant change with increasing weathered coal ($p > 0.05$). Effects of treatment time on the soil humus content in 0–20 cm soil depth all reached significant levels in addition to the 13 500 and 40 500 kg hm^{-2} treatment ($p < 0.05$). According to analysis this result is related to the root

Table 5. Effects of weathered coal treatments on soil humus

Dose of weathered coal (kg hm^{-2})	3 months		6 months	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
0	$0.03 \pm 0.00^{\mathrm{dA}}$[a)]	$0.02 \pm 0.00^{\mathrm{aA}}$	$0.03 \pm 0.00^{\mathrm{dA}}$	$0.03 \pm 0.00^{\mathrm{aA}}$
13 500	$0.06 \pm 0.00^{\mathrm{cA}}$	$0.02 \pm 0.00^{\mathrm{aB}}$	$0.06 \pm 0.01^{\mathrm{cA}}$	$0.04 \pm 0.01^{\mathrm{aAB}}$
27 000	$0.10 \pm 0.01^{\mathrm{bA}}$	$0.03 \pm 0.01^{\mathrm{aB}}$	$0.12 \pm 0.00^{\mathrm{bA}}$	$0.03 \pm 0.01^{\mathrm{aB}}$
40 500	$0.13 \pm 0.01^{\mathrm{aA}}$	$0.03 \pm 0.00^{\mathrm{aB}}$	$0.12 \pm 0.00^{\mathrm{bA}}$	$0.03 \pm 0.00^{\mathrm{aB}}$
54 000	$0.10 \pm 0.01^{\mathrm{bB}}$	$0.04 \pm 0.00^{\mathrm{aC}}$	$0.15 \pm 0.01^{\mathrm{aA}}$	$0.03 \pm 0.00^{\mathrm{aC}}$

[a)] Mean of three replicated observations ± standard deviation. In a column, means followed by a common letter are not significantly different ($p < 0.05$) by Duncan's multiple range test (DMRT).

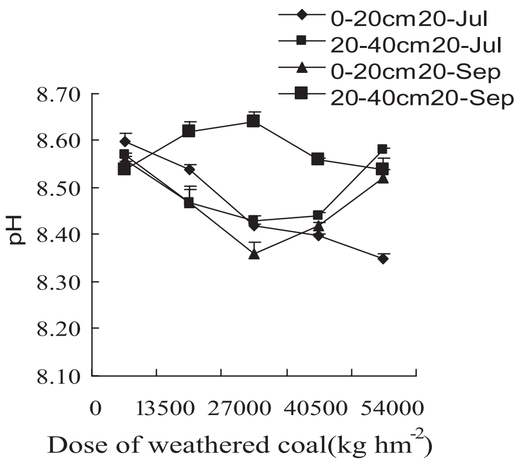

Figure 1. Effects of different weathered coal treatments on soil pH.

secretions of *R. pseucdoacacia* accelerating the formation of humus. Effects of the weathered coal treatment in 20–40 cm depth on soil humus content did not reach significant levels. After remediation with *R. pseucdoacacia* soil humus contents of different depths of the control group had no significant difference. For all the other treatments in the circumstances of the same application amount of weathered coal, soil humus content of 0–20 cm depth was significantly higher than that of 20–40 cm depth.

3.1.4 Soil pH value

Soil pH did not show significant changes with the increase in the weathered coal application amount (Fig. 1) ($p > 0.05$), the maximum 8.62 and the minimum 8.35. Soil pH in 0–20 cm soil depth is the minimum of 8.35 when the applied weathered coal amount is 54 000 kg hm^{-2}. Results showed that effects of application of weathered coal on soil pH were within the scope of the small variation, which did not affect the planting and normal growth of the vegetation.

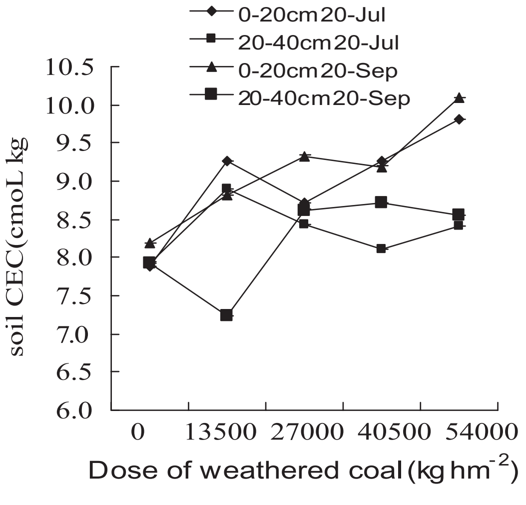

Figure 2. Effects of different weathered coal treatments on soil CEC.

3.1.5 Soil cation exchange capacity

Soil cation exchange capacity increased with the increased application of weathered coal, which was all significantly greater than that of the control group (Fig. 2). And with the extension of the remediated time it continued increasing, of which the largest increase is 9.33 cmol kg^{-1} at 27 000 kg hm^{-2} treatment and 1.14 times of the control group. When the applied weathered coal was 54 000 kg hm^{-2}, it reached a maximum of 10.09 cmol kg^{-1} and 1.23 times of that of the control group. Apart from the 13 500 kg hm^{-2} treatment, soil cation exchange capacity of all other pilot areas in 20–40 cm depth showed an increasing trend. After planting *R. pseucdoacacia*, soil cation exchange capacity between the different depths of control group had no significant difference, while the soil cation exchange amount in 0–20 cm-depth for other treatment combinations in the same amount of applied weathered coal was all higher than that of 20–40 cm depth.

3.2 Effects of weathered coal treatments on soil enzyme activities

Soil urease activities of 0–20 cm soil depth (Tab. 6) significantly increased with the increased weathered coal, and it reached the highest (3.25 mg g^{-1}), 2.6 times of the control in the 54 000 kg hm^{-2}of applied weathered coal. The content of urease in the same topsoil had a significant reduction with the extension of improved time. Results showed that planting *R. pseucdoacacia* can significantly increase urease activities in soil, and the application of appropriate weathered coal would also increase urease activities, but the interaction of *R. pseucdoacacia* and weathered coal reduced soil urease activities [1–6, 11–19].

Soil invertase activities of all the treatments showed the first-declining trend after applying the weathered coal and then increased and with the increasing treatment time the invertase activities had a significant increase (Tab. 6). The changes in the invertase activities in all levels of the soil shown that the invertase activity of 20–40 cm soil depth was higher than that of 0–20 cm soil depth. So, the effects of planting *R. pseucdoacacia* and applying weathered coal on soil invertase activities were closely related to the soil levels and the treated time. Its relevance needs further study.

4 Discussion

4.1 Effects of weathered coal on soil physical and chemical properties

Soil aggregates are the most basic unit of soil structure and also an important component of the soil, which have significant effects on many physical and chemical properties of the soil [7–10, 25–31]. Applying weathered coal could increase the content of soil water stable aggregates (Tab. 3). Content of water stable aggregates increased with the time, and reached the maximum and then got balanced with the modest increase in the organic matter content when the application amount of weathered coal was 27 000 kg hm^{-2} [1]. Pan et al. [13] once targeted several common soil and water conservation forests in the middle and upper reaches of the Yangtze River for his study of the effects of the plant roots on the amount of soil water stable aggregates. The findings of the study proved that the root system of the plants in the middle and upper reaches of the Yangtze River could enhance the quantity of soil water

Table 6. Effects of weathered coal treatments on soil enzyme activities

Dose of weathered coal (kg hm^{-2})	Catalase				Urease				Invertase			
	3 months		6 months		3 months		6 months		3 months		6 months	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
0	0.20 ± 0.01^{aC}[a]	0.35 ± 0.00^{aA}	0.27 ± 0.01^{aB}	0.11 ± 0.00^{cD}	1.23 ± 0.00^{dB}	0.13 ± 0.01^{cD}	1.39 ± 0.01^{dA}	0.57 ± 0.01^{aC}	0.94 ± 0.01^{bC}	0.79 ± 0.01^{aD}	1.63 ± 0.02^{bB}	1.83 ± 0.02^{aA}
13 500	0.12 ± 0.01^{bB}	0.26 ± 0.01^{bA}	0.14 ± 0.00^{bB}	0.09 ± 0.01^{cC}	0.87 ± 0.01^{eA}	0.11 ± 0.00^{dC}	0.71 ± 0.01^{eB}	0.12 ± 0.00^{dC}	0.07 ± 0.00^{eC}	0.46 ± 0.01^{cAB}	0.47 ± 0.01^{eA}	0.43 ± 0.01^{cB}
27 000	0.18 ± 0.01^{aB}	0.25 ± 0.01^{bA}	0.10 ± 0.01^{cC}	0.17 ± 0.01^{bB}	2.30 ± 0.01^{bA}	0.45 ± 0.01^{aC}	1.77 ± 0.00^{cB}	0.21 ± 0.00^{bD}	0.88 ± 0.02^{cB}	0.58 ± 0.02^{bC}	1.51 ± 0.01^{cA}	0.27 ± 0.01^{dD}
40 500	0.07 ± 0.01^{cD}	0.16 ± 0.01^{cC}	0.27 ± 0.01^{aA}	0.21 ± 0.001^{aB}	1.84 ± 0.00^{cB}	0.20 ± 0.00^{bC}	2.05 ± 0.00^{bA}	0.18 ± 0.001^{cD}	0.14 ± 0.01^{dD}	0.26 ± 0.01^{dC}	1.45 ± 0.02^{dA}	0.44 ± 0.01^{cB}
54 000	0.09 ± 0.02^{bC}	0.11 ± 0.00^{dC}	0.14 ± 0.00^{bB}	0.18 ± 0.01^{abA}	3.25 ± 0.00^{aA}	0.21 ± 0.00^{bC}	2.14 ± 0.01^{aB}	0.07 ± 0.00^{eD}	1.14 ± 0.01^{aB}	0.25 ± 0.01^{dD}	2.02 ± 0.01^{aA}	0.52 ± 0.02^{bC}

[a] Mean of three replicated observations ± standard deviation. In a column, means followed by a common letter are not significantly different ($p < 0.05$) by Duncan's multiple range test (DMRT).

stable aggregates through the role of less than 1 mm diameter of fibrous roots. Our researches found that in arid Loess Plateau areas the root system of trees can effectively improve the quantities of soil water stable aggregates, of which the root exudates are still the most important factor. It is worth noting that soil organic matter, soil humus, and soil pH is linked closely, which should be paid to more attention [24–29].

As damage of mining activities (stripping, transport, heaping and padding, and subsidence) to the mine surface [6], fundamental changes have taken place in the original soil physical properties and the external environment. For the reclaimed soil of coal mine on the loess areas, moisture, temperature, bad soil structure, major capacity, nutrient-poor soil, spontaneous combustion of gangue, and many other negative factors have become the main reasons of restricting ecology and vegetation restoration [10]. Therefore, the focus on restoring vegetation should also focused on the improvement of the soil at the same time, and research of reclamation technology should focus on not just the establishment of crops factors but the reconstruction of soil microenvironment [11–17, 20–25, 29–34]. To achieve optimal productivity of the reclaimed soil, it was the most fundamental to construct optimal soil physical, chemical, and biological conditions [17]. And the increase in soil exchange amount as an evaluation indicator of soil fertility conservation was even more important for raising the capacity of reclaimed soil in colliery regions in conserving quantity of nutrients. Results indicated that the application of weathered coal could improve the cation exchange capacity of reclaimed soil in colliery regions, and the best measures for improvement was to apply 54 000 kg hm^{-2} of the weathered coal.

4.2 Effects of weathered coal treatments on soil enzyme activities

Catalase is the indicator for measuring the direction and intensity of the soil oxidation, whose activity levels reflect the capacity of soil lifting the hydrogen peroxide produced during soil respiration process [20]. Our research showed that applying weathered coal significantly inhibited the soil catalase activities (Tab. 6) and after omitting the weathered coal and planting *R. pseucdoacacia*, soil catalase activities of 0–20 cm depth significantly increased.

Research on urease was more important in the soil enzymatic study and its enzymatic reaction product, ammonia is one of the sources of plant nitrogen. Its activities reflected the conversion capacity from organic nitrogen to effective nitrogen and its supply capacity of the soil inorganic nitrogen [1, 9, 18, 21–32].

Invertase was another important enzyme that widely exists in the soil, which plays an important role in increasing the soluble nutrients in the soil. The results presented here demonstrate that after applying appropriate weathered coal, the quality of soil aggregates significantly improved the content of water stable aggregates increased, organic matter, humus, and cation exchange capacity of arable soil significantly improved. But it did not have significant effects on soil pH value. In the 0–20 cm soil depth the soil organic matter, humus, cation exchange capacity, as well as the activities of urease and invertase were higher than those in 20–40 cm soil depth, while pH value in the 0–20 cm was significantly less than those in the 20–40 cm [30–34].

Planting *R. pseucdoacacia* can significantly enhance the activities of catalase, urease, and invertase, although, the application of weathered coal can inhibit the activity of catalase. The application of appropriate weathered coal can significantly increase the urease activity and the activities of catalase, urease, and invertase are all closely related to the soil depths and the treated time [24–34].

When the amount of applied weathered coal is 27 000 and 54 000 kg hm^{-2}, respectively, all the physical and chemical indicators and the enzyme activities were significantly higher than those of the other treatments, and there are no significant differences between the two treatments. Therefore, the study recommends that the best applied amount of weathered coal for the reclaimed soil remediation is 27 000 kg hm^{-2} in the opencast-mining of the Loess Plateau of China.

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