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Vegetation Development on Coal Waste Pile in Panyi Coal Mine†

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Exploitation and utilization of coal can result in a series of ecological environment problems. Coal waste was the solid waste released in the process of coal mining. When coal waste was dumped to form pile, it not only occupies lots of arable land, but also endangers the ecological system in coal mine district. In this study, coal waste pile of Panyi coal mine were surveyed for naturally occurring plant species and limiting factors for plant residence. The plant species, Summed dominance ratio, Species diversity index and Evenness index were calculated for the plant communities grown at the bottom of pile. Heavy metal concentrations and chemical properties in coal waste compared with uncontaminated soil were also determined. Results showed that two stable plant communities (*Synodon dactylon* + *Setaria viridis community and Humulus scandens* community) could adapt to the harsh conditions at the bottom of coal waste pile. *Synodon dactylon* and *Humulus scandens* were the dominant plants that may prove useful in future revegetation programs of coal waste pile. Elevated levels of Cd and electrical conductivity and lower levels of total P and total K might be the limiting factors affecting the residence and growth of pioneering plants.

Key Words: Heavy metal, Limiting factor, Plant community, Coal waste pile.

INTRODUCTION

Coal plays an important role in energy consumption. Coal mining drastically alters the ecological system. Particularly, opencast and underground mining could result in a drastic disturbance mining area due to high yield of coal waste. Usually, coal waste was dumped in adjacent gullies and gradually accumulated to form coal waste pile. Up to now, lots of coal waste piles are stockpiled per year in China and it is increasing at a ratio of 10 %. Coal waste pile is difficult to reclaim due to high potential acidity, very coarse texture, low water retention and fertility.

The coal waste piles possess very rigorous conditions for plant growth[1,2]. At present, new methods based on ecological restoration and reconstruction had been put out for the management and utilization of these piles. Revegtation is essential for conservation, biodiversity and to make the piles productive[3,4]. Ecological restoration and reconstruction has been the hot issue for the management and utilization of coal waste pile. Using native and indigenous plant species in revegetation programs has been emphasized to restore the ecological system in coal waste pile. Besides, it is essential to find the dominant plant species to adapt the harsh conditions in coal waste pile. As the plant grown on the pile, properties for limiting the growth were also needed to be determined to control the success of revegetation. Early studies have shown these two aspects in restoration process of coal waste piles in some sites[5,6].

Panyi coal mine, located in the northern part of Huainan city, is one of the biggest coal mines in the city. It was constructed in 1973 and operated in 1983. It has an area of 58.4 km^2, with an output of more than 6 million tons of raw coal since 2007. During the exploitation and exploration of coal, large quantities of coal waste were produced and dumped outside the coal mine. However, little literature exists about plants grown and distributed at the coal waste pile in this coal mine as well as in Huainan. Thus, it's necessary to investigate the natural colonization of plant species grown on this coal waste pile and determine the limiting factors affecting the residence of pioneering plants to stimulate the reclamation and management of the environment in the vicinity of this pile. It was also expected that such research would lead to identify plant species having the potentials in future revegetation projects for coal waste pile in Huainan.

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TABLE-1
CHEMICAL PROPERTIES OF COAL WASTE AND UNCONTAMINATED SOIL

Samples	OM (%)	pH	EC (us·cm^{-1})	Total (N/mg·kg^{-1})	Total (P/ mg·kg^{-1})	Total (K/g·kg^{-1})
Uncontaminated soil	0.92	6.64	124.81	1261.50	1142.10	10.14
Coal waste	1.64	7.52	201.67	2039.15	609.59	7.76

TABLE-2
HEAVY METAL CONCENTRATION OF COAL WASTE AND UNCONTAMINATED SOIL (mg kg^{-1})

Samples	Zn	Pb	Cd	Ni	Mn	Cr	V	Cu
Uncontaminated soil	27.61	12.87	0.04	14.94	317.44	28.35	34.22	12.90
Coal waste	30.62	14.41	0.12	17.27	320.13	49.75	54.35	21.75
Background value of Huainan soil[11]	80.81	30.47	0.06	25.74	415.68	64.93	96.03	24.16

EXPERIMENTAL

The coal waste pile lies between 32º47'50.2"-32º47'45.5"N lat and 116º50'00.9"-116º50'08.6" E Long. The climate of this area is a typical seasonal temperate semi-humid monsoon with an annual temperature of 15.1 ºC and an average annual rainfall of 920.30 mm. The primary wind direction is from east to west. According to the survey, the minerals in the coal waste are mainly composed of kaolinite, quartz, illite, calcite, pyrite and pyretic.

Survey of composition of naturally occurring plant species in coal waste pile was conducted in April 2012. Plant species, height, number and coverage were recorded by using 60, 1 × 1 m quadrats (randomly placed, avoiding patches) at the bottom of the pile. The Summed dominance ratio (SDR_3, counted by height, coverage and density, %), species diversity index (D) and Evenness index (E) were calculated by Shannon and Weaver formula (1963)[7]. The equations are expressed as follows:

$$D = 1-\Sigma Pi^2 \quad (1)$$

$$E = (-\Sigma Pi \log_2 Pi)/(\log_2 S) \quad (2)$$

where Pi is the proportion of individuals in the ith species; S is the number of species; Pi = Ni/N (Ni is the number of individuals in the ith species, N is the number of individuals).

Nine coal waste samples (at a depth of 20 cm) were collected adjacent to root of plant. Five soil samples were also collected in an uncontaminated area (10 Km away from Panyi coal mine). Coal waste and soil samples were air dried, ground and wet digested (HNO_3/HCl = 1:3). The pH, EC (electric conductivity), OM (organic matter), total N, total P and total K in coal waste and soil were determined using standard method recommended by Chinese Society of Soil Science[8]. The concentrations of Zn, Pb, Cd, Ni, Mn, Cr, V and Cu in digested solutions were determined by ICP-OES (PerkinElmer Optima 2100 DV). For quality control, strict measures were implemented, which include reagent blanks and duplicate samples, the standard reference soil sample (GBW 07403) (from the National Research Center for Standards in China) were included in each analytical run to verify the accuracy and precision of the digestion procedure and subsequent analyses. The precision and bias of the chemical analysis was <10 %.

RESULTS AND DISCUSSION

Spoil characteristic: Coal waste are usually deficient in nutrients and have high metal content, low hydrological regime and high pH, which do not favour seed germination and consequent vegetation development[9]. The chemical properties and heavy metal concentration in coal waste compared to uncontaminated soil were presented in Tables 1 and 2. The average values of OM, pH, EC and total N in coal waste were 1.64 %, 7.52, 201.67 us·cm^{-1} and 2039.15 mg·kg^{-1}, respectively, which were higher than that in uncontaminated soil. However, coal waste was deficient in total P (609.59 mg·kg^{-1}) and total K (7.76 g·kg^{-1}). This result suggested that the coal waste was alkaline and relatively barren. Salinity in coal waste was also much higher, which may due to the oxidation of residual elemental or iron sulphur and would hamper root-growth of plant[10]. Consequently, compared with uncontaminated soil, elevated level of EC and lower levels of total P and total K might be the limiting factors inhibiting the growth of vegetation.

According to Table-2, concentrations of Zn, Pb, Cd, Ni, Mn, Cr, V and Cu in coal waste averaged 30.62, 14.41, 0.12, 71.27, 320.13, 49.75, 54.35 and 21.75 mg·kg^{-1}, respectively, were greater than that in uncontaminated soil. However, except Cd in coal waste, which value (0.12 mg·kg^{-1}) was two times higher than background value of Huainan soil, the other metal concentrations in coal waste were all lower than the correspondent metal levels in background value of Huainan soil. It is well known that Cd is a toxic element and would impair the growth of a plant at such a low level. Thus, high level of Cd would pose some negative effects to the environment and might affect the residence of pioneering plant.

Plant community composition: Many published works on spontaneous revegetation of various spoil heaps and different groups of plants appeared naturally on coal waste pile[4]. According to published literatures, physical and chemical properties and other factors were patched in coal waste pile, the composition and structure of vegetation was not identical in different community[12]. In this study, two stable plant communities (*Synodon dactylon + Setaria viridis community and Humulus scandens* community) were observed at the bottom of the pile based on the analysis of Species diversity index (D) and Evenness index (E) for the vegetation grown at the bottom of the coal waste pile (Table-1). Also, values of species number, Species diversity index and Evenness index were much higher in community of *Synodon dactylon + Setaria viridis*, which suggested that this plant community might have more adaptability to thrive in harsh conditions of coal waste pile. This result was in agreement with published researches on the vegetation grown on coal waste pile reported by Yang[13] and Wei *et al*[14] who found the similar plant species could adaptable to the rigors of the environment.

Plant species composition: Altogether 18 naturally occurring plants were observed at the bottom of coal waste pile (Table-4). Plants grown on the pile were scattered sparsely. *Synodon dactylon* and *Humulus scandens* showed much higher values of SDR_3 among the plants, which indicated that these two plants were the dominant plants and might have adaptability to thrive in this rigorous condition of pile. Further, *Synodon dactylon* and *Humulus scandens* grown on this pile might be useful for reconstruction and restoration of coal waste pile and could be used as pioneer plants. Based on Tables 4 and 5, the plant species were belonged to 12 families and majority of them were herbaceous (14 species), suggesting that the herbaceous might be more adapted to the harsher circumstances. However, two liana species, one shrub species and one deciduous species were also occurring at the bottom of the pile that may pointed out the trend of succession[15]. Banerjee *et al.*[16] also reported that some tree and shrub species appeared on coal waste pile. The result suggested that the succession of vegetation from herbaceous to shrub or liana may be sponsored after then[17]. Other researches also demonstrated that trends of species richness and diversity increased with increase in the age and common occurrence of certain shrubs and other species emerged after then[18-20]. As a result, shrub and liana plants grown in this pile not only suggested the future direction of succession, but also showed the good condition altered by the pioneering plants for the following colonized vegetation.

TABLE-3
PATTERNS AND CHARACTERISTICS OF PLANT COMMUNITIES

Community	Species number	Species diversity index (D)	Evenness index (E)	Dominant plants
Synodon dactylon + Setaria viridis	10	0.71	0.67	*Synodon dactylon, Setaria viridis, Lxeris denticulate*
Humulus scandens	8	0.56	0.59	*Humulus scandens, Bedstraw*

TABLE-4
VEGETATION COMPOSITION AND SYNTHESIZED DOMINANCE RATIO

Family	Species	SDR_3 (%)
1. Gramineae	*Synodon dactylon*	97.53
	Setaria viridis	60.53
	B.Syzigachne(Steud)Fernald	10.43
2. Cruciferae	*Cardamine scaposa*	30.05
3. Asteraceae	*Erigeron annus*	14.74
	Cirslum japonicum	18.86
	Lxeris denticulate	23.67
	Cirsium setosum.MB	7.52
	Erigeron bonariensis.L	29.51
4. Euphorbiaceae	*Euphorbia helioscopia*	8.81
5. Umbelliferae	*Dancus carota*	8.32
6. Chenopodiaceae	*Sansevieriatrifasciata*	3.82
7. Rosaceae	*Eosa muitiflora*	16.09
8. Cannabinaceae	*Humulus scandens*	66.81
9. Rubiaceae	*Bedstraw*	30.90
10. Salicaceae	*Salix matsudana*	40.55
11. Onagraceae	*Ludwigia ovalis*	1.90
12. Convolvulaceae	*Calustegia hederacea wall*	8.50

TABLE-5
LIFE FORMS OF VEGETATION

Species number	Deciduous	Shrub	Liana	Annual, biennial herb	Perennial herb
18	1	1	2	7	7

Conclusion

When coal waste was dumped in cone-shaped heaps, it poses the potential risk to pollute air, soil and water. Vegetation restoration is proved to be an efficiency approach for controlling the environment pollution of coal waste pile and is also a topic of current interest in restoration ecology and degradation system ecology. In this study, coal waste pile of Panyi coal mine was surveyed for naturally occurring plant species. This project concluded that two stable communities (*Synodon dactylon + Setaria viridis* community and *Humulus scandens* community) were found adaptive to the harsh environment of the pile. *Synodon dactylon* and *Humulus scandens* were the dominant plants in the communities. Elevated levels of Cd and EC and lower levels of total P and total K might inhibit the growth of vegetation.

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