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COMPARISON OF DIFFERENT PLANTATION MODES IN ECOLOGICAL RESTORATION IN ANTAIBAO OPENCAST MINING SITES IN SHANXI PROVINCE, NORTH CHINA

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ABSTRACT Reestablishment of the vegetation ecosystem is a key approach to ecological restoration of the landscape of mining sites. Antaibao opencast mining area, located at 112°10′–113°30′E, 39°23′– 39°37′N, is a typical large-scale restoration mining region in North China. Developing plantations on levelled slagheap covered loess soils is a common solution in ecological restoration in Antaibao. There are various plantation modes used in the restoration. Comparison of ecological efficiency of different plantation modes is useful for future restoration. Six plantation modes of woody species, mode I Robinia pseudoacacia + Pinus tabulaeformis, mode II Robinia pseudoacacia + Hippophae rhamnoides, mode III Ulmus pumila + Elaeagnus angustifolia, mode IV Elaeagnus angustifolia + Hippophae rhamnoides, mode V Hippophae rhamnoides and mode VI Caragana korshinskii, were compared over a period of ten years after planting in Antaibao. Based on the analysis of species composition, community structure, life form, species diversity and soil physical and chemical characteristics, we can see that the growth and development speed and efficiency of ecological and environmental improvement in the first ten years followed the order of Mode I > mode II > mode III > mode IV > mode V > mode VI. We can conclude that it is a suitable way to plant woody species directly and develop scrubland and forest in opencast mining area, and that planting trees or trees plus scrubs at the beginning of restoration is better than planting scrubs only. Mode I Robinia pseudoacacia + Pinus tabulaeformis and mode II Robinia pseudoacacia + Hippophae rhamnoides are the best species configurations in restoration of Antaibao opencast mining sites in the early stages.

Keywords: restoration ecology; abandoned mining area; ecological engineering; plantations; the Loess Plateau.

INTRODUCTION

Mining industry is important to national and local economy in China and coal mining industry is particularly important to Shanxi province (Zhang and Liang 2001). Large-scale opencast mining results in an ecological disaster at the landscape level, especially in terms of destruction of soil and vegetation (Maiti 2007; Guo et al. 2009). Reestablishment of the vegetation ecosystem is a key approach to ecological restoration of the landscape of mining site. However, the ecological restoration of such highly disturbed ecosystems presents a great challenge. Although a large number of vegetation restoration modes have been developed in mining sites, the application of traditional recultivation methods often destroys valuable ecological potential by leveling of the surface, ameliorating of nutrient-poor substrates, and seeding or planting of plants not suited to the present habitat conditions (Hüttl and Weber, 2001; Badia et al., 2007). Therefore, choosing suitable plant species and species configuration is a key step for successful restoration in mining area (Bai et al., 2000; Zhang and Chen, 2007; Badia et al., 2007).

The Antaibao open mine is the largest opencast coal mine and is a typical large-scale restoration mining region in North China. Because Antaibao is located in semi-arid region of the eastern Loess Plateau (Zhang et al., 2006), the ecological restoration is comparatively difficult (Zhang and Chen, 2007). The evaluation of restoration effects and techniques is significant to the sustainable development of local environments and economy (Tischew and Kirmer, 2007). Some studies on the techniques of leveling of slag land, recovering soil, reclaimed vegetation and soil in early restoration stages have been done in Antaibao (Wang et al., 1999; Guo et al., 2009). Now the early plantations in restoration have been developed over ten years and it is necessary to examine their growth and development in restoration process by comparing their composition, structure and diversity. This paper aims to test the hypotheses that planting woody species directly in leveling of slagheap plus recovering soil in opencast mining sites is effective, and that tree species configuration is more effective than only shrub species mode. The ultimate goal is to determine the most useful modes of plantation in the restoration of opencast mining lands in the Eastern Loess Plateau, North China.

STUDY AREA

Antaibao mining area, located at 112°10′–113°30′E, 39°23′– 39°37′N, is in the Pinglu division of Shuozhou city, Shanxi Province, North China (Fig. 1). Its elevation varies from 1360 to 1520 m. This region has a typical semi-arid continental monsoon climate, hot and raining in summer and cold and dry in winter. The annual mean temperature is 5.8°C. The annual mean precipitation is around 450 mm, 70% of which focus in June to September. The average frost-free period is 125 d. The annual days of wind beyond 8 m/s are 35d, and sandy wind days are 29d. The soil types vary from loess soil to chestnut cinnamon. The temperate forests and temperate grasslands are inter-distributed in this region according to Chinese vegetation regionalization (Wu, 1980, Zhang et al., 2006).

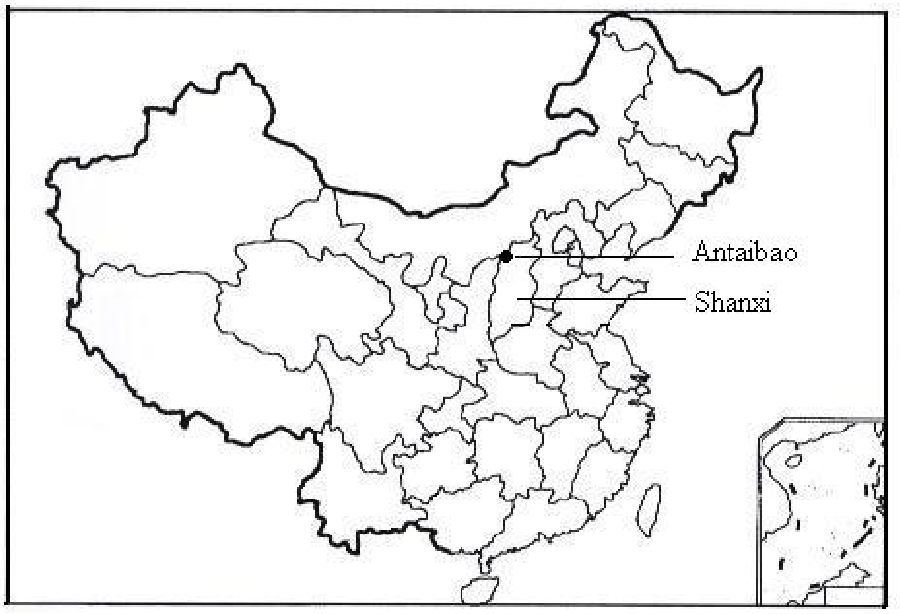

Fig. 1. Geographical position of Antaibao opencast mining area in Shanxi Province, North China.

As one of the largest mines in China, the Antaibao mine was originally a China-US joint-venture company built in 1985, and was formally put into production in 1987. The annual raw coal output was 1.5×10^7 t, and the annual stripped rock and soil output was 1.5×10^9 t. The emission of stripped material formed many different artificial hills. Ecological restoration on different artificial hills has been performed since 1990s'. The restoration procedure is: first, the slagheap hills were leveled of using tractors; second, loess soils of 50 cm in depth were covered on leveled hills; third, planting trees and scrubs and seeding grass and herbs. Various vegetation communities were formed due to different pioneer species and different configurations.

METHODS

Six common plantation modes, representing the general communities in restoration, were selected in this study. These plantations were planted and developed by ten years. They are: mode I *Robinia pseudoacacia* + *Pinus tabulaeformis*, mode II *Robinia pseudoacacia* + *Hippophae rhamnoides*, mode III *Ulmus pumila* + *Elaeagnus angustifolia*, mode IV *Elaeagnus angustifolia* + *Hippophae rhamnoides*, mode V *Hippophae rhamnoides* and mode VI *Caragana korshinskii* (Table 1). Grasslands were not included because they were reseeded and replanted several times since they did not grow and develop well (Guo et al., 2009). The topographical and initial conditions for these plantations were similar (Table 1). Five quadrats (10 m × 10 m) for each plantation mode were set up. The cover, height, DBH, individual number for trees, and the cover, height, abundance for shrubs and herbs were measured in each quadrat. The cover of plants was estimated by eye, and the heights were measured using a height-meter for trees and using a ruler for shrubs and herbs.

Table 1. Topographical conditions of different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Elevation (m)	Soil types	Slope (°)	Aspect	Initial conditions
Mode I	*Robinia pseudoacacia + Pinus tabulaeformis s*	1360	Loess	8	EN	Leveled slagheap + 50 cm loess soil
Mode II	*Robinia pseudoacacia + Hippophae rhamnoides*	1400	Loess	10	EN	Leveled slagheap + 50 cm loess soil
Mode III	*Ulmus pumila + Elaeagnus angustifolia*	1420	Loess	12	EN	Leveled slagheap + 50 cm loess soil
Mode IV	*Elaeagnus angustifolia + Hippophae rhamnoides*	1435	Loess	12	EN	Leveled slagheap + 50 cm loess soil
Mode V	*Hippophae rhamnoides*	1460	Loess	13	EN	Leveled slagheap + 50 cm loess soil
Mode VI	*Caragana korshinskii*	1475	Loess	12	EN	Leveled slagheap + 50 cm loess soil

Five soil sample points in each quadrat were selected and two soil cores of 20 cm in depth were taken in each sample point by use of soil cylindered core sampler. One soil core from each sample point was put into soil box in their nature status in order to measure physical characteristics, such as Bulk density, Porosity, water content etc. And the other soil cores of these samples were thoroughly mixed and then one quarter was collected in a cloth bag and taken to laboratory for chemical analysis. By use of soil cores, soil physical variables were measured. Soil bulk density and porosity were measured by using 100 cm^3 ring and oven method (at temperature of 105-110°C for 10hs). Soil water content was measured by oven method. For chemical analysis, soil samples in bags were air dried and analyzed in the School of Environmental and Resources Science laboratories, Shanxi University. Soil organic matter, total nitrogen, available phosphorus and K were measured in chemical analysis. The nitrogen was estimated using the method of Kjeldahl extraction, and the phosphorus was measured by use of molybdovanadate method with 721-spectrophotometer. The organic matter was measured using the method of $K_2Cr_2O_7$– capacitance. The K was estimated using Atomic Absorption Spectrophotometer (Anderson, 1992). Soil pH was measured by a pH-value meter.

Three species diversity indices, one for species richness, one for species diversity, and one for species evenness were used to calculate species diversity in the plantations. They are

Species number (as a richness index): $D = S$

Shannon-Wiener diversity index: $H' = -\sum P_i \ln P_i$

Pielou evenness index: $E = (-\sum P_i \ln P_i)/\ln S$

Where P_i is the relative importance value of species i, $P_i = N_i / N$, N_i the importance value of species i, N the sum of importance values for all species in a quadrat, S the species number present in a quadrat (Pielou, 1975; Zhang, 2004).

RESULTS

Community structure

The total community coverage of the six plantations ten years after planting varied from 75% to 93% and their community height varied from 1.5 m to 3.5 m (Table 2), which suggests that they are all effective in restoration of opencast mining area in semi-arid region in North China. About the six plantation modes, the total community coverage and community height followed the order of Mode I > mode II > mode III > mode IV > mode V > mode VI. The modes I – IV are young forests dominated by tree species and the modes V – VI are scrublands dominated by scrub species. The former has three obvious structure layers (trees, scrubs and herbs) and the latter has two structure layers only (scrubs and herbs) (Table 2).

Table 2. Community structure and coverage of different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Community height (m)	Total coverage (%)	Tree layer coverage (%)	Shrub layer coverage (%)	Herb layer coverage (%)
Mode I	*Robinia pseudoacacia* + *Pinus tabulaeformis s*	3.5	93	75	40	30
Mode II	*Robinia pseudoacacia* + *Hippophae rhamnoides*	3.3	85	65	35	35
Mode III	*Ulmus pumila* + *Elaeagnus angustifolia*	3.0	90	70	35	35
Mode IV	*Elaeagnus angustifolia* + *Hippophae rhamnoides*	2.9	92	60	30	40
Mode V	*Hippophae rhamnoides*	1.7	80	--	70	30
Mode VI	*Caragana korshinskii*	1.5	75	--	60	30

Species composition and life form

The species composition of the six plantations was comparatively rich and stable after ten years development (Zhang 2005). Successful invasion species in different plantation modes varied from 11 species to 16 species (Table 3). The order of the six modes in successful invasion species number is Mode I > mode III > mode II = mode IV > mode VI > mode V. The dominant species and common species were varied in different plantation modes in spite of some species occurring in two or more modes (Table 3). This showed that each plantation had its own inner environment which is suitable for some species (Moreno-de las et al. 2009).

Table 3. Species composition of seed plant in different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Number of species		Common species
		Planted	Invasion	
Mode I	*Robinia pseudoacacia* + *Pinus tabulaeformis s*	2	16	*Populus simonii, Caragana korshinskii, Agropyron cristatum, Poa annua, Artemisia capillarie, Stipa capillata, Saussurea japonica, Lespedeza duhurica, Carex* sp.
Mode II	*Robinia pseudoacacia* + *Hippophae rhamnoides*	2	14	*Ulmus pumila, Lespedeza duhurica, Elymus dahuricus, Artemisia annua, Poa annua, Stipa capillata, Lepadium apetalum*
Mode III	*Ulmus pumila* + *Elaeagnus angustifolia*	2	15	*Caragana korshinskii, Artemisia capillaries, Artemisia annua, Artemisia lavendulaefolia, Diacocephalum moldavica*
Mode IV	*Elaeagnus angustifolia* + *Hippophae rhamnoides*	2	14	*Brassica jucea, Salsola collina, Suaeda glauca, Setaria viridis, Chenopodium album, Viola yedoensis*
Mode V	*Hippophae rhamnoides*	1	11	*Lespedeza bicolor, Lycium chinense, Elymus dahuricus, Lepadium apetalum, Capsella buisa-pastoris, Saussurea japonica*
Mode VI	*Caragana korshinskii*	1	12	*Elymus dahuricus, Aster tataricus, Vicia amoena, Poa annua, Amaranthus retroflexus, Thymus quinquecostatus*

The life form spectral of species in different plantation modes was different (Table 4). The number of Therophyte, shrub and tree species did not show a strong regulation among these six modes, because tree and shrub species were mainly planted species and Therophyte species was changed frequently by years. However the number of perennial herb species changed greatly, from 7 species to 12 species, among these plantations. The order of the perennial herb species was Mode III > mode I > mode II = mode IV > mode V > mode VI (Table 4).

Table 4. Change of life forms of seed plant species in different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Total number of species	Therophytes	Perennial herbs	Shrubs	Trees
Mode I	*Robinia pseudoacacia* + *Pinus tabulaeformis s*	18	2	11	3	2
Mode II	*Robinia pseudoacacia* + *Hippophae rhamnoides*	16	1	10	2	3
Mode III	*Ulmus pumila* + *Elaeagnus angustifolia*	17	2	12	1	2
Mode IV	*Elaeagnus angustifolia* + *Hippophae rhamnoides*	16	1	10	2	3
Mode V	*Hippophae rhamnoides*	12	2	8	2	0
Mode VI	*Caragana korshinskii*	13	3	7	3	0

Tree growth

From field observation, the six plantation modes all grown well. Their density of woody species varied and related to but not equal to initial planting density (Table 5). The mean height and mean canopy area per individual plant were Mode I > mode II >

mode III > mode IV > mode V > mode VI. The average DBH of tree species is Mode I > mode II > mode III > mode IV (Table 5).

Table 5. Comparisons of growth of woody species in different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Density ($n.ha^{-1}$)		Height (m)	DBH (cm)	Canopy area (m^2)
		Species	Total			
Mode I	*Robinia pseudoacacia*	1335	2655	3.5	2.5	1.8
	Pinus tabulaeformis	1320		3.3	3.6	2.4
Mode II	*Robinia pseudoacacia*	1856	2979	3.4	2.6	1.8
	Hippophae rhamnoides	1123		1.8	Scrub	1.2
Mode III	*Ulmus pumila*	1675	2909	3.0	2.5	1.1
	Elaeagnus angustifolia	1234		2.7	2.0	0.9
Mode IV	*Elaeagnus angustifolia*	1453	3323	2.8	2.1	1.2
	Hippophae rhamnoides	1870		1.7	Scrub	1.3
Mode V	*Hippophae rhamnoides*	3198	3198	1.7	Scrub	1.5
Mode VI	*Caragana korshinskii*	3321	3321	1.5	Scrub	1.2

Species diversity

Species richness, diversity and evenness in community varied obviously among the six modes (Fig. 2). Compared with local mature community, these plantations were rich in biodiversity (Zhang et al. 2006). The order of species richness and diversity were the same, e.g. Mode I > mode III > mode II > mode IV > mode VI > mode V, while that of species evenness was Mode I > mode III > mode II > mode IV > mode V > mode VI (Fig. 2). Overall, forest communities, modes I –IV, were greater than scrubland communities, modes V –VI, in species richness, diversity and evenness.

Soil conditions

Soil characteristics varied significantly among these plantation modes (Table 6). The bulk density followed the order of Mode I < mode II < mode III < mode IV < mode V < mode VI, while the porosity followed the order of Mode I > mode II > mode III > mode IV > mode V > mode VI. Soil water content was Mode I > mode II > mode III > mode IV > mode V > mode VI. The organic matter and all nutrient elements had the same order of Mode I > mode II > mode III > mode IV > mode V > mode VI. The variation of soil pH values was not apparent (Table 6).

DISCUSSION

Plantations are very important to restoration of the mining lands in the world and to fixation of CO_2 to slow down global climate change (Dirnbock et al., 2003; Yang et al., 2006). Usually, artificial restoration of the mining sites starts from developing grasslands by seeding or planting grasses and herbs because mining sites have serious environment which is not suitable for growth of woody species (Maiti 2007, Tischew and Kirmer 2007). The vegetation succession in the eastern Loess Plateau is also following the law of grassland, scrubland and forest (Zhang 2005, Zhang and Dong 2009). However, woody plantations grown and developed better than grassland which was degraded caused by drought and replanted several times (Guo et al. 2009) in Antaibao opencast mining area. This is perhaps due to the covering with 50 cm loess soil on leveling slagheap, because Antaibao has rich loess soil resources, 20-80 m in depth (Liu 1992). Therefore, planting woody species directly and developing scrubland and forest is the suitable way for restoration of opencast mining area in the Loess Plateau, North China (Zhang, 2005, Zhang and Chen 2007, Guo et al. 2009).

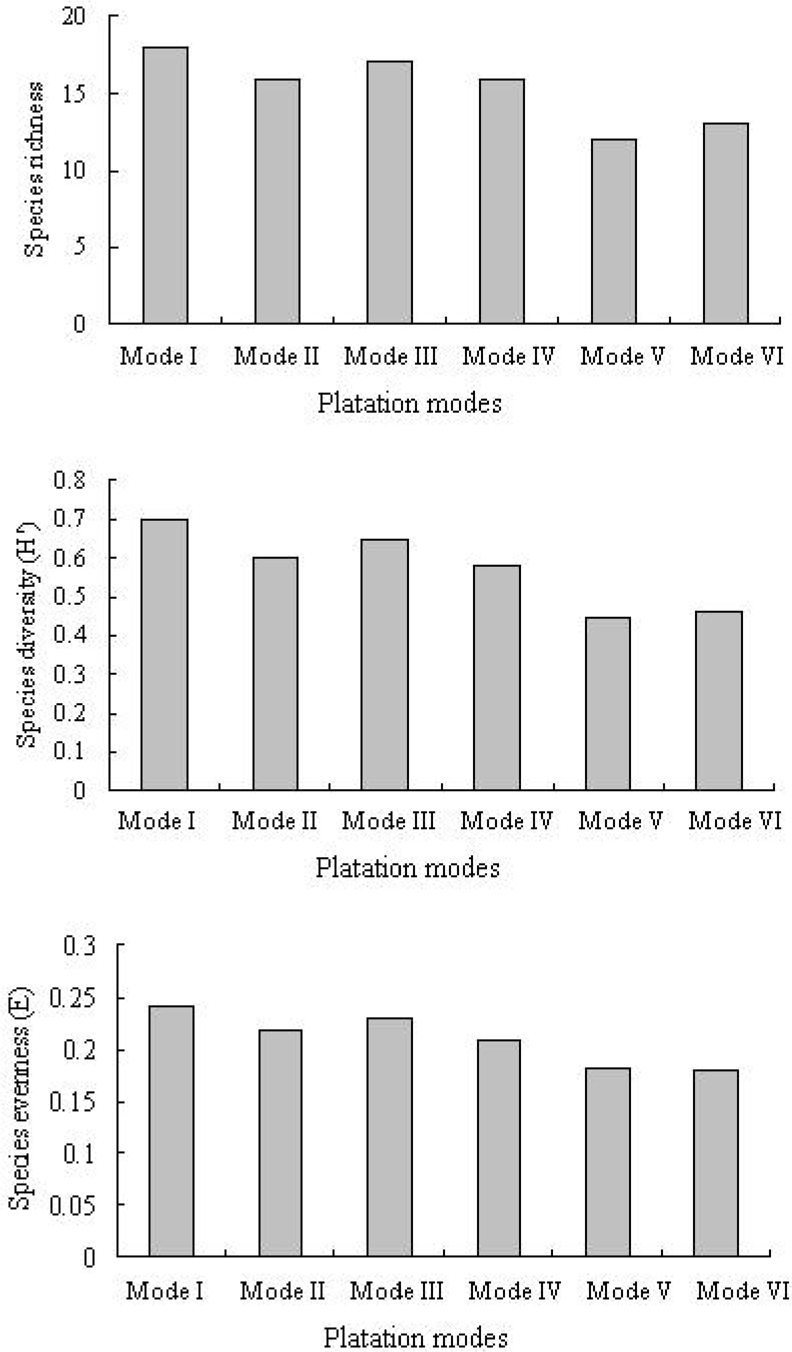

Fig.2. Changes of species richness, diversity and evenness in different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China. Mode I *Robinia pseudoacacia* + *Pinus tabulaeformis,* mode II *Robinia pseudoacacia* + *Hippophae rhamnoides,* mode III *Ulmus pumila* + *Elaeagnus angustifolia,* mode IV *Elaeagnus angustifolia* + *Hippophae rhamnoides,* mode V *Hippophae rhamnoides* and mode VI *Caragana korshinskii.*

Table 6. Soil characteristics in different plantation modes in Antaibao opencast mining sites in Shanxi Province, North China.

Reclamation type	Species configuration	Bulk density (g. cm^{-3})	Porosity (%)	Water content (%)	Organic matter (%)	Total N ($g.kg^{-1}$)	Total P ($g.kg^{-1}$)	Total K ($g.kg^{-1}$)	Alkali-Hydrol N ($mg.kg^{-1}$)	Available P ($mg.kg^{-1}$)	Available K ($mg.kg^{-1}$)	pH
Mode I	*Robinia pseudoacacia* + *Pinus tabulaeformis s*	1.31	48.3	15.1	3.44	0.906	0.598	16.911	25.41	15.79	186.3	8.43
Mode II	*Robinia pseudoacacia* + *Hippophae rhamnoides*	1.36	45.1	14.9	3.42	0.904	0.597	16.909	25.37	15.71	185.2	8.44
Mode III	*Ulmus pumila* + *Elaeagnus angustifolia*	1.38	44.0	14.7	3.37	0.902	0.596	16.895	25.33	15.68	183.7	8.45
Mode IV	*Elaeagnus angustifolia* + *Hippophae rhamnoides*	1.36	43.5	14.7	3.31	0.903	0.597	16.801	25.34	14.91	182.9	8.43
Mode V	*Hippophae rhamnoides*	1.68	42.0	14.3	3.01	0.901	0.595	16.360	25.21	14.10	181.2	8.44
Mode VI	*Caragana korshinskii*	1.70	41.3	14.1	2.92	0.898	0.594	16.276	25.16	13.66	180.5	8.43

Note: values are the mean of five quadrats for each plantation modes.

The species planted in the six modes all performed well in the first ten years of restoration of Antaibao opencast mining area, which suggest that they are suitable species in ecological restoration in the eastern Loess Plateau (Zhang et al. 2006). They are all local high productivity species (Wu 1980). Species *Robinia pseudoacacia* and *Caragana korshinskii* are in family of Leguminosae and species *Hippophae rhamnoides* and *Elaeagnus angustifolia* in family of Elaeagnaceae. They have rich root nodules and can grow well in poor soils like the Loess Plateau (Zhang and Chen 2007). *Pinus tabulaeformis* and *Ulmus pumila* are local common planted tree species and can normally develop in loess area (Ma 2001). The mixture of these species can produce fine plantations in restoration of disturbed lands (Wang 1999, Zhang and Chen 2007).

The six plantation modes were significantly varied in community structure, composition, species diversity and soil conditions ten years after plantation. However, their change trend was similar. The community structure followed the order of Mode I > mode II > mode III > mode IV > mode V > mode VI; the successful invasion species number followed Mode I > mode III > mode II = mode IV > mode VI > mode V; the height and canopy growth speed was Mode I > mode II > mode III > mode IV > mode V > mode VI and the DBH growth speed was Mode I > mode II > mode III > mode IV; species diversity was mode I > mode III > mode II > mode IV > mode VI > mode V; the soil improvement effects were mode I > mode II > mode III > mode IV > mode V > mode VI. Based on these, we can conclude that the growth and development speed and the efficiency of ecological and environmental improvement following the order of Mode I > mode II > mode III > mode IV > mode V > mode VI. The modes I – IV were forests dominated by tree species and the modes V – VI were scrublands dominated by scrub species. Therefore, planting trees or trees plus scrubs at the beginning of restoration (modes I – IV) was better than planting scrubs only (modes V - VI). This is identical to some studies of plantations in eastern Loess Plateau (Bai et al. 2000, Zhang 2005, Zhang and Chen 2007, Guo et al. 2009).

Among the four forest modes, the restoration efficiency followed the order mode I > mode II > mode III > mode IV, e.g. mode I *Robinia pseudoacacia + Pinus tabulaeformis* and mode II *Robinia pseudoacacia + Hippophae rhamnoides* are the most useful species configuration in restoration of Antaibao opencast mining sites in the early stage. For the long-term effects, further monitoring study is expected (Moreno-de las et al. 2009, Zhang and Dong 2009).

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