Pak. J. Bot., 52(1): 317-322, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-1(18)

THE CORRELATION BETWEEN ECO-RESTORING MODES AND SOIL QUALITY SUCCESSION DURING PLANT RE-VEGETATION IN LARGE-SCALE MINING AREAS

DONGGANG GUO[1*], ZEYU SHI[2], HUA LI[1], ZHONGKE BAI[2] AND HONGBO SHAO[3,4*]

[1]*College of Environmental and Resource Sciences, Shanxi University, Taiyuan 030006, China*
[2]*School of Land Sciences & Technology, China University of Geosciences, Beijing 100083, China*
[3]*Salt-soil Agricultural Center, Key Laboratory of Agricultural Environment in the Lower Reaches of Yangtze River Plain, Institute of Agriculture Resources and Environment, Jiangsu Academy of Agriculture Sciences (JAAS), Nanjing 210014, China*
[4]*Jiangsu Key Laboratory for Bioresources of Saline Soils, Jiangsu Synthetic Innovation Center for Coastal Bio-agriculture, Yancheng Teachers University, Yancheng224002, China*
[*]*Corresponding author's email: gdghjkx@126.com;shaohongbochu@126.com*

Abstract

By using the fixed monitoring sample sites of two re-vegetation modes in the opencast coal mine dump of Zhongmei Pingsuo as platform, we analyzed the number and the dynamic characteristics of the spatial distribution of all naturally re-generated seedlings in 2010 and 2014, sampled the corresponding soil, and investigated the correlation of two re-vegetation modes and soil quality parameters. Our results indicated that (1) the plant vegetation seedlings of SII site reduced and those of SI site significantly increased, which was opposite to saplings, and in 2014, the number of saplings in SII site substantially increased twice than the number in 2010; (2) from the respective of spatial distribution, the spatial map of seedlings and saplings showed that the their distribution of major species was consistent in 2010 and 2014. The dense and sparse areas in 2010 kept a similar distribution in 2014, which corresponds to the quantity of the species; (3) stepwise linear regression analysis between the survival rates of seedlings and saplings of various species and soil parameters indicated that the survival rate of elm seedlings significantly negatively correlated with soil moisture content and positively correlated with pH, and that the survival rate of locust saplings exhibited an extremely positive correlation to the organic matter content.

Key words: Large-scale mining areas; Plant re-vegetation; Renewal mode; Soil quality.

Introduction

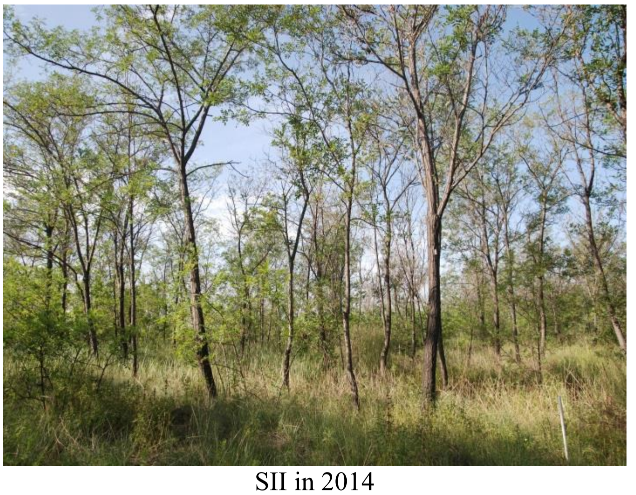
Large-scale mining in Antaibao open-pit coal mine has resulted in the significant destruction of land resources and potential safety hazards of ecological environment in mining areas, Shanxi, China (Li & Bai, 2000; Li *et al*., 2009; Bai & Yan, 2008; Guo *et al*., 2013). Previous study of the ecological restoration in mining area generally believed that vegetation restoration is the premise and basis for the ecological restoration of the damaged land in mining areas (Guo *et al*., 2013). Whether the artificial plant community constructed by the self organization principle of plant communities can be self-renewed in the process of vegetation succession is directly related to whether there is a dynamic and balanced relationship between revegetation and local environmental conditions (Mao *et al*., 2017; Bhanu *et al*., 2019). During vegetation restoration, the transition from seedling to saplings is the bottleneck stage of tree planting and vegetation construction, which is considered as the most vulnerable stage for individual growth and the most sensitive stage to environmental changes (Wright *et al*., 2005; Chang *et al*., 2009; Shoaib, 2019). Therefore, exploring the ecological characteristics and impacting factors of regenerated seedlings and saplings at different stages of artificially restored plant communities facilitates the understanding for the new approaches of species synchronization in the process of vegetation restoration to reveal the root cause affecting the dynamics of artificial revegetation communities, which is of great significance for the reasonable evaluation of the adaptability of artificial revegetation (Wang *et al*., 2000; Wang & Bai, 2002; Wei *et al*., 2004; Bai & Yan, 2008; Song *et al*., 2017; Shao *et al*., 2017).

Materials and Methods

General information of the experimental sites: The experimental sites are located in the south dump of Antaibao coal mine in Pinglu District, Shuozhou City of northern Shanxi, 39°24'N～39°38'N, 112°11'E～113°32'E.The region belongs to temperate semi-arid continental monsoon climate with the average annual precipitation of 428.2mm, the average annual temperature of 5.5°C, the ≥10°C accumulated temperature of 2300~2500°C, and the frost free period of 117d. The local vegetation in mining area was grassland type. The south dump of Antaibao coal mine was an outer dump with the final elevation of 1465m, the capacity of 116 million m^3 and the dumping height of 150m. It started to dump in 1985 until 1989, and revegetation was initiated in 1993. It is one of the earliest areas for ecological restoration in Antaibao Mine. Other than watering during tree planting, no other management practices were applied. At present, the vegetation restoration areas showed rich biodiversity with mainly locust (*Robinia pseudoacacia*) and elm (*Ulmus pumila*), and have basically covered the bare surface of the dump, so the ecological environment has been effectively regenerated (Li & Bai, 2000). The region was the transitional zone between chestnut soil and chestnut brown soil, and the main zonal soil was chestnut soil with the distribution in alluvial, alluvial plain and river secondary or gully terrace. Its parent materials were mainly loess alluvium, diluvium, slope deposit, and some zonal aeolian deposits, mostly weathering products of granite and gneiss. Therefore, the soil exhibited strong physical weathering, and the soil is sandy and dry with good the aeration and vigorous activity of aerobic microorganism. The carbonate content in the soil was above 8% and the lime reaction was strong in the entire soil body. Most of the soil in hilly loess areas, sloping ground and valley gully is farmland, and only a few is woodland and wasteland. Due to poor natural conditions, extensive tillage and poor soil, the organic matter content in the topsoil is generally between 5.0 and 9.0 g/kg, some even lower than 5.0g/kg. Total nitrogen content is generally between 0.3-0.6g/kg, and the range of available phosphorus content is 5.0-8.0mg/kg with a few above 10mg/kg and some between 2.0-3.0mg/kg. The available potassium content is usually between 50-90mg/kg with a few more than 100mg/kg.

Sites with fixed monitoring: The fixed monitoring sites of mixed forest of locust, elm and heaven trees (SI) and pure locust forest (SII) were located in the ecological reclamation area of south dump (Fig. 1). The sample plots were square (10m x 10 m) with the area of 1 ha. The whole plot was relatively flat and gentle with an average altitude of 1386m. In 2010, according to CTFS method, the total site was divided into 100 of 10 m x 10 m sample plots which was further divided into 4 of 5 m x 5 m small sample plots. Species identification, height and DBH measurement, location and listing were performed for all woody plants in the sample plots.

SII in 2010



SII in 2014

Fig. 1. Re-vegetation comparisons from two types of restoration.

Investigation of vegetation: All trees with DBH smaller than 3 cm and with DBH between 3 cm and 7 cm were considered as seedlings and saplings, respectively. Their species, height, DBH and coordinates were recorded.

Soil sampling and test: Based on CTFS soil sampling plan and combining with the site status, 1 hm^2 sample plot was divided into 100 of 10 m x 10 m grids. The center of each grid was set as the sampling base point and samples were collected from four corners of each base point with the depth of 0-20 cm and 20-40 cm.According to the map, the sampling points were marked (red rope) using compass and tap. If the sampling point happens to be a big rock or tree root, then the samples were collected within 50 cm of its vicinity with the sampling point as the center. For sampling, the surface dry branches and fallen leaves were removed, soil was collected using ring cutter to measure its bulk density, and fresh soil was collected with a aluminum box. Three soil samples were collected within 20 cm of the sampling point using the earth boring auger with 5 cm diameter, and they were mixed and stored in valve bags. The sampling depth were 0-20 cm and 20-40 cm. Finally, the soil moisture at the sampling point was determined using TDR at the depth of0-20 cm. In addition, the representative original soil in the vicinity of the reclamation area was selected as the control.

Soil quality parameters test: The soil samples were dried and sieved at 2mm. The aluminum boxes were put into 105℃ oven for 12h to measure the soil moisture and to calculate the soil bulk density. The soil physical and chemical properties, including pH, organic matter, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus and available potassium, was determined as previously described in "Soil Agrochemical Analysis Method" edited by Lu Rukun (1999) and "Soil Agrochemical Analysis" edited by Bao (2001) (Guo *et al*., 2013).

Data analysis and important value: The important values of tree layer, shrub layer and herbaceous layer were calculated as follows:

$$AI = \frac{Ab + Co + Hi}{3} \quad (1\text{-}1)$$

$$SH = \frac{Co + Hi}{2} \quad (1\text{-}2)$$

$$HE = \frac{Co + Hi}{2} \quad (1\text{-}3)$$

where, *AI*, *SH* and *HE* are the important values of tree layer, shrub layer and herbaceous layer, respectively; *Ab* is the relative abundance, *Co* indicates the relative coverage and *Hi* represents the relative height.

Size class and spatial distribution: Akima, spatstat and spatial packages in the internationally recognized software R2.11.1 (http://www.r-project.org) were used for the analysis and map-making.

Correlation analysis of soil quality and plant communities: The data processing and analysis were performed using SPSS13.0 software. The single factor ANOVA was used to determine the effect of various plant allocation modes on the physical and chemical properties of soil, and LSD test was performed to check the significance ($p<0.05$). The regression analysis between soil factors and the average density, DBH and height of various populations was carried out, and its reliability was determined with t-test. The principal component of the soil factors in the regression equation was demonstrated using Principal Component Analysis (PCA).

Results

Quantitative dynamics of young seedlings under various modes: Based on the investigation data of two plant allocation modes, SI and SII, in the reclamation area of Pingshuo opencast coal in 2010 and 2014, we explored the variation on the species composition, quantity composition, and composition of new and dead seedlings, which were as follows: The results of SI indicated that four species, *Salix elliottii*, *Populus microphylla*, Torch tree and *Lycium chinensis*, disappeared from the plot due to individual death, and no new species were found during 2010 -2014 (Table 1). A total of 4216 seedlings and 687 saplings were recorded in 2010 and the net increase of seedlings and saplings was 6917 and 40, respectively, in 2014. The net increase in the number of seedlings and saplings was contributed by heaven trees and elm with the increase of elm accounting for 92.22% of the total increase. The majority of dead seedlings was locust, which was 932 individuals, accounting for 58.73% of the total number of dead seedlings (Tables 2 and 3).

Table 1. Species composition of SI.

	2010	2014
Species composition	elm, locust, heaven tree, dryland willow, simon poplar, armeniaca, torch tree, sea-buckthorn, *caragana microphylla*, Chinese wolfberry	elm, locust, heaven tree, armeniaca, sea-buckthorn, *caragana microphylla*

Table 2. Seedling and sapling quantity of various species in SI.

		2010	2014
Seedling	Elm	3231	10189
	Locust	847	315
	Heaven tree	138	673
Sapling	Elm	79	472
	Locust	240	109
	Heaven tree	368	146

No species variation was observed in SII during 2010-2014, and there were still 3 species locust, elm and *Caragana microphylla* (Table 4). Within 4 years, seedlings decreased from 1856 to 1755, while saplings increased from 102 to 172. The decrease of seedlings was mainly attributed to the death of locust seedlings. There were no dead individuals observed in elm seedlings, and the mortality rate of locust was higher than that of elm (Tables 5 and 6).

Table 3. The survival dynamics of seedlings and saplings of various species in SI.

		2010	2014		
			Seedling	Sapling	Death
Seedling	Elm	3231	1843	456	932
	Locust	847	175	81	591
	Heaven tree	138	53	21	64
			Seedling	**Sapling**	**Death**
Sapling	Elm	79	34	34	11
	Locust	240	60	56	124
	Heaven tree	368	120	42	206

Table 4. Species composition of SII.

	2010	2014
Species composition	elm, locust and *Caragana microphylla*	elm, locust and *Caragana microphylla*

Table 5. Seedling and sapling quantity of various species in SII.

		2010	2014
Seedling	Elm	123	264
	Locust	1733	1491
Sapling	Elm	3	46
	Locust	99	226

Table 6. The survival dynamics of seedlings and saplings of various species in SII.

		2010	2014		
			Seedling	Sapling	Death
Seedling	Elm	123	56	46	21
	Locust	1733	900	229	604
			Seedling	**Tree**	**Death**
Sapling	Elm	3	3	0	0
	Locust	99	20	41	38

The spatial distribution of seedlings and saplings under different modes: The elm seedlings were aggregated in the northeast, northwest and south of SI site in 2010 with the northwest being the most crowded. In 2014, the elm seedlings exhibited large-scale gathered distribution, and its number was significantly increased. The elm saplings showed even distribution throughout the plot in both 2010 and 2014. In 2010, the locust seedlings were evenly distributed within the site with concentrated distribution in certain small plots. Because of the substantial death of seedlings during 4 years, its number was significantly decreased, so it exhibited random distribution within the site. The elm sapling also showed even distribution in 2010, but from then a great number was dead at the southwest and northwest of the site. In 2010, the seedlings of heaven were gathered in the southwest and east of the site with southwest being the densest. Until 2014, the seedlings were aggregated in northeast, middle and east of the site with east being the most crowded, and the quantity was significantly increased. Its sapling exhibited random distribution in both 2010 and 2014. In 2010, the distribution of elm seedling in SII site was random, but they were gathered in the middle, and exhibited dense distribution in certain small plots. Due to the small quantity, its saplings were randomly distributed within the site. The locust seedlings were evenly distributed in the site with gathering in certain small plots in 2010.No dramatic variation on seedling numbers was observed in 2014.Saplings showed a similar distribution in 2010, but a gathered distribution was seen at the east top in 2014, and the quantity was higher than that in 2010 (Fig. 1).

The general characteristics of soil physical and chemical properties in dump: According to the national classification standard of soil nutrient content, the soil pH of reclamation area of Antaibao open-pit mine dump ranged from 7.59 to 8.49 with the average of 8.23, so it belonged to alkaline soil. Range of soil bulk density was $0.92g/cm^3$-$1.38g/cm^3$ with the average of $1.13g/cm^3$, exhibiting a desirable bulk density. The organic matter content was medium, third class, with the range of 17.45g/kg-34.28g/kg and the average of 26.13g/kg. The total nitrogen content was medium, third class with the range of 0.53g/kg-1.42g/kg and the average of 1.23g/kg. The total phosphorus content was slightly deficient, fourth class, with the range of 0.36g/kg-0.56g/kg and the average of 0.45g/kg. The range of total potassium was 18.76g/kg-21.43g/kg with the average of 20.40g/kg, so K was slightly rich, second class. The available nitrogen was extremely deficient, sixth class with the range of 7.54mg/kg-36.12mg/kg and the average of 18.60mg/kg. The available phosphorus was fourth class, slightly deficient, and it ranged from 3.46mg/kg to 8.75mg/kg with the average of 6.36mg/kg. The available potassium level was medium, third class, and its range was 122.4mg/kg-194.6mg/kg with the average of 160.8mg/kg. In all, the soil nutrients in the reclamation area of opencast coal dump in Antaibao was medium to slightly deficient. Further analysis showed that the variation coefficient of various soil physical and chemical properties was not large. The available N exhibited the largest variation coefficient, followed by moisture content, and that of pH was the smallest. Variation coefficient reflects the spatial variation of specific parameters. Generally, CV＞1.0, 0.1≤CV＜1.0 and CV＜0.1 respectively indicate strong variation, medium variation and weak variation. Other than pH, total P and total K content, which showed weak variation, all other indicators exhibited medium variation, suggesting the heterogeneous characteristics of the soil physical and chemical properties in this area (Table 7).

The relationship of seedling survival and soil factors: The correlation between the seedling survival rate of various species and all the indicators listed in Table 7 showed that the correlation coefficient between the survival rate of elm seedling and soil moisture content was -0.988 (p<0.05), suggesting a significant negative correlation. In addition, it was significantly positively correlated with soil pH with the correlation coefficient of 0.953 (p<0.05). Furthermore, linear regression was carried out with soil water content and pH as independent variables and survival rate of elm seedlings as dependent variables. The parameter estimation of regression model was not significant, so the regression analysis was not performed. Similarly, there was no significant correlation between all the soil factors and the seedling survival rate of locust/ heaven tree, so no regression was carried out.

Table 7. Distribution characteristics of soil physical and chemical properties under different plant allocation modes.

Indicators	S Ⅰ	S Ⅱ
Bulk density (g/cm^3)	1.31 ± 0.04a	1.14 ± 0.02b
Moisture content %	15.24 ± 3.04a	13.42 ± 2.58a
pH	8.25 ± 0.03b	8.30 ± 0.01a
Organic matter (g/kg)	21.54 ± 0.97bc	29.47 ± 0.76b
Total nitrogen (g/kg)	1.01 ± 0.05bc	1.30 ± 0.02a
Total phosphorus (g/kg)	0.51 ± 0.03a	0.39 ± 0.05bc
Total potassium (g/kg)	18.25 ± 1.29bc	18.02 ± 1.13bc
Available nitrogen (mg/kg)	16.23 ± 0.27bc	16.21 ± 0.20bcd
Available phosphorus (mg/kg)	5.95 ± 0.19b	8.24 ± 0.04a
Available potassium (mg/kg)	152.4 ± 27.9b	162.5 ± 30.2a

Letter represents the statistical significance tested by LSD (p＜0.05)

Table 8. Linear regression between the sapling survival rate of locust and soil factors.

Variant	Parameter estimation	Partial regression coefficient	Model R^2	*t*	*t*-test
Intercept	-0.277			-5.326	0.033
Organic matter	0.035	0.994	0.994	17.828	0.003

The relationship of sapling survival and soil factors: The correlation between the seedling survival rate of various species and all the indicators listed in Table 7 showed that the survival rate of locust saplings exhibited a extremely significantly positive correlation to soil organic matter content with the correlation coefficient of 0.997 (p<0.05). With organic matter content as independent variable and survival rate of locust saplings as dependent variable, linear stepwise regression (Table 8) was carried out and the regression equation was fitted according to the parameter estimation of variables: Y=0.035x-0.277. Where, Y is the survival rate of locust saplings and x indicates the organic matter content. The variable of organic matter content showed extremely significant difference in t-test (p<0.01). The determination coefficient of the model R2 was over 0.99, indicating that the variation of survival rate of locust saplings can be well explained by soil organic matter content. The scatter points of the residual analysis were randomly distributed on the baseline, along with the high determination coefficient, it suggests that the regression equation is well fitted.

There was no significant correlation between the sapling survival rate of elm/ heaven tree and soil factors, so no regression analysis was performed.

Discussions

Soil development is an integral process of mining spoil restoration, which is critical for vegetation establishment and may help to predict reclamation success (Huang *et al*., 2016; Hou *et al*., 2018; Jing *et al*., 2018 Ivana *et al*., 2019). In our study, changes in soil properties and plant community structure, were examined at different rehabilitated phases in chronosequence reclaimed coal mine spoils ecosystems, and discussed potential functional relationships. From the perspective of species composition, the species composition of seedlings and saplings in SI varied, but not in SII. The main reason for such change is that the original species disappeared from the plot due to individual death with no adding of new individuals, and new species are supplemented by the emergence of its new individuals (Li & Bai, 2000; Liu *et al*., 2009; Chang *et al*., 2009). From the perspective of quantity, the seedling number in SII reduced, and it was substantially increased in SI, which was opposite for saplings (Song *et al*., 2017). However, in 2014, the sapling number in SII was dramatically elevated to twice of that in 2010 (Fig. 1).

From the number and composition of new addition and death, elm was the species with the biggest increase in seedlings in both sites, and locust showed the largest increase in saplings. The most seedling death was observed in locust with the mortality rate over 50%, so only a few seedlings grew into saplings during 4 years.

The correlation analysis between the survival rate of seedlings and saplings in various species and the soil factors showed that the survival rate of elm seedlings was significantly negatively correlated to soil moisture content and positively correlated to pH, and that an extremely and significantly positive correlation was observed between the survival rate of locust and soil organic matter content (Deng & Zhang, 2010; Liu *et al*., 2011; Liu *et al*., 2014; Sanjoy *et al*., 2015; Lenka *et al*., 2018; Maja *et al*., 2019).

The comparison of data collected in 2010 and 2014 demonstrated that the greater the number of individuals in 2010 was, the greater the number of deaths was, regardless of seedlings and saplings. The survival rate of both elm seedlings and saplings was significantly higher than that of locust. The variation in the renewal capability allows the transit of allocation mode from one equilibrium state to another equilibrium state in sample site (Liu *et al*., 2014; Yuan *et al*., 2018; Silvano *et al*., 2019; Liu *et al*., 2019). The survival rate of seedlings is the key factor to determine the position of species in one plot, but the low survival rate becomes the bottleneck of self-renewal, and thus, its dominant position may be replaced by other species in the plot.

Conclusions

The present study was only based on the investigation data from two sites, and time is not very sufficient to monitor the regeneration status of artificial forest and the effect of soil factors on the survival of seedlings. In addition, the evaluation factors we selected were not comprehensive in the analysis of the factors affecting the survival of seedlings, such as topographic and light environment factors. Therefore, long term monitoring and more factors are needed to fully reveal the renewal mechanism of species in the vegetation restoration area.

Acknowledgements

This study was supported by the Key Laboratory Opening Fund for Land Consolidation and Rehabilitation (20140136), Excellent Scientist Plan of JAAS and Shuangchuang Talent Plan, Jiangsu, China.We also thank Prof. Hao Zhanqing for the guidance during the plot establishment and vegetation investigation.

References

Bai, Z.K. and W.J. Yan. 2008. A case study on Pingshuo mining area land rehabilitation and reutilization in mining districts. *Resour. Ind*., 10(5): 32-37.

Bhanu, P., M. Arideep and A. Madhoolika. 2019. Assessment of seasonal and site specific variations in soil physical, chemical and biological properties around Opencast Coal Mines. *PEDOSPHERE* doi: 10.1016/S1002-0160(17)60431-4

Chang, C., Z.Q. Xie and G.M. Xiong. 2009. Characteristics of soil nutrients of different vegetation types in the three gorges reservoir area. *J. Ecol*., 29(11): 5979-5984.

Deng, L. and W.H. Zhang. 2010. Natural development pattern of robinia pseudoacacia plantations in loess hilly region. *Forest. Sci*., 46(12): 15-22.

Guo, D.G., B.Q. Zhao and T.L. Shangguan. 2013. Dynamic parameters of plant communities partially reflect the soil quality improvement in eco-reclamation area of an opencast coal mine. *Clean Soil Air Water*, 41(10): 1018-1026.

Hou, X.Y., S.L. Liu, F.Y. Cheng, Y.Q. Zhang, S.K. Dong and G.H. Liu. 2018. Vegetation community composition along disturbance gradients of four typical open-pit mines in Yunnan Province of southwest China. *Land Degrad. Dev*., 28: 1-11.

Huang, L., P. Zhang, Y.Q. Hu and Y. Zhao. 2016. Vegetation and soil restoration in refuse dumps from open pit coalmines. *Ecol. Eng*., 94: 638-646.

Ivana, M.R.P., J.F.S. María, N.D. Avelino, M.M. Carmen and M.V. Felipe. 2019. Efficacy of two different reclamation strategies to improve chemical properties and to reduce Al toxicity in a lignite mine dump during a 20-year period. *Land Degrad Dev*., 30: 658-669.

Jing, Z.R., J.N. Wang, Y.C. Zhu and Y. Feng. 2018. Effects of land subsidence resulted from coal mining on soil nutrient distributions in a loess area of China. *J. Cleaner Prod.*, 177: 350-361.

Lenka, Š., C. Gábor, K. Anita, V. Kamila, O.A. Adrienne, P. Karel and R. Klára. 2018. Spontaneous revegetation versus forestry reclamation-Vegetation development in coal mining spoil heaps across Central Europe. *Land Degrad Dev.*, 28: 1-9.

Li, J.C. and Z.K. Bai. 2000. Land reclamation and ecological reconstruction in open-pit coal mines: Research and practice of Pingshuo open-pit mine. Beijing: Science Press.

Li, J.C., Z.K. Bai and S.J. Chai. 2009. Study on technology of land reclamation and ecological rehabilitation of waste land in Pingshuo surface mine. *Sci. & Technol. Guide*, 2009: 27(17): 30-31.

Liu, B.Y., S.Y. Liu and J.F. Fan. 2009. Effects of regional climate change after restoration of vegetation in dump of open-pit mine. *J. Liaoning Tech. Uni. (Nat.Sci. Edi.)*, 28: 226-228.

Liu, J.H., X.F. Wang and T.J. Cai. 2011. Influence of different vegetation restoration pattern on composition structure for plant communities in gangue waste lands. *Prot. Forest Tech*., 4: 16-18.

Liu, W.F., Y.Y. Li, G.M. Huang, J.P. Wu, H.L. Duan, Y.C. Liao, R.Z. Huang, Z.P. Xu and Fan, H.B. 2019. Nutrient leaching of Chinese fir (*Cunninghamia lanceolata*) seedlings under simulated nitrogen deposition. *Pak. J. Bot*., 51(5): 1587-1592.

Liu, W.H., B.Q. Zhao and Z.K. Bai. 2014. Correlation of soil nutrients and plant community in ecological reclamation of opencast coal mine in a semiarid area. *J. Ecol*., 33(9): 2369-2375.

Maja, R., K. Eugeniusz, D.V. Magdalena, M.G. Zygmunt and C. Artemi. 2019. Soils from an iron and steel scrap storage yard remediated with aided phytostabilization. *Land Degrad Dev*., 30: 202-211.

Mao, P.L., Q. Tang, B.H. Cao and H.B. Shao. 2017. Eco-physiological adaptability in mixtures of *Robinia pseudoacacia* and *Fraxinus velutina* and coastal eco-engineering. *Ecol. Eng*., 106: 106-115.

Sanjoy, K., K.M. Subodh and C. Subrato. 2015. Soil development in 2–21 years old coalmine reclaimed spoil with trees: A case study from Sonepur-Bazari opencast project, Raniganj Coalfield, India. *Ecol. Eng.*, 84: 311-324.

Shao, H.B., H.Y. Lu, G. Xu and M. Brestic. 2017. Integration into plant biology and soil science has provided insights into the total environment. *Sci. Total Environ*., 579: 928-929.

Shoaib, U.R.R. 2019. Major nutrient fluxes and water use efficiency of winter vegetables under peri-urban farming of North-western Punjab, Pakistan. *Pak. J. Bot.,* 51(5): 1753-1759.

Silvano, R., R.S. Borges, D.M.S. Santos and I.F. Oliveira. 2019. Practices for rehabilitating bauxite-mined areas and an integrative approach to monitor soil quality. *Land Degrad Dev.*, 30: 866-877.

Song, H.J., Y.D. Xu, J. Hao, B.Q. Zhao, D.G. Guo and H.B. Shao. 2017. Investigating distribution pattern of species in a warm-temperate conifer-broadleaved-mixed forest in China for sustainably utilizing forest and soils. *Sci. Total Environ*., 578: 81-89.

Wang, G.L. and Z.K. Bai. 2002. Main limiting factors for re-vegetation and measures of dumping site in Antaibao opencast mine. *Soil Water Conserv. Res.*, 99(1): 38-40.

Wang, G.L., Z.K. Bai and J.K. Zhao. 2000. *Robinia* growth on the dump of Antaibao open-pit mine. *Coal Environ. Prot*., 14(2): 21-24.

Wei, Z.Y., R. Ma and Z.K. Bai. 2004. Research on water erosion characteristics and its control measures in large dump of opencast coal mine in loess area-In the case of the south dump of ATB opencast coal mine. *J. Soil Water Conserv*., 18(1): 164-167.

Wright, S., H. Muller-Landau, N. Calderon, W.T. Smith and L. Mitas. 2005. Annual and spatial variation in seed fall and seedling recruitment in a neotropical forest. *Ecology,* 86: 848-860.

Yuan, Y., Z.Q. Zhao, S.Y. Niu, X.Z. Li and Y.Y. Wang. 2018. Reclamation promotes the succession of the soil and vegetation in opencast coal mine: A case study from *Robinia pseudoacacia* reclaimed forests, Pingshuo mine, China. *Catena*, 165: 72-79.

(Received for publication 20 July 2018)