Degradation of Grassland Covered by Coal Dust in a Temperate Steppe

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Abstract: The exploitation of open pit mines in grassland brought many environmental problems. In this study, two sizeable open-pit lignite mines in Inner Mongolia grassland were selected for study. We investigated the vegetation and soil status of grasslands surrounding the coal mines. By comparing grasslands covered with coal dust (GD) to the adjacent normal grasslands (CK), we found that the vegetation coverage, grass yield, soil organic carbon, and soil nitrogen content of GD grasslands were lower than those that in the CK grasslands. Based on the Chinese grassland degradation standards, we made an evaluation and found that there was moderate-severe degradation of grassland around the mines after seven years of mining. We can conclude that the exploitation of lignite mines caused the degradation of surrounding grasslands, and we should pay attention to the controlling of pollutants emission and protecting the natural grassland.

1 INTRODUCTION

With the development of industrialization and the increment of the world's population, human demand for fossil fuels is increasing. Coal plays an important role in supporting global energy consumption and economic development (Bhattacharya et al., 2015). China is one of the top five coal mining countries in the world, including China, the United States, India, Indonesia, and Australia (World Coal Association, 2014). About 90% of China's coal resources are distributed in northern China (China geology survey, 2016), where most of land is grassland. About 41% of China's land surface is natural grassland, which plays a vital role in the economic development of pastoral areas and in improving people's living (Sun, 2000). It is an important issue that rational management and protection of grassland resources to achieve regional eco-economic-social sustainable development in the world. Besides boostting the economic and social development of the region, the exploitation of coal resources may also cause many potential ecological and environmental problems, which includs pollution of the surrounding areas of the mining area—air pollution, water pollution, soil erosion, and desertification, leading to ecosystem degradation, changes of fauna and flora, loss of biodiversity, damage to landscapes (Ejaz et al., 2014; Si et al., 2010). The causes of such pollution are mainly the emission of gaseous pollutants and the disturbance of groundwater and surface drainage. Dust and gaseous pollutants are more serious pollutants in arid areas. The areas affected by these pollutants are mainly the mining operation area in the mining area and the surrounding area of the mining area.

The atmospheric pollutants produced by coal mining impact on individual plants and plant populations. For the plant leaves, the air around the coal mine often

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contains sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and total suspended particulates (TSP) (Pandey et al., 2014). These substances would inhibit the plant growth. The dust deposition would decrease the stomata conductance of the plant leaves and affect on respiration and photosynthesis. Coal dust reduced the CO_2 gas exchange and photosynthesis efficiency of African mangrove leaves (Naidoo and Chirkoot, 2004). Coal powder addition can also inhibit the root growth of forages (Wang et al., 2016). As the development of individual plants is affected by coal mine pollutants, it will further affect the competition between populations and species, leading to changes in community structure (Pandey et al., 2014). Exploration of coal mining would reduce the number of plant species in contaminated areas, thereby reducing biodiversity (Spencer and Tinnin, 1997). Coal dust can change the dominant trees in wetlands by modifying the succession of plant communities (Naidoo and Chirkoot, 2004). There is a general perception that dust accumulation on plant surfaces causes negative impacts on plants. While after five years of observation, it was found that there was no significant correlation between the emissions of inert dust sourced from the Australian mines and the growth of the Tetratheca paynterae or the composition of the flora (Matsuki et al., 2016). Because the amount of natural dust in the arid area has been relatively large historically, the plant has specific adaptability. As a dry area, the plant of Inner Mongolia grassland is often disturbed by dust. The open-pit mines of the grassland also would produce a large amount of dust during the mining process. How this coal dust depositions affect the grassland is one of the scientific problems of this study.

Most of large open-pit coal mines in China are distributed in an arid and semi-arid area with vulnerable environments. Among them, four of the five larger open-pit mines in China distributed in Inner Mongolia grassland (Ratcliffe, 1974; Bai et al., 2006). From 2006 to 2010, coal production of Inner Mongolia was the biggest in China (Liao and Wei, 2011). Eleven out of the 14 open-pit coal mines in China are found in Inner Mongolia grasslands (Geng, 2008; Ma et al., 2006). Thus, dust pollution may affect the livelihood of local herders via its damage to rangeland health. The production of lignite was biggest in the typical steppe of Inner Mongolia. The addition of humic acid extracted from lignite is beneficial to improve soil fertility and promote plant growth (Tahir et al., 2011). Then, after the lignite dust deposition on grassland around the coal mine, how does the grass growth, soil, and grassland health change? We hypothesize that the deposition of lignite dust will hurt the development of grass, especially in arid regions where is a lack of rainwater to wash the dust on the leaves. To certify our hypothesis, we selected two open-pit coal mines in the typical steppe of Inner Mongolia as the research object and evaluated by comparing the health of adjacent grasslands around the mining area.

2 MATERIALS AND METHODS

2.1 Study Area and Sampling Design

Two large coal mines in this study situated in Xilinhot, Inner Mongolia. The mean annual temperature is -0.4 ℃ with extremes ranging from -27.0 to 28.6 ℃ (Xiao, 1997). The long-term mean annual precipitation is 360 mm and varies from 180 to 500 mm. The prevailing winds of the two mining areas are western wind, and the soil types are kastanozems (FAO, 1991). The coal types are brown coal. In this study, the vegetation and soil survey of W3 mine was completed in 2014, and the data survey of B3 mine was completed in 2016.

Case 1: Shengli Coalfield West No. 3 Open-pit Coal Mine (W3) is situated in Shengli Town, about 3km north of Xilinhot City. The geographical location is between 43° 58'10.0" N, 43° 58'52.8"N and 115° 57'03.8"E, 116 ° 00'20.8"E (Fig. 1-a). The coal mine was established in 2007, with an annual output of about 600 million tons (Beijing Huayu Engineering co., 2015). The area is 2.47 square kilometers. The coal quality is medium ash, medium sulfur, and low phosphorus lignite (Feng et al., 2005). The study area is set in downwind of the mining area and was fenced and used as an area for high-voltage transmission lines. Based on the surface dust coverage, two areas were selected as the control area (CK) with almost no dust cover and the dust great deposition area (GD), respectively. The GD area was generally covered the black coal dust, while the CK area had almost no coal dust on the ground. The GD area is 100 meters from the edge of the pit. The CK areas located at the neighboring side of the GD areas within 1km. The sample plot is rectangular with an area of 10 m×10 m. There are three sample plots in both CK and GD area. There are four quadrats in each plot with an area of 1 m2.

Case 2: Baiyinhua No. 3 Mine (B3) is situated in Baiyinhua Town, Xiwuzhumu County, Xilinhot City. It is located between 44° 56'03.7"N, 44° 51'42.3"N and 118° 31'40.5" E, 118° 37'39.0"E (Fig.1-b). The mine was established in 2006. Lignite of Baiyinhua

coalfield is high-quality, medium-ash, low-sulfur content. The designed production capacity is 1.4 million t/a. The terrain of the study area is gentle. There is no river around the mining area. The annual average precipitation of Baiyinhua Town is 345.9 mm, and the annual evaporation is 1769.0 mm. The annual rainy season is June, July and August, accounting for 68% of the annual precipitation. The soil type is chestnut soil.
The study area is set in downwind of the mining area, which was fenced and used as a mowing grassland. The grass was harvested in September once a year. The GD area is 100 meters away from the edge of the pit. The CK area is set on the east of the contaminated area 1km. The sampling method is the same as that for the W3 coal mine.

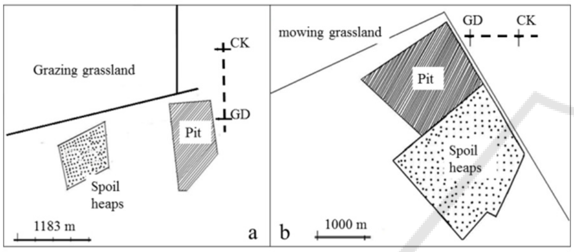

Figure 1: Location of the study sites near the coal mine (GD indicates an area with coal dust significant deposition, while CK indicates a control area inW3 coal mine (a) and B3 coal mine(b))

2.2 Monitoring the Plant Community Traits

Monitoring transects were set in the study area. Three sampling plots (10 meters × 10 meters) were put on the section with an interval distance of 100 meters, and four square quadrats (1-meter × 1 meter) were placed at the corners of the sample plot. Height, coverage, density, and biomass of each species were determined at the beginning of August (Li et al., 1994). The biomass was thought to be the climax between the end of July and the beginning of August. And important values were calculated as follows.
Important value = [relative density + relative height + relative coverage] / 3.
To observe the dust on the leaf, a binocular dissecting microscope was used with 15 x magnifications. Ten leaves of dominant species in the GD area surrounding the coal mine were carefully and randomly sampled and wrapped in a plastic film and then fixed into a book.

2.3 Monitoring the Soil Traits

Considering that topsoil covered by coal dust deposition, we sampled soil stratified by depth into 0–3 cm, 3–10 cm, 10–20 cm, and 20–30 cm. At the same time, a certain amount of brown coal powder was sampled in the coal yard of the W3 coal mining.
For preparation of determining of soil total carbon, total nitrogen, and total sulfur, the soil was air-dried, ground, and pass through a 100 mesh sieve. The elemental analyzer (Vario EL elementar, Germany) was used to determine the carbon, nitrogen and sulfur content. Hydrochloric acid was added to the soil to remove calcium carbonate. Soil organic carbon was finally resolved by an elemental analyzer.
Soil carbon isotopes were measured by Picarro CM-CRDS (Picarro, USA).
Soil moisture and temperature were measured by the TDR moisture meter WET-2 Sensor (Delta-T Devices, UK). The profile was excavated in each plot for plant survey, and parameters were measured at three depths: 0–10 cm, 10–20 cm, and 20–30 cm.

2.4 Data Analysis

One-way analysis of variance was used to compare each variable between CK treatment and GD treatment (SPSS 19.0 for Windows). The variables include total C, N, S, δ 13C, soil water content and soil temperature and plant yield and vegetation cover. This section must be in one column.

3 RESULTS

3.1 Soil Traits Surrounding the Coal Mine

The distribution of coal dust on grassland around the mining area had great spatial heterogeneity. The color of the topsoil in the contaminated area was not uniform. The coal powder accumulated in the low-lying area, and the color was black (Appendix-Figure S1). We analyzed the carbon isotope of the soil and lignite in the GD area of the W3 mine. We found that the carbon $^{13}\delta$ in the surface soil (0–3 cm) was the small in the CK area, while it was the large in the coal powder (Fig. 2). The Carbon $^{13}\delta$ in the soil of GD area was between the CK area and coal powder, which shows that the deposition of coal dust increased the ^{13}C isotope content of the surface soil around the mining area, indicates that coal dust in the surface soil of GD area is derived from coal.

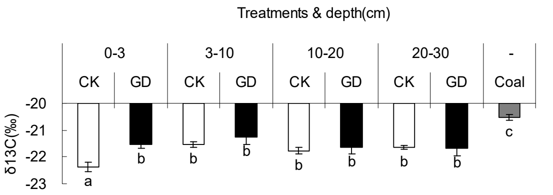

Figure 2: Carbon isotope content of soil and coal in the grassland surrounding the W3 coal mine.

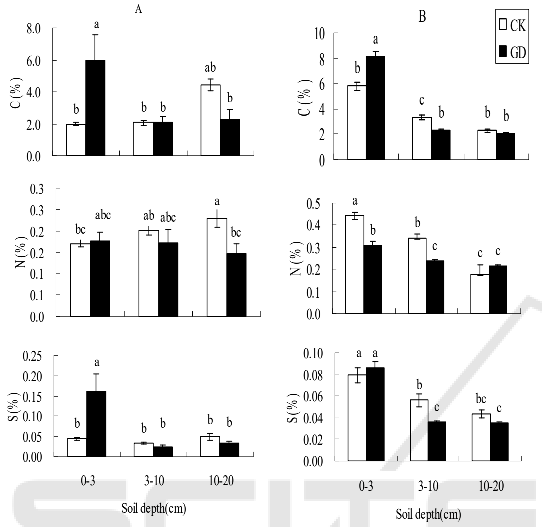

Figure 3: Contents of carbon, nitrogen, and sulfur of soil in the grassland surrounding the W3 coal mines (A) and B3 coal mines (B).

Fig. 3 shows the carbon, nitrogen, and sulfur content of the soil around the mining area. For 0–3 cm soil, the soil total carbon and total sulfur content in the GD area are substantially higher than that in the CK area, while the total nitrogen of 10–20 cm soil in the CK area was significantly higher than that in the GD area. There was no significant difference between CK and GD area in other soil layers.

3.2 Vegetation Traits of Grassland Surrounding the Mining Area

The dominant species of climax community on grassland surrounding W3 mining are Achnatherum splendens, Stipa krylovii, and Stipa grandis. At the same time, the GD area was dominated by Neopallasia pectinata, Achnatherum splendens, and Convolvulus ammannii (Table 1). Species also changed to some extent. The important values of Leymus chinensis and Stipa krylovii in the CK area were higher than those in the GD area, indicating that the community composition was unstable and in succession (Table 2).

For the grass yield of the community (Table 3), the grass yield in the CK area of the B3 mine was significantly greater than that in the GD area. The grass yield of the CK area in the W3 mine was greater than that in the GD area (p=0.051). Compared with the grass yield in the CK area, the grass yield of the GD area decreased by 37.8% and 36.7% in the W3 mine and B3 mine, respectively.

Table 1**:** Dominant plant species in grassland surrounding the W3 coal mine.

Order	CK area		GD area	
	Latin name	Important value	Latin name	Important value
1	*Stipa krylovii*	42.20	*Neopallasia pectinata*	17.93
2	*Achnatherum splendens*	18.05	*Convolvulus ammannii*	17.51
3	*Stipa grandis*	12.31	*Stipa krylovii*	17.41
4	*Chenopodium aristatum.*	9.86	*Stipa grandis*	16.95
5	*Cleistogenes squarrosa*	4.16	*Agropyron mongolicum*	16.73

Table 2: Dominant plant species in grassland surrounding the B3 coal mine.

Order	CK area		GD area	
	Latin name	IV*	Latin name	IV
1	*Leymus chinensis*	46.90	Agropyron cristatum	21.90
2	Carex korshinskyi	15.47	Leymus chinensis	17.01
3	Artemisia sacrorum	18.71	leistogenes squarrosa	16.32
4	Phragmites australis	10.88	Carex korshinskyi	13.80
5	Iris lactea	9.84	Allium mongolicum	12.94

*IV means Important value

Table 3: Changes in aboveground biomass (g) in grassland surrounding the W3 and B3 coal mine.

Sites	W3	B3
CK	162.11±18.01a*	93.63±13.22a
GD	100.85±23.67b	59.27±6.99b

* Letters indicate that the difference is significant at the 0.05 level.

The grassland cover of the GD area was lower than that of the CK area (Table 4). Compared with the CK area, the cover decreased by 33.6% and 32.9% in the W3 mine and B3 mine, respectively.

Table 4: Changes in the cover of grassland surrounding the W3 and B3 coal mine.

Sites	W3	B3
CK	70.83%±4.43%a	45.33%±6.37%a
GD	46.75%±4.13%b	26.2%±3.69%b

4 DISCUSSIONS

4.1 Evaluation of Grassland Health based on Vegetation Cover, Grass Yield, and Soil Index of Grassland around the Coal Mine

Based on data of grassland vegetation and soil around the mine area, we evaluated the grassland health status with reference to the Chinese standard of natural grassland degradation(GB 19377 - 2003, 2013). Table 5 lists the main indicators of the standard.

Table 5: Classification and grading indicators of degradation level of natural grassland in China.

Determined indexes	Class of degradation and the relative percentage of reduction in each indicator			
	No degradation	Light degradation	Medium degradation	Heavy degradation
Grassland cover	0-10	11-20	21-30	>30
CAD#	0-10	11-20	21-40	>40
Grass yield	0-10	11-20	21-50	>50
0–20cm SOM †	0-10	11-20	21-40	>40
0–20cm soil total N*	0-10	11-20	21-25	>25

#CAD means comprehensive arithmetic dominance of dominant species in grassland, CAD= (C’+P’)/2, Relative cover (C’) = the cover of a species / the maximum cover of a species among the community. Relative weight (P') = the weight of a species / the maximum weight of a species shoots in the community. † SOM means soil organic matter. *Soil nitrogen is a selective parameter. Other parameters are essential.

Based on the criteria in Table 5, the changes in grassland–related indicators in coal mines are evaluated. We found that the grassland surrounding the two coal mines has moderate to heavy degradation (Table 6, Table 7).

Table 6: Evaluation of grassland degradation based on the related indicators of grassland surrounding the W3 mine.

Monitoring index	CK area %	GD area	Reduction rate	Degradation level
Total cover / %	70.80	46.8	34.00%	heavy
CAD(*S. krylovii*)	1	0.47	52.82%	heavy
Grass yield / $g.m^{-2}$	162.10	100.80	38.00%	medium
3–20cm SOM /$g.kg^{-1}$	17.63	11.87	32.68%	medium
3–20cm soil N/$g.kg^{-1}$	2.15	1.60	25.73%	heavy

Table 7: Evaluation of grassland degradation surrounding the B3 coal mine.

Monitoring index	CK area	GD area	Reduction rate	Degradation level
Total cover / %	45.33%	26.20%	42.21%	heavy
CAD*(L. chinensis)*	1	0.46	53.72%	heavy
Grass yield / $g.m^{-2}$	93.63	59.27	36.70%	medium
3-20cm SOM /$g.kg^{-1}$	15.34	11.87	22.62%	medium
3-20cm soil N /$g.kg^{-1}$	2.59	2.27	12.36%	light

The two coal mines were established almost at the same time: the W3 mine (2007) and the B3 mine (2006). The production capacity of the B3 coal mine (140 million tons/year) was bigger than W3 coal mine (6 million tons/year), so the emissions of pollutants from W3 mine should be more than that of B3, which may be one reason for the difference of reduced rate of SOM and soil nitrogen content of the B3 and W3 coal mines. Although browning brown coal-derived products can improve soil organic matter and promote plant growth (Tahir et al., 2011), however, the addition of lignite and a mixture of minerals with lignite into the soil does not promote the growth of alfalfa (Little, 2015). It is found that the soil data changes less than the data of vegetation within one coal mine (Table 6, Table 7). The increment of total carbon content in the soil around the mining area could attribute to high content of carbon in the coal powder itself. At the same time, the increase in soil sulfur content is also related to the deposition of coal dust, because the sulfur content of the coal powder is high at the W3 mine (Feng et al., 2005). Open pit mines will produce a large number of air pollutants (particle matter and SO_2, NO_2) as all the works related to mining in the area sites near coal mining areas (Mishra and Koshta, 2018). There was a lot of dust and SO_2 emitted from the open-pit mines in this study, which can fall over the leaf and inhibit the grass growth (Wang et al., 2016; Wu, 2014). This may be one of the essential factors contributing to grassland degradation in this study.

4.2 Relationship between Grassland Degradation and Coal Dust Deposition, Soil Temperature, and Moisture around the Coal Mine

The factors causing grassland degradation around the coal mine may be related to the deposition of coal dust. There was a lot of coal dust on the ground of grassland in the GD area in this study. The coal dust falling on the grass leaves would affect the photosynthesis of plants. Studies have found that coal dust can reduce the photosynthetic rate of African mangrove leaves (Naidoo & Chirkoot, 2004). Our study also found that the deposition of coal dust can reduce of photosynthetic rate and the growth of several herbaceous plants (Wang et al., 2016), which may be a reason for the low grass yield in the GD area. In addition, we sampled the leaves of several plants in the GD area of the W3 coal mine and observed the dust distribution on the leaves (Fig. 4). The leaves of Leymus chinensis, Stipa grandis and Stipa krylovii had a different amount of coal dust on their leaves. The leaves of these plants were rough and had epidermal hairs. These morphological structures facilitate the retention of dust particles! The leaves of Neopallasia pectinata was relatively small, and they were needle-like with a smooth and hairless surface. At the same time, the coal dust was only retained on the hairy stem when observed under the microscope. This may be the reason for the dominance of Neopallasia pectinata in the GD area. Furthermore, plants with low stature, rigid branches and leaves, sunken stomata, smooth epicuticular wax or pubescent leaves and branches were more likely to accumulate dust (Turner, 2013). Meanwhile, some studies found that plant in the arid region had a strong resistance and adaption to dust stress (Matsuki et al., 2016); However, the dust in this study is lignite powder with a black color which is different from the inert dust of some studies.

The deposition of lignite dust would influence soil temperature and water content. In this study, the GD grassland around B3 had a higher surface temperature and lower soil water content (Table 8 and Figure 5). In the same topographic condition, the difference of soil temperature between the two areas was more than 5 °C, while the soil moisture in the topsoil of CK was higher than that in the GD area (Fig. 5). This may be caused by the coal dust deposition to the grassland since the black dust on the ground is easy to absorb more solar radiation, causing the ground temperature to rise.

Table 8: Changes in soil water content of grassland surrounding theW3 coal mine.

Study area	0–10 cm soil	10–20 cm soil	20–30 cm soil
CK-2015	4.51±0.28A*	5.40±0.32A	5.54±0.24A
GD-2015	2.84±0.28B	3.25±0.31B	3.71±0.47B

* Capital letters indicate that the difference is significant at the 0.001 level.

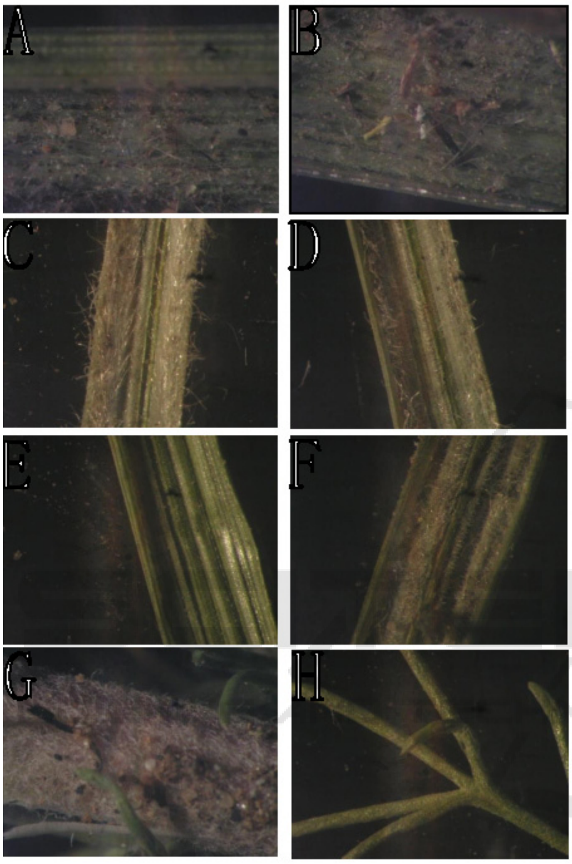

Figure 4: The dust covered on the leaf of dominant species in the GD area surrounding the W3 coal mine (A, B—Leymus chinensis; C, D—Stipa grandis; E, F—Stipa krylovii; G, H—Neopallasia pectinata).

The evaporation of soil water accelerated, which was easily led to soil drought. Plants are more susceptible to drought stress, resulting in reduced biomass or the death of certain species. Black coal powder is different from inert silicon-containing dust, such as white kaolin. Repeated application of a thin film of inert dust (kaolin clay) increased crop yield (Glenn and Puterka, 2005). Kaolin clay protects plants from excess radiation resulting in reduced stomata conductance and increased water use efficiency as it is white.

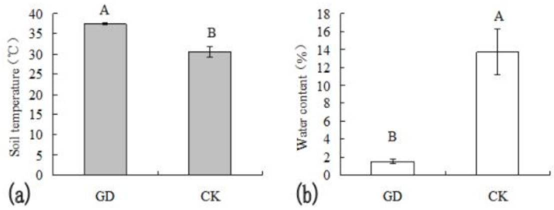

Figure 5: Temperature (a) and water content (b) of soils in the grassland surrounding the B3 coal mine.

5 CONCLUSIONS

In this study, we investigated the vegetation and soil of grassland surrounding the coal mines in Inner Mongolia steppe. After mining for 7 years, different amounts of coal dust around the mine had been accumulated. By comparing the soil and vegetation status in the adjacent areas, we found that the vegetation cover, aboveground biomass, important values of dominant species, soil organic matter, and total nitrogen decreased in the GD area, and the species composition of the community changed. We can conclude that the mining of lignite led to the degradation of grasslands surrounding the coal mine. we should pay attention to the controlling the emission of gaseous pollutants such as dust and SO2 and protecting the grassland around the mining area.

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REFERENCES

Bai, Z.K., Geng, H.Q., Guo, E. M. and Song L. (2006) Several opinions of the coal mine exploitation and ecological compensation, *Environmental Protection*, (05A): 46-48. (In Chinese).

Beijing Huayu Engineering co., General Plan of Shengli Mining Area in Xilin Gol League, Inner Mongolia (updated version), *Environmental Impact Report*, http://jz.docin.com/p-1254718103.html (Accessed June 2015)

Bhattacharya, M., Rafiq, S. and Bhattacharya, S. (2015) The role of technology on the dynamics of coal consumption–economic growth: New evidence from China, *Applied Energy*, (154): 686-695.

China geology survey, report of China Energy Resources, http://www.cgs.gov.cn/ddztt/cgs100/bxcg/fwgj/201611 /P020161125577066113658.pdf(Accessed 25 November 2016)

Ejaz, S., Camer, G.A., Anwar, K. and Ashraf, M. (2014) Monitoring impacts of air pollution: PIXE analysis and histopathological modalities in evaluating relative risks of elemental contamination, *Ecotoxicology*, (23)3: 357-369.

FAO. 1991. World Soil Resources. An Explanatory Note on the FAO World Soil Resources Map at 1:25,000,000 Scale. *World Soil Resources Report* 66, Rome, 61 pp.

Feng ,Y.J., Zhang, F.Y., Bao, B.H. [etc.], report of coal exploration in the first mining area of west No. 2 open pit mine in Shengli Coalfield, Xilinhot City, Inner Mongolia Autonomous Region, (Accessed June 2005)

GB 19377-2003, G.A.o.Q.S., Inspection and Quarantine of the People's Republic of China. (2013) Parameters for Degradation, Sandification and Salification of Rangelands: National Standards of the People's Republic of China, Standards Press of China, Beijing (In Chinese).

Geng, H.Q. (2008) The main environmental &social problems in China's large coal mine construction, *Science*, (60) 3: 33-37.

Glenn, D.M. and Puterka, G.J. (2005) Particle films: a new technology for agriculture, *Horticultural reviews*, (31): 1-44.

Little, K.R. (2015) Commercial Lignite Coal-Derived Amendments for Improved Pasture Growth and Soil Health. Ph. D. Thesis, Monash University, Melbourne, VIC, Australia.

Liao, H. and Wei, Y.M. (2011) Twelfth Five-Year Plan for China's Energy and Carbon Emissions and Prospects, *Proceedings of the Chinese Academy of Sciences*, (26) 2: 150-153

Li, Z.H., Pei, H., Liu, Z.L. and He, T. (1994) Study on the restoration succession of degraded communities in Leymus chinensis steppe. *Journal of Inner Mongolia University (Natural Science Edition)*. (25) 1: 88-98

Ma, J.J., Zhang, S.L.and Li, Q.F. (2006) The Intrusion Rule of Wild Plant Species on Reclaimed Land of Heidaigou Opencast Coal Mine and Effect to Ecosystem, *Research of Environmental Sciences*, (19) 5: 101-106.

Matsuki, M., Gardener, M.R., Smith, A., Howard, R.K. and Gove, A. (2016) Impacts of dust on plant health, survivorship and plant communities in semi‐arid environments, *Austral Ecology*, (41) 4: 417-427.

Mishra, S. and Koshta, M. (2018) Impact of coal mining on ambient air: a case study of jamuna kotma coal mines area. *International Research Journal of Engineering and Technology*, (5) 5: 724-729.

Naidoo, G. and Chirkoot, D. (2004) The effects of coal dust on photosynthetic performance of the mangrove, Avicennia marina in Richards Bay, South Africa, *Environmental Pollution*, (127) 3: 359-366.

Pandey, B., Agrawal, M. and Singh, S. (2014) Coal mining activities change plant community structure due to air pollution and soil degradation, *Ecotoxicology*, (23)8:1474-1483.

Ratcliffe, D. (1974) Ecological effects of mineral exploitation in the United Kingdom and their significance to nature conservation, *Proc. R. Soc. Lond. A*, (339)1618: 355-372.

Si, H., Bi, H., Li, X. and Yang, C. (2010) Environmental evaluation for sustainable development of coal mining in Qijiang, Western China, *International Journal of Coal Geology*, (81) 3:163-168.

Spencer, S. and Tinnin, R. (1997) Effects of coal dust on plant growth and species composition in an arid environment, *Journal of Arid Environments*, (37) 3: 475-485.

Sun, H.L. et al (Eds.), (2000) China Resources Science Encyclopedia, China Encyclopedia Press,Beijing.

Tahir, M., Khurshid, M., Khan, M., Abbasi, M. and Kazmi, M. (2011) Lignite-derived humic acid effect on growth of wheat plants in different soils, *Pedosphere*, (21)1:124-131.

Turner, G.F. (2013) Vulnerability of vegetation to mining dust at the Jack Hills, Western Australia. University of Western Australia.

World-Coal-Association. (2014) Coal facts 2014, [online] Statistic resources, World Coal Association, London. https://www.worldcoal.org/file_validate.php?file=coal_facts_2014(12_09_2014).pdf (Accessed 09 December 2014)

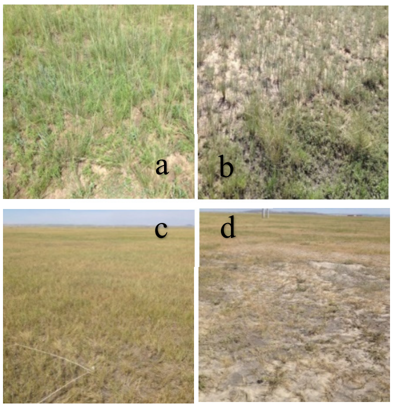
Wang, Z.Y., Hou, J., Guo, J.Y., Wang, C.J., and Wang, M.J., (2016) Coal dust reduce the rate of root growth and photosynthesis of five plant species in inner Mongolian grassland, *Journal of Residuals Science & Technology*, (13)S1: 63-73.

Wu, X.X. (2014) The impact of sulfur dioxide emissions from open pit mines in Xilinhot city on grassland productivity, Master's thesis, Inner Mongolia Technology University, Hohhot, China.

Xiao, X. (1997) Land cover classification of the Xilin River basin, Inner Mongolia using Landsat imagery, Research on Grassland Ecosystem (5): 240-252.

APPENDIX

Figure S1**:** Photos of the grassland around the W3 and B3 coal mine showing CK area (a) and GD area (b) in the W3 coal mine, CK area (c) and GD area (d) in the B3 coal mine.


a
b
c
d