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Short communication

Ecological restoration in contaminated soils of Kokdzhon phosphate mining area (Zhambyl region, Kazakhstan)

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ABSTRACT

This study provides results of an ecological restoration activity performed in the Kokdzhon phosphate mining of the Zhambyl region (a semi-desert mining area of Kazakhstan).

The test area was made by a quarry-hole, about 1.25 hectares wide, that was preliminarily filled with the earthy material of a dump and, subsequently, levelled. The total volume of human transported material (HTM) used was 700 tonnes. Soil samples were taken from 0 to 30 cm depth at 23 sampling sites and several soil quality parameters were determined. In the test area 750 tree species were planted in suitable dug holes: (150 seedlings of Russian Olive; 150 seedlings of Black Saxaul); 150 seedlings of Androsov Elm; 150 seedlings of Salt Cedar; 150 seedlings of Russian Salt Tree). In addition, a mixture of cereal and legume seeds (in equal amount of weight for each species) was seeded in 4 furrows, in between the tree lines. The results of this preliminary activity show a low engraftment of the plants used for the ecological restoration over one year. This could reasonably be due to the unfavourable soil characteristics of the test area that can be regarded as a human transported material (HTM), on which the action of the soil genetic factors, particularly, the biotic one, has yet to play out fully.

1. Introduction

Mining of mineral resources imposes various degrees of impacts on ecosystems and landscape connectivity through land clearance and transport, and results in extensive soil damage (Bradshaw, 1997; Bell et al., 2001; Yan et al., 2013). As stressed by Wong (2003), the direct effects of mining activities may include losses of arable lands, forests and pastures, and the overall reduction of soil productivity that leads to the destruction of vast amounts of land. The indirect effects may include soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity and pedodiversity, and ultimately loss of economic wealth (Sheoran et al., 2010; Ramazanova and Kydyrbaeva, 2011; Yan et al., 2013).

In many countries legislation requires that surface soils be conserved and replaced, but there is a vast heritage of degraded land left by past mining that requires restoration. Republic of Kazakhstan, with an area of 272 Mha, is the ninth largest country in the world. According to the Kazakh Agency of Land Resources (Kozybayeva, 2011), the anthropogenically disturbed land in the Republic is about 184,700 ha (less than 0.07%). Inside this, mining disturbed area is about 51,920 ha (less than 0.02%). The reclamation of these landscapes, i.e. the process by which derelict or highly degraded lands are returned to productivity, and by which some measures of biotic function and productivity is restored, is particularly important.

Even if only 2924 ha of mining disturbed land have been reclaimed (Kozybayeva, 2011), the ecological restoration and mine reclamation have become significant parts of the sustainable development strategy in Kazakhstan. Ecosystem restoration on mining sites is of particular importance for environmental protection and ecological maintenance. Correct planning and environmental management will minimize the impacts of mining on the environment and will help in preserving eco-diversity.

The basic mode of land reclamation in mine area includes agriculture, forestry, fishery, construction, and entertainment (Bing-yuan and Li-xun, 2014). Among these, the establishment of vegetation is a cost-effective and environmentally sustainable method of stabilizing and reclaiming derelict land in mining areas (Yan et al., 2013).

The processes of natural succession demonstrate that nature can achieve restoration unaided, and develop fully functioning soils. Although there are problems set by the processes of dispersal, once they are established plants demonstrate that they can readily provide organic matter, lower soil bulk density, and bring

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mineral nutrients to the surface and accumulate them in an available form (Bradshaw, 1997). Kuter et al. (2014), in a survey aiming at determine the suitable plant species for the reclamation of an abandoned coal mine area in the province of Cankiri (Turkey), after considering the soil features of the study area, suggested a total of 28 taxa, excluding natural plant species identified on the site. The positive efficiency and function of vegetation cover was also stressed in landscape disturbed by opencast mining in West Bohemia (Pecharova et al., 2011), and in the Appalachian region (Holl et al., 2009).

Anyway, in many cases for the restoration process it is necessary to introduce, artificially, the most appropriate plant species that can then be left to develop and spread on its own. In mined lands, however, may occur extreme soil conditions that prevent plant growth, particularly physical conditions, severe lack of specific nutrients and/or toxicity. It is important that these are firstly identified and well known, otherwise the whole restoration process might either not begins, or fails after a few years (Bradshaw, 1997).

For the purpose of suggesting, for the first time in a Kazakh semi-desert mining area, the ecological restoration using plant species as effective reclamation measures, this communication provides the first year results of an ecological restoration activity performed in the Kokdzhon phosphate mining of the Zhambyl region (a semi-desert mining area of Kazakhstan).

2. Materials and methods

2.1. Study area

The study area is situated near by the Kokdzhon mine (43°33′16.72″ N; 69°31′50.09″ E). This is a 277.83 hectares wide rock phosphate deposit, located in the Zhambyl region, in the central-southern area of Kazakhstan (Fig. 1). The climate is dry and arid (BWk according to Koppen classification). Annual precipitation ranges between 200 mm and 250 mm. Within the region the average annual temperature ranges from 6.5 °C to 10.5 °C. On average, during the warm period of the year air temperature is around 18–19 °C. In some years, the hottest daytime temperatures in the desert part rise up to 45–47 °C.

The mine is made by several quarry-holes in the land (Fig. 1). These are from 1.6 to 2.98 km long, 360–430 m wide and 90–95 m deep. The phosphate mining, have originated several 50–70 m high multi-layer industrial dumps on the surface all around the mine (Mirzaev et al., 1991). For the purpose of the work and, as test area, we have chosen a small hole (less than 2 hectares wide) that was filled with a dump's material.

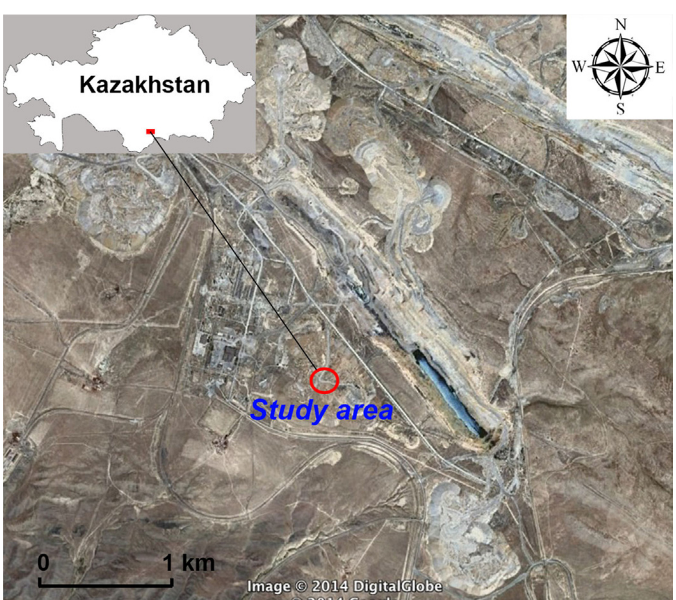

Fig. 1. Location of the study area.

Table 1
Particle size analysis and chemical data of the topsoil (0–30 cm) of the test area (N = 23).

Parameter	Mean	Min	Max	Max-Min	SD
Sand (1.0–0.25 mm)	5.4	2.93	14.8	11.87	2.4
Sand (0.25–0.05 mm)	21.9	15.1	32.1	17.0	4.5
Silt (0.05–0.01 mm)	29.5	21.7	50.5	45.8	6.4
Silt (0.01–0.005 mm)	8.6	4.6	16.8	12.2	2.3
Silt (0.005–0.001 mm)	16.3	2.5	20.6	18.1	3.8
Clay (<0.001 mm)	18.3	0.5	23.1	40.7	4.5
Humus (%)	0.35	0.07	0.52	0.45	0.14
Gypsum (%)	1.9	0.2	4.6	4.4	1.2
N tot (%)	0.042	0.014	0.07	0.056	0.02
N hydrolyzable (mg kg^{-1})	28.5	19.6	36.4	16.8	5.3
$CaCO_3$ (%)	13.3	8.42	16.5	8.08	2.22
P_2O_5 total (%)	0.09	0.05	0.14	0.09	0.03
P_2O_5 movable (mg kg^{-1})	5	4	9	5	1.3
K_2O total (%)	0.7	0.2	0.94	0.92	0.2
K_2O movable (mg kg^{-1})	87	60	150	90	32.4
Reaction (pH)	8.4	8.34	8.52	0.18	0.07
Ca_{exc} (cmol$_+$ kg^{-1})	11	8	13	5	1.1
Mg_{exc} (cmol$_+$ kg^{-1})	3.9	2.8	5	2.2	0.6
Na_{exc} (cmol$_+$kg^{-1})	1.14	0.77	1.66	0.89	0.21
K_{exc} (cmol$_+$ kg^{-1})	0.08	0.05	0.16	0.11	0.03

2.2. Materials and methods

Among the mine's dumps we selected a test-field made by a quarry-hole, about 1.25 hectares wide, that was preliminarily filled with the earthy material of a dump and, subsequently, levelled. The total volume of human transported material (HTM) used was 700 tonnes. In this first phase, the result was that, at the same time, a dump and a hole were eliminated from the land surface.

After completing of the levelling operations, the topsoil (0–30 cm) of the test area (a rectangular shaped area, about 110 m × 115 m) was randomly sampled (total 23 soil samples). Air-dried samples were gently crushed and passed through a 2 mm sieve. Most of the soil analyses were carried out following the Russian Handbook on the Chemical Analysis of Soils (Arinushkina, 1961). Soil particle distribution was analyzed according to Kachinsky (Vadyunina and Korchagina, 1986); total carbonates was determined by gas-volumetric method (Zatula and Prozhorina, 2008); total potassium was determined according to Michigan (Radov et al., 1965); heavy metals (Zn, Cu, Pb, Cd) were performed following Chebotarev et al. (1995).

In the test area 750 tree species were planted (May 2013) in suitable dug holes (40 cm × 40 cm), opened along 2 lines. Inside each hole 150 g of biochar and 70 g of urea were added (Ippolito et al., 2012; Beesley et al., 2008). In particular we used: 150 seedling of

Table 2
Heavy metals in the topsoil (0–30 cm) of the test area (N = 23).

Metal	Form	Mean	Min	Max	Max-Min	SD	Threshold*
		mg kg^{-1}					
Cd	Total	3.4	3.2	3.6	0.4	0.23	1.5
	Movable	1	0.9	1.2	0.3	0.2	
Cu	Total	26.8	25	28	3	1.53	100
	Movable	2.9	2.1	3.7	1.6	0.7	
Pb	Total	34.1	29	39.6	10.6	4.7	100
	Movable	13.6	11	15.6	4.6	2.2	
Zn	Total	58.5	54	62.4	8.4	3.7	200
	Movable	2.2	1.2	2.8	1.6	0.72	

* Proposed threshold values with soil pH > 7 [20].

Table 3
Data concerning the plants used in the ecological restoration of the test area.

Tree species	Seedlings	Survived plants	Height cm Min	Height cm Max	Cover crop	Height cm Min	Height cm Max
Russian Olive	150	2	55	100	Smooth brome	11	23
Black Saxaul	150	9	55	90	Russian wildrye	8	11
Androsov Elm	150	10	58	150	Tall oat-grass	12	21
Salt Cedar	150	10	30	95	Perennial ryegrass	14	27
Russian Salt Tree	150	0			Meadow fescue	10	20
					Cock's-foot	7	9
					Alfalfa	13	28
					Common sainfoin	15	36
Total Trees	750	31					

Russian Olive (*Elaeagnus angustifolia* L.); 150 seedling of Black Saxaul (*Haloxylon aphyllum* (Minkw.) Iljin); 150 seedling of Androsov Elm (*Ulmus minor* Mill.); 150 seedling of Salt Cedar (*Tamarix gracilis* Willd.); 150 seedling of Russian Salt Tree (*Halimodendron halodendron* (Pall.) Voss). Tree species were selected for their adaptability to climatic and pedoclimatic conditions. In addition, a mixture of cereal and legume seeds (in equal amount of weight for each species), were seeded in 4 furrows, in between the tree lines. Twice per week, seedlings were irrigated: the trees in small basins around the tree trunk and the cereals in furrows. Two times per week (from May 2013 to September 2013) very simple phenological observations (such as number and height of survived trees) were performed.

3. Results and discussion

The main analytical data of the topsoil in the test area are reported in Tables 1 and 2. Topsoil shows a clear prevalence of the silt fraction (total 54.4%) followed respectively by the sand fraction (total 27.3%) and the clay one (18.3%). The considerable amount of silt, accountable for the powdery aspect of the topsoil, negatively influences the soil: in forming aggregates, cation exchange capacity, soil permeability and porosity. The main fertility parameters of the topsoil show values that, in general, cannot be considered favourable for the optimal plant growth. Soil reaction is sub-alkaline with a pH average of 8.4 (range 8.34–8.52); such result is favoured by the presence both of carbonates (13.3% in average) and gypsum (1.9% in average). Humus values are very low (0.35% in average) as well as the values of nitrogen (13.3% in average), phosphorus (0.09% in average) and potassium (0.7% in average). Cation exchange capacity, in average, is 16.12 $cmol_+\ kg^{-1}$, with Ca^{2+} the most represented cation, followed in decreasing order by Mg^{2+}, Na^+ and K^+.

As far as concern the actual content of heavy metals in the topsoil (Table 2) are below than of the proposed thresholds for the European soils (EC, 2006), except for Cd. The sub-alkaline pH values play a positive role because the solubility of most heavy metals in the soil tends to decrease with the increasing of the pH. In other terms the higher the soil pH, the more likely heavy metals remain immobilized in the soil.

The results of this preliminary activity of ecological restoration performed in the test area of the Kokdzhon phosphate mine are summarized in Table 3.

Only 4.1% of the planted trees survived. More suitable were: Androsov Elm (10 plants with minimum and maximum height ranging from 58 cm to 150 cm); Salt Cedar (10 plants with minimum and maximum height ranging from 30 cm to 95 cm); and Black Saxaul (9 plants with minimum and maximum height ranging from 55 cm to 90 cm). Russian Salt Tree did not survive and Russian Olive had the lowest success (only 2 plants).

As far as concern the cover crops, shoots were rare, irregular, with some spots. Minimum and maximum height reached by these of these are shown in Table 3.

4. Conclusions

The low engraftment shown by the plants used for the ecological restoration could reasonably be due to the unfavourable soil characteristics. Effectively, the soil of the test area can be regarded as a human transported material (HTM), on which the action of the soil genetic factors, particularly the biotic one, has yet to play out fully.

However, some observations made one year after the planting confirmed the observations from Mosseler et al. (2014) about the possibility of further regrowth of plants. Also in our study case, after passing a period of dormancy, the tree species began to vegetate again by issuing new shoots from the roots.

Results also indicated the species more tolerant that could be more suitable for the restoration.

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