# SOILS AND PLANTS IN AN ANTHROPOGENIC DUMP OF THE KOKDZHON PHOSPHORITE MINE (KAZAKHSTAN)

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## Abstract
Soil development is a crucial aspect in the process of mine spoil restoration and is also critical for the establishment of the vegetation. In this short paper, we present the features of mine proto-soils (i.e. soils at the early stage of development) and the natural vegetation species colonizing mine sites in a dry arid environment of Kazakhstan characterized by surface disturbance due to mine activity to access phosphorite deposit. These disturbed soils showed morphological features very different from each other (particularly horizons depth and sequence), even if the main chemical features were quite homogeneous. This is reasonably linked to the features of the Human Transported Material derived from mine operation that was scattered around the mine area. The most abundant natural plants found in the study area belong to the Poacee, Asteraceae and Fabacee families (with 4 species each). Biomass contribution for all species is very low; the root biomass was greater than above ground biomass, contributing to a modest soil development.

**Keywords:** *mine soils, soil development, natural vegetation, plant biomass*

## Introduction

Mining activities significantly contribute to the economic development of Kazakhstan due to an abundant supply of accessible mineral and fossil fuel resources. However, mining activities frequently result in remarkable modifications to the environment in terms of total quality of both landscape and soilscape. Opencast mining causes significant surface disturbance because, as stressed by Li (2006), the disturbed footprint is from 2 to 10 times more than that of underground mining. Opencast mining results in clear changes in landscape morphology and aesthetics by the formation of huge overburden dumps and pits that create landscapes with no vegetation and the presence of bare soils characterized by limited soil biodiversity (Herath et al., 2009; Keskin and Makineci, 2009).
In such environments, the knowledge of the soil reorganization processes is of paramount importance from an environmental point of view because they may give useful suggestions about the possible monitoring strategies and measures to be in-

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troduced to promote and facilitate the environmental health and quality (Pellegrini et al., 2016). Consequently, a sound knowledge of how "mine soils" evolve during restoration is of great importance to support the development of ecological restoration strategies (Toktar et al., 2016). Indeed, their physical and chemical features are directly driven by the physical and chemical properties of the parent material on/with which they form (Mukhopadhyay et al., 2016) while organic carbon pools and microbial activity and diversity, consequent to the vegetation development, drive the biological processes (Canfora et al., 2015; Camilli et al., 2016).
Studies on mine soils have shown that soil properties affected by plant communities (Clark and Zipper, 2016), are not static but develop over time (Pellegrini et al., 2016). Mine soil properties and their influence on vegetation development and/or on soil biological activity, has been surveyed in several environments, including abandoned mine-tailings (Knops and Tilman, 2000; Wang et al., 2008); forests (Matlack, 2009) and afforested post-mine sites (Józefowska et al., 2016); urban areas (Schadek et al., 2009); glaciers (Hodkinson et al., 2003).
Nevertheless, there are few examples of surveys that, in restoration projects, have considered mine soil properties and evolution as well as vegetation succession and the biological properties of anthropogenically disturbed areas of phosphorite deposit in the dry arid environment of Kazakhstan (Toktar et al., 2016).
The goal of this short paper is to show the features of mine protosoils and the vegetation species that developed in a dry arid environment of Kazakhstan characterized by huge disturbed areas due to mine activity in phosphorite deposit. In particular we aim at: i) defining the main features of some mine protosoils in this particular environment and ii) investigating the vegetation development and it role in producing organic matter.

## Study area

Zhambyl region, in Southern Kazakhstan (Fig. 1), is characterized by rock-outcrops belonging to the carboniferous age and mainly composed by conglomerates, lime-gypsum-bearing rocks underlain by red arkoses sandstones and limestone with interbedded shale and sandstones. These rocks are sometimes covered with a 0.5 - 1 m layer of deposits. Takyr and Takyr-like soils together with Chestnut and Gray-Brown soils characterize the pedological panorama of the region (Saparov, 2014). Climate, arid and dry, is defined *BWk* according to Koppen classification. Annual mean precipitation does not exceed 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 could rise up to 45–47°C.
The mine, whose activity started in 1991, is made by three units: Shulaktau, Zhanatas and Kokdzhon. Kokdzhon is a phosphorite deposit of sedimentary origin belonging to the Proterozoic-lower Palaeozoic age, which extends for about 8 km and contains a phosphorite member with up to 30% $P_2O_5$. The member rests on phosphatic shale which contains up to 20% $P_2O_5$ (Notholt et al., 2005).

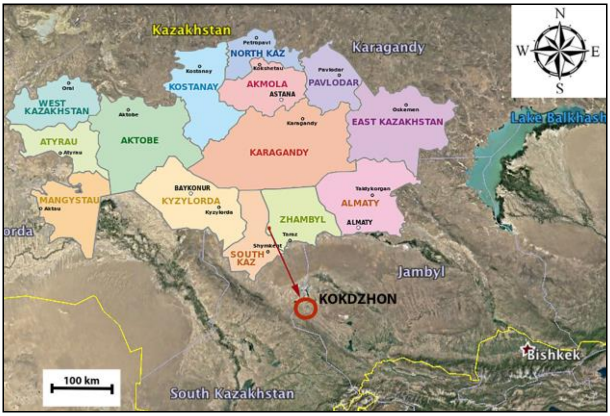


**Figure 1**
*The study area is located in the Zhambil region nearby the central southern border of Kazakhstan.*

The study area falls inside the Kokdzhon mine (43° 33'.09.93" N; 69° 32'02.72" E) (Fig. 2). In particular it is a phosphate mine 277.83 hectares large, located nearby the Zhanatas village, in the Zhambyl region. Several quarry-holes shattered in the landscape characterize the area (Fig. 2). These are from 1.6 to 3 km long, 360 - 430 m wide and 90 - 95 m deep. Mining activity resulted in the formation of five dumps covering 110 hectares and characterized generally by three tilted strata (Fig. 3) with slope gradient ranging around 60-70°.


**Figure 2**
*From left to right, the blue line indicates respectively the borders of the Kokdzhon, Zhanatas and Shulaktau mines. The red line indicates the study area.*

**Figure 3**
*Mining activity resulted in the formation of dumps generally characterized by three tilted strata showing a slope ranging around 60-70°.*

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## Materials and Methods

To fit the aims of this study, we considered one dump of the Kokdzhon mine. Four soil profiles were surveyed in 2011: one in a natural area nearby the dump (N1); three, which were disturbed soils (D1; D2; D3) - were dug in the dump (Fig. 4).

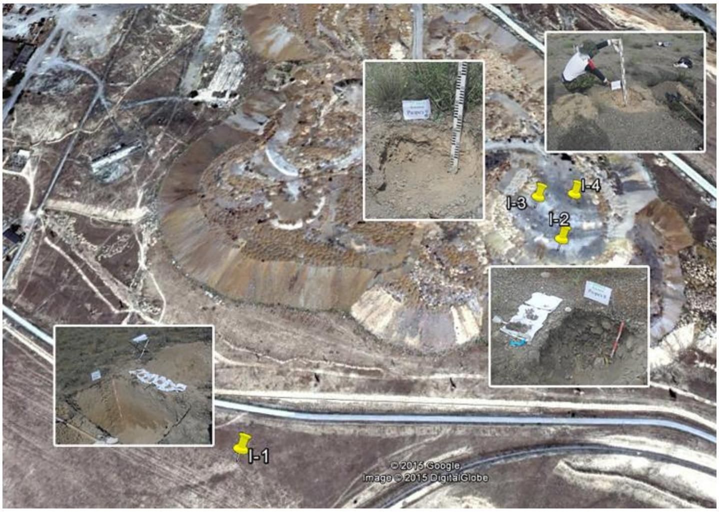


**Figure 4**
*Aerial photo of the dump n. 2 with the location of the soil profiles surveyed.*

Soil profiles were described according to standard soil survey methods (Schoeneberger et al., 2012). From each soil horizon, representative samples were collected. Bulk soil samples were air dried, gently crushed and passed through a 2-mm sieve and analysis undertaken using fine earth. Soil texture was analysed using the pipette method following dispersion after 3-h shaking with 0.1 M $Na_4P_2O_7$ (Gee and Bauder, 1986; Sheldrick and Wang, 1993). Total carbonates were determined by gas-volumetric method (Zatula and Prozhorina, 2008). Soil pH was measured potentiometrically in 1:2.5 w/v suspension (soil:1M KCl and soil:H2O), using a Metrohm 691 with a glass electrode AC 9101. Total N was determined by Kjeldhal's method (1883).  The analysis of organic carbon was performed using the Walkley–Black Wet Oxidation method (Nelson and Sommers, 1982) and organic matter was calculated from $C_{org}$ (i.e. $C_{org}$ x 1.724). Total potassium was determined according to Radov et al., (1965). $P_2O_{5tot}$ was carried out following the Russian Handbook on the Chemical Analysis of Soils (Arinushkina, 1961). To investigate the natural vegetation a floristic survey was performed in the area of the dump. Quadrat method was used for evaluation of plants communities in four randomly selected areas of 1 $m^2$ around each pedon. Moreover, to highlight the contribution of the vegetation in producing organic matter, the weight of above ground biomass (collected by clipping), of litter and of the roots at two depths (0-5 and 5-10 cm) was measured in the same four randomly selected areas. The plant root biomass was determined after the soil samples were accurately washed and sieved with a set of 3 sieves (with a diameter of 2 mm; 1 mm; 0.5 mm respectively).

## Results

### *Soil features and properties*

The main morphological and chemical features of the soils profiles investigated in the study area are reported in Table 1 and in Table 2.

**Table 1.** *Main morpho-descriptive characteristics of the pedons surveyed*.

| Pedon | M(orizon | Depth (cm) | [a]Boundary | Color (dry) | [b]Structure | [c]Texture | [d]Rock fragments | [e]Consistence (dry) | [f]Effervescence | [g]Roots |
|---|---|---|---|---|---|---|---|---|---|---|
| N1 | A | 0-12 | C | 10YR6/3 | gr&sbk, f&m,1 | SL | 0 | SH | 2 | 1,f |
| | AB | 12-25 | C | 10YR6/4 | sbk, f&m,1 | SL | 0 | H | 2 | 1,f |
| | Bw | 25-46 | G | 10YR6/4 | abk, f&m, 2 | SL | 0 | H | 2 | 0 |
| | 2C1 | 46-90 | G | 2.5Y6/6 | abk, m, 2 | SL | 0 | VH | 3 | 0 |
| | 2C2 | >90 | U | 2.5Y6/6 | abk, m, 2 | SL | 0 | VH | 3 | 0 |
| D1 | ^A | 0-6 | C | 10YR4/2 | sbk, f, 1 | L | C- 1,2 | SH | 2 | 1,f |
| | ^R&A1 | 6-17 | G | 10YR5/2 | sbk, f, 1 | SL | M - 3,2,1 | - | 3 | 0 |
| | ^R&A2 | 17-30 | U | 10YR5/2 | sbk, f, 1 | L | M - 2,1 | - | 2 | 0 |
| D2 | ^A1 | 0-7 | C | 2.5Y6/2 | sbk, f | L | C -1 | SH | 2 | 1,f |
| | ^A2 | 7-17 | C | 2.5Y6/4 | sbk, f-m, 1 | L | C - 1,2 | SH | 2 | 0 |
| | ^A3 | 17-32 | U | 2.5Y6/4 | sbk, m, 2 | SL | M - 2,1 | SH | 2 | 0 |
| D3 | ^A1 | 0-13 | C | 2.5Y5/2 | sbk, f | SL | F - 1,2 | SH | 3 | 1,f |
| | ^A2 | 13-27 | C | 2.5Y6/3 | sbk, f-m, 1 | SL | M - 3,2,1 | SH | 2 | 0 |
| | ^A3 | 27-31 | U | 2.5Y6/3 | sbk, m, 2 | SL | C - 1,2,3, | SH | 3 | 0 |

[a]Boundary: C=clear; G=gradual; U=unknown.
[b]Structure: gr=granular; sbk=subangular blocky; abk=angular blocky; f=fine; m=medium; 1=moderate, 2=strong.
[c]Texture: L=loam; SL=sandy loam.
[d]Rock fragments: 0=absent; F=few, C=common, M=many; 1=small; 2=medium; 3=coarse
[e]Consistence: SH=sligthly hard; H=hard; VH=very hard.
[f]Effervescence: 1=slightly; 2= strongly; 3= violently
[g]Roots: 0=absent; 1=few; f=fine

**Table 2.** *Main chemical properties of the pedons surveyed.*

| Pedon | Horizon | Depth | Clay | $CaCO_3$ | pH | | N tot. | $P_2O_5$ tot. | $K_2O$ tot. | O.M. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (cm) | (g kg$^{-1}$) | (g kg$^{-1}$) | $H_2O$ | $CaCl_2$ | (‰) | (‰) | (‰) | (%) |
| N1 | A | 0-12 | 121 | 62.0 | 8.20 | 8.00 | 0.8 | 0.44 | 21.1 | 1.28 |
| | AB | 12-25 | 130 | 63.9 | 8.23 | 8.10 | 0.6 | 1.08 | 18.9 | 0.71 |
| | Bw | 25-46 | 126 | 74.8 | 8.25 | 8.14 | 0.4 | 1.08 | 17.8 | 0.51 |
| | 2C1 | 46-90 | 150 | 95.8 | 7.95 | 7.80 | 0.4 | 0.92 | 17.3 | 0.49 |
| | 2C2 | >90 | 139 | 77.3 | 7.79 | 7.61 | 0.3 | 0.72 | 18.9 | - |
| D1 | ^A | 0-6 | 156 | 85.7 | 7.58 | 7.23 | 0.4 | 2.04 | 18.3 | 0.71 |
| | ^R&A1 | 6-17 | 167 | 127.0 | 8.20 | 8.12 | 0.3 | 1.72 | 14.4 | 0.17 |
| | ^R&A2 | 17-30 | 122 | 75.4 | 8.50 | 8.27 | 0.3 | 2.04 | 13.8 | - |
| D2 | ^A1 | 0-7 | 130 | 71.0 | 8.56 | 8.32 | 0.7 | 3.24 | 16.1 | 0.86 |
| | ^A2 | 7-17 | 168 | 98.4 | 8.46 | 8.22 | 0.2 | 3.16 | 14.4 | 0.1 |
| | ^A3 | 17-32 | 147 | 83.1 | 8.28 | 8.10 | 0.2 | 3.80 | 12.5 | - |
| D3 | ^A1 | 0-13 | 185 | 122.0 | 8.13 | 8.00 | 0.6 | 2.88 | 14.4 | 0.88 |
| | ^A2 | 13-27 | 209 | 66.8 | 7.55 | 7.25 | 0.3 | 0.60 | 13.5 | 0.27 |
| | ^A3 | 27-31 | 179 | 118.0 | 7.58 | 7.36 | 0.3 | 0.84 | 12.5 | - |

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According to the Soil Taxonomy system (Soil Survey Staff, 2014), N1 pedon (Fig. 5a) is classified as a Typic Haplocambid. It is characterized by a pale brown fairly shallow solum that lies on a lithological discontinuity. Organic matter decreases regularly with the depth as well as the content of nutrients. Soil pH is sub-alkaline while texture is sandy-loam, characterized by a clay content ranging from 121 to 150 g $kg^{-1}$.

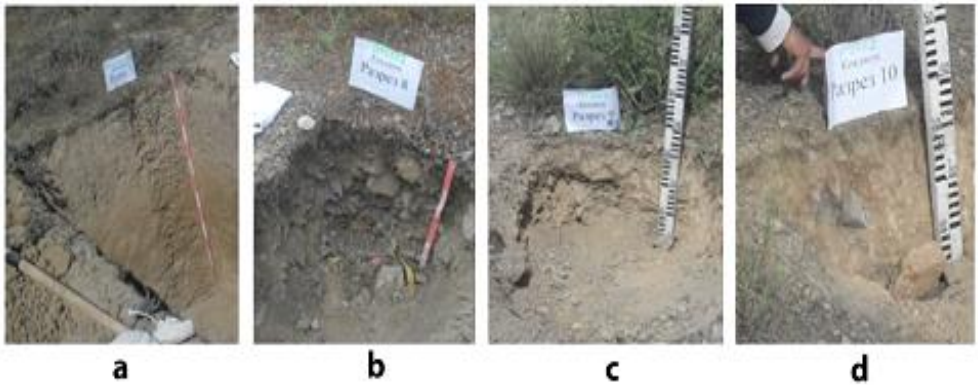


**Figure 5.** *Soil profiles of surveyed pedons*

Pedons D1, D2 and D3 (Figs. 5b; 5c; 5d) are classified as Anthroportic Torriorthents. These “anthropogenic soils” are characterized by a HTM (Human Transported Material) horizon that shows week signs of pedogenesis. Generally, these pedons show a shallow to thin ^A horizon with colours ranging from greyish brown to light yellowish brown. Organic matter decreases regularly with the depth as well as the content of nutrients. Soil reaction is sub-alkaline while texture ranges from loam to sandy loam, with a clay content ranging from 122 to 209 g $kg^{-1}$. Distinctive is the variability of $CaCO_3$ (from 66.8 to 127.0 g $kg^{-1}$) and the presence of rock fragments randomly distributed in the soil profile and with a notable variability in content and dimension due to their HTM origin.

### *Vegetation*

The survey of the natural vegetation in the study area showed very low species richness. We found only 22 different plant species belonging to 12 different taxonomic families (Table 3). The biomass contribution for all species is very low and reflects in the release of low amount of organic matter on the topsoil (Table 4).

The underground biomass shows higher values in the disturbed soils than in the control soil (Table 4). This is a positive aspect if we consider the general role of the organic matter in conditioning the features and the soil formation. Moreover, in the study site D1 and D2 the underground biomass is greater than the biomass on the soil surface. Litter and mowing in the disturbed areas are very low especially in D2.

**Table 3.** *Natural plants in Kokdzhon dump.*

| Family | Scientific name | Common name |
|---|---|---|
| *Poaceae* | *Hordeum murinum* subsp. *leporinum* (Link) Arcang. | Hare Barley |
| | *Bromus sericeus* Drobow | Fire silky |
| | *Bromus tectorum* L. | Drooping brome |
| | *Stipa hohenacheriana* Trin. & Rupr. | Feather grass |
| *Ephedracee* | *Ephedra intermedia* Schrenk & C.A. Mey. | Ephedra |
| *Polygonaceae* | *Atraphaxis pungens* (Bieb.) Jaub. & Spach | Kurchavka princky |
| *Scrophulariacee* | *Verbascum turkestanicum* Franch. | Cow Turkestani |
| *Plantaginacee* | *Linaria popovii* Kuprian | Toadflax |
| *Caryophyllaceae* | *Dianthus acicularis* Fisch. ex Ledeb. | Clove prickle leaf |
| | *Silene fruticosa* L. | Smolevka bushy |
| *Asteraceae* | *Chondrilla brevirostris* Fischer & C. A. Meyer | Chondrilla shortnose |
| | *Scorzonera pubescens* DC. | Kozlets downward |
| | *Artemisia heptapotamica* Poljakov | Sagebrush Semirechie |
| | *Heteroderis leucocephala* (Bunge) Leonova | Heteroderis white head |
| *Lamiacee* | *Nepeta ucrainica* L. | Cat Ukraine |
| *Boraginaceae* | *Heterocaryum rigidum* A.DC. | Heterokariy hard |
| *Rubiaceae* | *Asperula setosa* Jaub. & Spach. | Woofruff bristly |
| *Apiaceae* | *Schrenkia involucrata* Regel & Schmalh. | Schrenkia wrapped |
| *Fabaceae* | *Trigonella geminiflora* Bunge | Fenugreek primrose |
| | *Oxytropis capusii* Franch. | Oxytrope Kapu |
| | *Astragalus semenovii* Bunge | Astragal Semenov |
| | *Onobrychis chorassanica* Bunge | Sainfoin Khorassansky |

**Table 4** *Biomass of the natural vegetation in the dump in 2011.*

| Pedon | Organic | Depth (cm) | Values (kg ha$^{-1}$) Max | Min | Range | Mean | St dev |
|---|---|---|---|---|---|---|---|
| N1 | Mowing | | 58 | 12 | 46 | 37 | 19 |
| | Litter | | 30 | 18 | 12 | 12 | 6.0 |
| | Roots | 0-10 | 20 | 7.0 | 13 | 13 | 5.0 |
| D1 | Mowing | | 29 | 10 | 19 | 19 | 8 |
| | Litter | | 11 | 3.0 | 8.0 | 6.0 | 3.0 |
| | Roots | 0-5 | 49 | 10 | 39 | 28 | 19 |
| | | 5-10 | 11 | 2.0 | 9.0 | 5.0 | 4.0 |
| D2 | Mowing | | 11 | 4.0 | 7.0 | 7.0 | 3.0 |
| | Litter | | 11 | 2.0 | 9.0 | 5.0 | 4.0 |
| | Roots | 0-5 | 49 | 4.0 | 45 | 22 | 20 |
| | | 5-10 | 4.0 | 0.8 | 3.0 | 2.0 | 1.0 |
| D3 | Mowing | | 47 | 11 | 36 | 28 | 14 |
| | Litter | | 25 | 5.0 | 2.0 | 15 | 10 |
| | Roots | 0-5 | 21 | 2.0 | 19 | 12 | 9.0 |
| | | 5-10 | 3.0 | 0.1 | 3.0 | 2.0 | 0.1 |

## Conclusions

Soil chemical and biological properties of anthropogenically disturbed soils were assessed to evaluate the progress and development of the some mine soils and of the primary succession of the vegetation in a selected dump of a phosphate mine. This could potentially give interesting information for a future reclamation of the whole Kokdzhon mine area. Disturbed soils show morphological features rather

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different each other even if the main chemical properties are quite homogeneous. This is reasonably due to the origin of the HTM. The most abundant natural plants found in the study area belong to the Poacee, Asteraceae and Fabacee families. All the plants contribute to the soil development mostly with their underground biomass. This research supports in understanding the first stage of soil evolution in phosphorite deposit mine areas as well as in verifying the influence of the plant cover in supporting early soil development on abandoned mine spoils.

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**SOLS ET PLANTES DANS UNE DÉCHARGE ANTHROPIQUE DE LA MINE DE PHOSPHORITE DE KOKDZHON (KAZAKHSTAN)**

**Résumé**

Le développement du sol est un aspect fondamental du processus de restauration des zones minières et est également essentiel à la plantation de la végétation. Dans cette note, nous décrivons les caractéristiques des proto-sols (sols à la phase du développement précoce) et de la végétation naturelle présentes dans les dépôts résultant de l'activité des mines de phosphore dans un environnement sec et aride du Kazakhstan. Ces sols anthropiques présentaient des caractéristiques morphologiques très différentes (en particulier la profondeur et la séquence des horizons), bien que les caractéristiques chimiques principales soient assez homogènes. Cela est raisonnablement lié aux caractéristiques du matériel dérivé des opérations minières, essentiellement un matériel transporté par l'homme (Human Transported Material), et dispersé par l'homme près de la zone minière. Les plantes naturelles les plus abondantes trouvées dans la zone d'étude appartiennent aux familles Poacee, Asteraceae et Fabacee (avec 4 espèces chacune). La contribution de la biomasse à toutes les espèces était très faible; cependant, la biomasse radicale était plus élevée que celle de la biomasse de surface, contribuant ainsi au développement modeste des sols.

**Mots-clés**: *sols de miniers, développement des sols, végétation naturelle, biomasse végétale.*

**SUOLI E PIANTE IN UN DEPOSITO ANTROPOGENICO DELLA MINIERA DI FOSFORITE DI KOKDZHON (KAZAKISTAN)**

**Riassunto**

Lo sviluppo del suolo è un aspetto fondamentale nel processo di ripristino delle aree di miniera ed è anche fondamentale per l’insediamento della vegetazione. In questa breve nota illustriamo le caratteristiche dei proto-suoli (suoli nella fase iniziale dello sviluppo) e della vegetazione naturale presenti in depositi derivanti dall’attività di miniere di fosforite di un ambiente secco e arido del Kazakistan. Questi suoli di origine antropica mostrano caratteristiche morfologiche molto diverse (in particolare profondità e sequenza di orizzonti), anche se le principali proprietà chimiche sono piuttosto omogenee. Ciò è ragionevolmente legato alle caratteristiche del materiale derivato dalle operazioni estrattive, sostanzialmente un Human Transported Material, e sparso dall'uomo in prossimità della zona della miniera. Le piante naturali più abbondanti rinvenute nella zona di studio appartengono alle famiglie Poacee, Asteraceae e Fabacee (con 4 specie ciascuna). Il contributo della biomassa per tutte le specie è risultato molto basso; tuttavia la biomassa radicale è stata superiore a quella della biomassa di superficie, contribuendo in tal modo ad un sia pure modesto sviluppo del suolo.

**Parole chiave**: *suoli di miniera, sviluppo del suolo, vegetazione naturale, biomassa vegetale.*