Effects of pumice mining on soil quality

A. Cruz-Ruíz[1], E. Cruz-Ruíz[1], R. Vaca[2], P. Del Aguila[2], and J. Lugo [2]

[1]Instituto de Ingeniería, Universidad Autónoma de Baja California. Mexicali, Baja California, México
[2] Facultad de Ciencias, Universidad Autónoma del Estado de México, Instituto Literario 100 Toluca, 50 000 México

Correspondence to: J. Lugo (jorgelug@gmail.com)

Abstract. Mexico is the world's fourth most important maize producer; hence, there is a need to maintain soil quality for a sustainable production in the upcoming years. Pumice mining is a superficial operation that modifies large areas in Central Mexico. The main aim was to assess the present state of agricultural soils differing in elapsed-time since pumice mining (0–15 years), in a representative area of the Calimaya region in the State of Mexico. The study sites in 0, 1, 4, 10 and 15 year-old reclaimed soils were compared with adjacent undisturbed site. Our results indicate that soil organic carbon, total nitrogen, microbial biomass carbon and microbial quotients were greatly impacted by disturbance. A general trend of recovery towards the undisturbed condition with reclamation age was found after disturbance, being the recovery of soil total N faster than soil organic C. Principal components analysis was applied. The first three components gathered explain 71.72 % of the total variability. The first factor reveals strong associations between total nitrogen, microbial biomass carbon and pH. The second factor reveals high loading of urease and catalase. The obtained results revealed that the most appropriate indicators to diagnose the quality of the soils were: total nitrogen, microbial biomass carbon and soil organic carbon.

1 Introduction

Land degradation refers to a process induced by human activities that cause the decrease of biological productivity or biodiversity, as well as the current capacity and/or potential to sustain human life (Oldeman, 1998). Land degradation and desertification affect many regions of the world (Cerdà et al., 1999; Bai et al., 2013; Izzo et al., 2013; Wang et al., 2013; Yan et al., 2015) and there is a need to restore those areas affected by land degradation processes (Guénon et al., 2013; Özcan et al., 2013; Kröpfl et al., 2013; Li et al., 2013; Tejada et al., 2014; Zucca et al., 2015). There are examples of studies in opencast coal mines, magnesite mines and limestone mines (Haigh et al., 2013; Martin-Moreno et al., 2013; Milder et al., 2013; Raizada and Juyal, 2013; Mukhopady and Maiti, 2014; Pallavacini et al., 2014; Wick et al., 2014) whilst there are few studies over opencast pumicite mines.

The open pit mining has great economic importance in Mexico therefore taking the volume of production of non-metallic minerals as an indicator, the State of Mexico is the largest producer of non-metallic minerals mainly extracted i.e. sand and gravel (Jimenez et al., 2006). In the agricultural area of the Municipality of Calimaya highlands in the State of Mexico, opencast mining is carried out. After extractive operations in the pumice areas, agricultural use is continued soil although productivity declines while the landscape and soil characteristics are substantially altered. These facts evidence the need of suitable correction management actions to accelerate the succession process and return of the degraded area to an environmentally acceptable and productive condition (Rogowski and Weinrich, 1987). Pumice is a volcanic rock with trapped gas bubbles formed during volcanic eruptions (Whitham and Sparks, 1986); is made up of Si, Al, K, Na, Fe oxides, with a small percentage of Ca, Mg, Mn, Ti oxides (Liguori et al., 1984).

The main causes of land degradation during mining operations are 1) removal of vegetation cover and topsoil, 2) excavation and dumping of overburden, 3) changes in the landscape (Mukhopadhyay et al., 2013), 4) disruption of surface and subsurface hydrologic regimes, 5) transformation of fertile cultivated land into wasteland and in some cases 6) serious environmental pollution and ecological degradation, which can lead to the loss of biodiversity (Keskin and Makineci, 2009). Soil in mined sites is replaced by overburden, which differs substantially from developed soils (Huggett, 1998; Keskin and Makineci, 2009), with adverse properties such as severe depletion of organic matter, erosion risk, toxicity, and nutrient deficiency, which commonly reduce productivity in post mining landscapes (Sourkova et al., 2005).

In a post-mining landscape, it is necessary, the regeneration of the uppermost soil layer, organ-mineral horizon, and soil biota, which transforms organic matter (Frouz et al, 2001). The accumulation of organic matter (OM) is critical because it results in positive changes in physical and chemical soil properties, such as water holding and sorption capacities, nutrient content and availability, soil bulk density, buffering capacity, increases microbial biomass and extractable carbon, microbial community structure and biodiversity. Moreover, OM is an energy source for the soil microorganisms, which drives decomposition and mineralization of plant residues, thereby releasing nutrients (Sourkova et al., 2005; Laudicina et al., 2015)

Soil quality included physical, chemical and biological properties, as well as soil processes and their interactions. The selection of some properties to asses soil quality is an effective way. Some authors have used independent indicators, while others preferred their combinations into models or expressions in which various properties are involved, these expressions are called indices (Zornoza et al., 2015). The establishment of multiparametric indices has been used as an adequate tool for integrating greater information of soil quality. It provides a more holistic measurement of soil quality (Brevik et al., 2015; Zhang et al., 2015). Several studies have generated indices from a data set using physical, chemical and biological indicators. Organic carbon, microbial biomass and enzymes activity have been widely used to assess impact of change in land use and reclaimed soils (Chodak and Niklinska, 2010).

Enzyme activities measurement is widely used to examine nutrient cycling processes in soil (Nannipieri et al., 1990; Tabatabai and Dick, 2002). Moreover, enzyme activities can provide indications of quantitative changes in SOM and are usually related to the presence of viable microorganisms and their oxidative activities (Gianfreda et al., 2005), which could be sensitive indicators of the effect of land degradation on soil microbial activity. Soil hydrolases measurements provide an early indication of changes in soil fertility, since they are related to the mineralization of important elements such as nitrogen, phosphorus and carbon and may provide some insight into the metabolic capacity of the soil (Shaw and Burns, 2006; García-Orenes et al., 2010). Urease plays an important role in soil nitrogen cycle because it can hydrolyze urea an important fertilizer in agricultural systems to ammoniacal nitrogen (Sinsabaugh et al., 2000, Caldwell, 2005). Catalase has a great effect on changing soil redox, chemical properties of soil solution, and accelerating transformation of organic matter (Wang, 2012). The metabolic quotient estimates the activity and efficiency of decomposition (or C use) by soil microbes (Anderson and Domsch, 1990) and has resulted a suitable indicator to provide evidence of soil perturbation (Zornoza et al., 2015).

Little information exists about how mining affects soil in cropland regions of the world and especially those of the central highlands of Mexico. The present work aimed to assess the changes produced in the agricultural soils differing in elapsed-time since pumice mining (0–15 years). With the information from this study we examine valuable indicators of surface mine reclamation progress in open cast mine.

2 Materials and methods

2.1 Study site

This study was conducted in Calimaya, State of Mexico (Central Mexico; 19º13’25’’ N; 99º44’02’’ W), where the mean annual temperature is 14 ºC and the annual rainfall is 800 mm (INEGI, 2009).The dominant climate is subhumid with summer rains. Dominant soils are Andosols (WRB, 2014). The main type of land use in the region is cropland based on maize. Cultivation techniques consist of monoculture, crop residues removal, and the use of N fertilizer, herbicides and pesticides. The change of use of agricultural land to urban has caused a decline in cultivated land from 7 508 to 5 350 ha between 2010 and 2011 (GEM, 2011- 2012). Following standard practice on surface mining sites, the topsoil was stripped and stockpiled until mining operations were completed; stored soil was then spread on top of overburden.

2.2 Sampling and processing

On February 2011, five mine sites, differing in elapsed-time since reclamation (0–15 years) of opencast pumice mine spoils in the Central of Mexico, were chosen on the basis of similarity of aspect as well as proximity to one another and an adjacent undisturbed site, for comparison, located about 2 800–2 950 m above sea level. Treatments were considered S_0, S_1, S_4, S_{10} and S_{15} land where the pumice extracted two months, 1, 4, 10 and 15 years respectively and land no mined (S). Pumice extraction is despite its depth. In all areas immediately after the removal maize crop was continued under seasonal conditions. The slopes of the sampling sites ranged from 25-30%. Pumice layer was located 30 to 180 cm deep.

Surface mining is one of the most complete forms of human-caused habitat alteration and degradation. In this case, mining eliminates vegetation, removes topsoil (30 cm) and overburden by excavation change topography and geological structures permanently. The reclamation process involved the return of topsoil after mining exploitation. These new altered soils are called reclaimed mine soils, which they have a different years of agriculture use.

These sites had been continuously cultivated since reclamation of mine spoils, surface soil samples (0–15 cm depth) were taken in February (during the dry season), June (onset of the rainy season), and March 2012 (during the dry season), stored at 4 ^{o}C for biochemical analyses. Afterwards, they were passed through a 2 mm mesh sieve.

The experiment had a completely randomized design with three spatially separated landscape-level plots (more of 3 ha) as replicates for each land use (n=3 for each land sue).

Sampling sites were selected considering the extraction pumice times; the distance between them was 450 m and the area of the 3 ha. The soil sampled from each field was pooled separately. Were obtained by systematic sampling at each site a composite sample from 30 subsamples was collected of six treatments (S, S_0, S_1, S_4, S_{10} and S_{15}).

The following parameters were analyzed: gravimetric moisture content (GMC) which was measured gravimetrically, water holding capacity (WHC) according to Forster (1995), and soil bulk density as described by Domínguez and Aguilera (1987). The pH soil and electrical conductivity were determined in soil/water (1:2.5 w/v), (Thomas, 1996). Content of soil organic carbon (SOC) was determined by the Walkley-Black method (Nelson and Sommers, 1996) and TN with Kjeldahl digestion (Bremner, 1996).

MBC of soil samples was estimated by chloroform fumigation and extraction method (Vance et al., 1987). Basal respiration (BR) was estimated by quantifying the carbon dioxide (CO_2) released by microbial respiration in 33 days of incubation at 25 ºC adjusted to 40 % water holding capacity (WHC). For this purpose, 25 g soil was filled into flasks, together with small flasks containing 10 mL of 0.2 mol L^{-1} NaOH, to capture the released CO_2, and hermetically sealed. CO_2 was determined by titration with 0.2 mol L^{-1} HCl, after precipitation of the barium carbonate resulting from the addition of $BaCl_2$ to the NaOH solution, using phenolphthalein diluted in 100 mL ethanol (60 %, v/v) as indicator (Alef and Nannipieri, 1995).

Catalase activity was measured by titrating the residual H_2O_2 added to the soil and not degraded by catalase with $KMnO_4$ (Johnson and Temple, 1964). Acid phosphatase activity was measured by spectrophotometry (400 nm) of *p*-nitrophenol released from 1.0 g soil after a 60 min incubation at 37 ^oC with a 0.025 mol L^{-1} *p*-nitrophenyl phosphate substrate, in 4 mL of 0.17 mol L^{-1} MUB (universal buffer), at pH 5 (Tabatabai and Bremmer, 1969). Urease activity was determined as the amount of NH_4^+ released from 5.0 g soil after a 120 min incubation with a substrate of 0.2 mol L^{-1} urea at 37 ^oC, 4.5 mL of THAM (Tris buffer) (Alef and

Nannipieri, 1995).The metabolic quotient (qCO_2) was calculated as the ratio of basal respiration to MBC (Anderson and Domsch, 1990).

A correlation analysis was performed in order to identify the relationships among the evaluated properties. Then Principal Components Analysis (PCA) was applied using data of physical and chemical soil properties as well as MBC, CO_2, qCO_2, enzyme activities to determine the degree of association of the variables analyzed. The number of components was determined by the eigenvalue-one criterion. Subsequently, a hierarchical cluster analysis (Ward´s method) was performed using the software STATGRAPHICS 5.1.

3 Results

3.1 Soil physic-chemical properties

Gravimetric moisture content ranged from 1.37 % (0 year old) to 2.81 % (15 year old) and were correlated with the water holding capacities ($r=0.74$; $p<0.01$). The pH values found ranged between 4.9 and 6.3 on mine soil. WHC values ranged from 27 g and 35 g 100 g^{-1} in mine soil amount representing 87 % of the value found in undisturbed soil. The SOC level was found higher in undisturbed soil than mine soil (Table 1). TN and SOC increased at a slower rate, in soil mine TN found came to represent 59 %, while SOC only the 26 % than in undisturbed soil.

3.2 Microbial properties

The highest value of MBC was found in the undisturbed soil, which coincides with the highest value of organic matter with respect to the mine soils (Table 2). After extraction of pumice MBC content, S_0 decreases > 50 % respecting to the S. The highest values in the microbial properties were obtained in undisturbed soil, while the rest of soils show similar values. This result indicated that the land degradation is associated to a strong decrease in the SOC content which lowered to 76 % in recently mine soils with respect to undisturbed soil. The respiration rate was higher in undisturbed soils than in another treatments.

Enzyme activities rise with increasing age of mined: undisturbed soil showed the highest enzyme activity values, while the mine soil the lowest (Table 2). In this study, urease activity in undisturbed soils was particularly high, recovered quickly on mined sites; 15 years after reclamation the urease activity levels had reached more than 87 %

The qCO_2 values were higher in mine soils compared to the undisturbed soils (Table 2), meaning that the microorganisms were more efficient in conserving C resources in the no mined sites as compared than in the mined sites.

3.3 Correlations

Correlation matrix revealed a negative correlation of qCO_2, with MBC, WHC, catalase and GMC. Closer correlations were found among chemical and biological variables; the MBC was positively correlated with WHC while correlations among catalase and urease activity were found. Additionally, both MBC and WHC were positively correlated with TN (Table 3).

Principal components analysis (PCA) was performed using all the data for soil characteristics to explore the differences between soils; the main results are shown in Table 4. The weighted loading values in each component were used to select the indicators, with ten percent of the highest weighted loading as a threshold for selection (Govaerts et al., 2006). The first component accounted for 33.27 % of the total variance and the highest loadings were found with TN followed by MBC and pH. Contribution from the second component of the total variance was 23.97 % with the highest loading was found with catalase and urease. PC3 accounted for 14.74 % of the total variance and was mainly associated with EC and P. According to the PCA results pH and TN were the most important characteristics that affected MBC.

3.5 Cluster analysis

Cluster analysis is often used to determine group associations and to assess the affinity among different variables (Hussain et al., 2008). The dendrogram obtained using Euclidean distance as similarity criterion (Fig. 1) revealed a clear separation into two major groups. The first cluster was found S_{10}, S_{15} and S, being greater the similarity between the soil with more years of mining (15) and undisturbed soil. The second group was formed by soils with shorter mined (S_0, S_1 and S_4), finding greater similarity between S_1 and S_4.

In the present study, Dendogram Analysis (DA) was applied to differentiate soils with different age of mined as well as to determine whether the difference was actually significant or not. Three major soil clusters were evident. Canonical scores indicate that S_{15} reclamation site is more similar to the S_{10} site than that of the others mined sites (Fig. 2). Although DA was clearly able to discriminate between disturbed and undisturbed ecosystems, indicated a trend towards the undisturbed condition with reclamation age. The graph showed two major groups, the first one consists of the three most disturbed soils (S_0, S_1 and S_4) and the second group corresponds to the two least disturbed soils (S_{15} and S_{10}).

4 Discussion

The loss of SOC and TN observed in soils post-pumice mining is typical of major ecosystem disturbance (Kimble et al., 2001). The depletion of organic C produces a decline in soil quality associated with to the reduction of available water capacity, nutrient concentration and soil structure (Schwenke et al., 2000).

Our results also indicate that disturbance was highly detrimental in SOC, only 45 % of amounts found for the undisturbed site. As result of direct photodegradation by solar radiation (Austin and Vivanco, 2006) as well as the mixing of surface soil with deeper soil layers (Ward, 2000). The quantity of organic matter (C and N) and rates of microbial C mineralization to CO_2 (respiration) were recovered with age in mining soil. Shrestha and Lal (2011), aimed to quantifying the effects of mining and reclamation processes on physical and chemical properties of reclaimed soils for three dominant soil series in Ohio. Mining and reclamation activities decreased (SOC) declined by 52 to 83 % of undisturbed sites and nitrogen (N) pools declined from 42 to 75 % of undisturbed sites.

The recovery of MBC in these soils was faster than organic C. This may indicate that the proportion of bio-available C in 15-year-old soils has become similar to that of undisturbed soils but may also be the result of an increased availability of TN (evidenced by lower C/N ratios in older soils) and inorganic P (as a result of fertilization). The MBC is greatly reduced from the undisturbed soil in the mine soil is estimated an average of only 76%. The results obtained by Insam et al. (1991) and Rodriguez et al. (2005) demonstrated the relationship between MBC and soil TN.

The increase in soil basal respiration in mine soil can be explained by an increase in the contents of SOC and nutrients, which would enhance microbial activity (Emmerling et al., 2000), and biomass cycling, thus leading to an increase in basal respiration (Fernandes et al., 2005).

To estimate the activity and efficiency of decomposition (or C use) by the soil microbes the qCO_2 was calculated (Anderson and Domsch, 1990). That establishes, as the MBC becomes more efficient in using the available resources, less C is lost as CO_2 through respiration (García-Orenes et al., 2010). Soil microbial quotients in several ecosystems have been found to increase immediately post-disturbance and subsequently decline with age (Insam and Domsch, 1988; Schipper et al., 2001; Graham and Haynes, 2004). This pattern of microbial quotient has been interpreted as indicative of a decrease in C bio-availability in the soil organic matter over time. The microbial quotient of 0-year-old was higher than other mine soils and it trend to increased with age. The respiration rate per unit of microbial biomass (respiratory quotient) is a variable that can be interpreted easier (Fernandes et al., 2005). The lower qCO_2 values at S site may suggest that is a more stable ecosystem with high levels of biological activity. The qCO_2 is a valid indicator of the efficiency of energy use by microbes (Yan et al., 2003). High qCO_2 values suggest that the soil microbes are competing intensely for the small amount of C available.

The principal components analysis indicated that TN, MBC followed similar an accumulating trend and, after 15 years of restoration point to successful recovery of the state conditions reference.

5 Conclusions

This study evidenced that pumicite extraction has had an adverse impact on the quality of soils cultivated with maize. What is most evident in the first years after the mine; after several cycles of cultivation and recovered MBC, increased enzyme activities, apparently as a result of the continuous additions of organic matter.

Using multivariate analysis provided information about soil indicators that contributed to a greater extent to determine the effects of extraction pumicite. Among the evaluated quality indicators soil, microbial biomass carbon stocks OC and TN, highlighted in the multivariate analysis and provided information to diagnose the quality of the soil where pumicite was removed.

6 References

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Table 1. Chemical and physical properties of soil samples with different years of extraction of pumice.

Sample		GMC	WHC	pH 1:2.5	EC	BD	P	TN	SOC	C/N
		(g·100g^{-1})		(soil:H_2O)	(dS m^{-1})	(g cm^{-3})	(mg kg^{-1})	(g·100g^{-1})		
S_0	February	2.33±0.11	31±0.57	5.5±0.31	0.13±0.00	1.18±0.01	16.2 3±0.19	0.08±0.03	1.30±0.12	18 ±5.30
	June	2.27±0.11	29±0.58	5.9±0.16	0.17±0.00	1.17±0.02	16.2 3±0.14	0.11±0.00	0.72±0.11	7±1.00
	March	1.37±0.09	30±0.58	6±0.08	0.16±0.01	1.12±0.01	16.91± 0.14	0.10±0.01	1.20±0.05	12±2.12
S_1	February	2.48±0.13	33±2.08	5.1±0.30	0.08±0.00	1.21±0.01	16.2 3±0.03	0.11±0.0	1.23±0.11	11±1.05
	June	2.40±0.01	30±0.58	6.2±0.16	0.35±0.01	1.15±0.01	17.8 0±0.01	0.11±0.00	0.84±0.11	8±1.05
	March	1.60±0.17	30±0.00	6.2±0.01	0.17±0.01	1.12±0.01	17.0 2±0.26	0.11±0.00	1.30±0.05	12±0.42
S_4	February	2.59±0.03	35±0.00	5.2±0.04	0.07±0.00	1.21±0.00	16.7 2±0.20	0.17±0.00	1.50±0.11	9±0. 65
	June	2.63±0.05	30±0.00	6.2±0.56	0.30±0.02	1.2±0.04	17.80 ±0.07	0.11±0.00	0.72±0.11	7±1.00
	March	1.67±0.02	30±0.00	6.3±0.04	0.21±0.00	1.2±0.02	17.57 ±0.42	0.12±0.02	1.25±0.08	11±1.00
S_{10}	February	1.68±0.02	30±0.00	4.9±0.14	0.10±0.00	1.31±0.00	21.9 5±0.64	0.19±0.03	1.56±0.20	8±0.66
	June	1.71±0.04	27±0.00	5.4±0.20	0.45±0.11	1.20±0.03	20.7 1±0.07	0.17±0.00	1.60±0.20	9±1.15
	March	1.289±0.25	27±0.00	5.5±0.03	0.27±0.00	1.24±0.02	23. 93±0.49	0.17±0.00	1.50±0.12	9±0.72
S_{15}	February	2.14±0.02	34±0.58	5.1±0.09	0.18±0.01	1.23±0.04	18.8 9±0.19	0.17±0.00	1.63±0.23	10±1.32
	June	2.81±0.06	31±0.58	5.4±0.10	0.47±0.01	1.10±0.01	2 0.43±0.13	0.11±0.00	0.78±0.00	7±0.00
	March	1.80±0.37	29±0.58	6.0±0.05	0.19±0.00	1.10±0.00	19.0 7±0.13	0.11±0.00	1.09±0.08	10±0.73
S	February	3.16±0.07	40±3.78	4.7±0.18	0.10±0.00	1.11±0.018	1 6.77±0.19	0.32±0.03	2.28±0.11	7±1.00
	June	3.11±0.02	34±0.58	5.6±0.14	0.13±0.00	1.02±0.01	15.7 4±0.05	0.23±0.02	2.67±0.11	12±0.75
	March	2.15±0.10	33±0.58	5.4±0.11	0.24±0.00	1.02±0.03	16.6 8±0.12	0.19±0.00	2.73±0.00	14±0.00

GMC: Gravimetric moisture content, WHC: water holding capacity, EC: electrical conductivity, BD: bulk density; P: available phosphorus, TN: total nitrogen, SOC: soil organic carbon, S_0: recently mined, S_1: one year old mined, S_4: 4 years old mined, S_{10}:10 old years mined, S_{15}: 15 years old mined, S: undisturbed soils. mean ± standard desviation.

Table 2. Enzymatic activity and soil microbial properties of soil samples with different years of extraction of pumice.

Sample		Urease		Phosphatase		Catalase		MBC	CO_2	qCO_2
		(µmoles $N\text{-}NH_4^+$ g^{-1} h^{-1})	Specific activity	(mmoles: PNP $g^{-1}h^{-1}$)	Specific activity	(mmoles H_2O_2 consumed g^{-1} h^{-1})	Specific activity	MBC (mg C kg s^{-1})	(mg $C\text{-}CO_2$ kg^{-1} s^{-1})	
S_0	February	5.33±1.15	5.52	2.70±0.26	4.25	0.11±0.06	2.11	246±28	1847±49	2.6±0.34
	June	6.67±0.58	12.07	2.14±0.07	9.68	0.12±0.01	3.04	134±25	837±39	3.1±1.25
	March	11.33±1.16	14.69	1.36±0.05	9.57	0.26±0.01	1.17	147±18	1669±40	4.4±1.27
	February	7.00±1.00	8.22	2.60±0.04	5.90	0.09±0.02	2.13	284±98	1849±22	2.2±0.15
S_1	June	10.67±0.58	16.14	2.01±0.13	1.02	0.14±0.02	2.43	150±19	861±00	2.0±0.23
	March	12.67±1.16	13.37	1.40 ±0.09	9.83	0.29±0.05	1.10	166±20	1804±16	3.8±0.40
	February									
	June	9.67±0.58	7.87	1.12±0.01	6.61	0.11±0.06	0.76	313±29	1849±23	2.1±0.17
S_4	March	6.33±1.15	11.01	2.76±0.42	9.41	0.16±0.03	3.95	150±19	862±00	2.0±0.23
		13.00±0.00	14.41	1.35±0.15	10.56	0.28±0.05	1.10	199±18	1749±55	3.3±0.60
	February									
	June	10.33±0.58	9.93	2.91±0.07	7.07	0.14±0.04	1.90	348±19	1904±28	1.9±0.10
S_{10}	March	4.00±1.00	6.94	3.17±0.21	2.88	0.13±0.02	2.07	115±12	899±00	4.1±1.38
		10.67±0.58	10.49	1.69±0.18	7.32	0.33±0.02	1.15	209±18	2078±62	3.7±0.83
	February									
S_{15}	June	11.67±1.52	9.15	3.07±0.04	7.47	0.20±0.01	1.92	388±9	1985±21	1.7±0.05
	March	10.33±1.53	15.59	3.18±0.06	13.71	0.15±0.02	4.09	117±18	903±00	2.8±0.46
		14.00±0.58	13.82	1.88±0.09	13.12	0.34±0.01	1.76	230±18	2240±19	3.6±0.50
	February									
	June	11.00±1.00	6.73	2.67±0.09	5.23	0.23±0.05	1.19	458±42	2146±66	1.6±0.20
S	March	8.34±2.10	3.53	3.68±0.04	3.47	0.12±0.01	1.40	259±32	966±13	1.3±0.15
	February	16.00±1.73	8.93	2.17±0.05	6.02	0.35±0.00	0.82	248±40	2369±60	3.4±0.75

MBC: microbial biomass C, CO_2: respiratory activity, qCO_2: metabolic quotient, S_0: recently mined, S_1: one year old mined, S_4: 4 years old mined, S_{10}:10 old years mined, S_{15}: 15 years old mined, S: undisturbed soils. mean ± standard desviation.

Table 3. Correlation matrix between the different parameters determined.

Parameter	EC	Catalase	MBC	SOC	CO_2	WHC	GMC	TN	pH	qCO_2	urease
EC	1										
Catalase	NS	1									
MBC	-0.67	NS	1								
SOC	NS	NS	0.53	1							
CO_2	-0.58	0.67	0.64	NS	1						
WHC	NS	NS	0.75	NS	NS	1					
GMC	NS	NS	NS	NS	NS	0.74	1				
TN	NS	NS	0.68	0.78	NS	0.64	NS	1			
pH	NS	NS	-0.76	NS	NS	NS	NS	-0.64	1		
qCO_2	NS	-0.77	-0.61	NS	NS	-0.66	-0.77	NS	NS	1	
Urease	NS	0.84	NS	NS	0.60	NS	NS	NS	NS	NS	1

EC: electrical conductivity, CO_2: activity respiratory, WHC: water holding capacity, GMC: gravimetric moisture content, TN: total nitrogen, qCO_2: metabolic quotient, NS: not significant, $p < 0.01$.

Table 4. Results of principal component analysis.

Variable	Component				
	1	2	3	4	5
GMC	0.371	-0.513	-0.464	0.451	-0.337
WHC	0.634	-0.037	-0.655	0.271	-0.132
pH	**-0.864**	0.151	0.081	0.303	-0.040
EC	-0.258	-0.204	**0.777**	0.259	-0.307
Bulk density	-0.019	-0.125	0.055	**-0.957**	-0.130
MBC	**0.803**	0.181	-0.483	-0.243	0.016
TN	**0.880**	0.127	-0.042	0.184	-0.193
SOC	0.762	0.193	-0.043	0.386	0.353
C/N	-0.035	0.050	-0.158	0.150	**0.942**
Urease	0.096	**0.891**	-0.043	0.235	-0.064
Phosphatase	0.523	-0.694	0.240	0.173	-0.018
Catalase	0.090	**0.938**	0.228	0.083	0.072
P	0.147	0.143	**0.785**	-0.481	-0.221
CO_2	0.392	0.707	-0.225	-0.269	0.397
qCO_2	-0.512	0.418	0.517	0.018	0.358
Variation	33.276	23.976	14.475	11.046	7.914
Cumulative variation	33.276	57.252	71.727	82.773	90.687

Bold values indicates the higher weight variables are considered highly weighted within 10 % of variation of the absolute values of the highest factor loading in each PC. GMC: gravimetric moisture content, WHC: water holding capacity, EC: electrical conductivity, MBC: microbial biomass C, TN: total nitrogen, SOC: soil organic carbon, P: available phosphorous, CO_2: activity respiratory, qCO_2: the metabolic quotient.

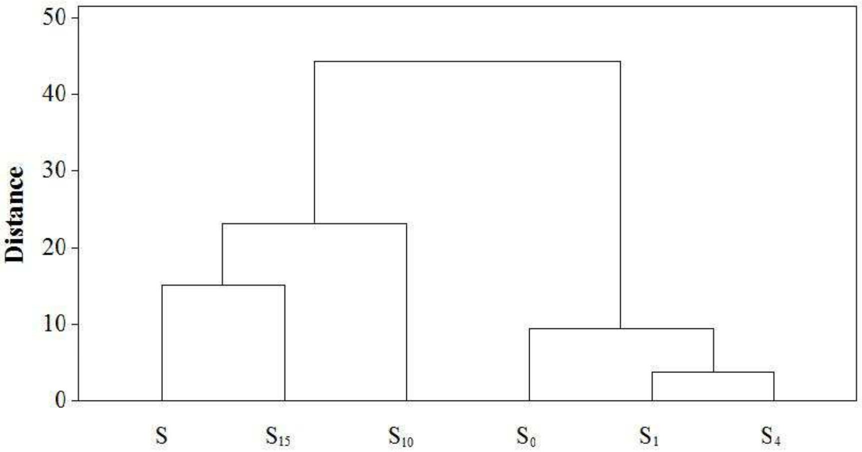

Figure 1. Dendogram obtained (Ward method) for cluster analysis of different age mined and undisturbed soil. S_0: recently mine, S_1: one year old mine, S_4: 4 years old mine, S_{10}:10 old years mine, S_{15}: 15 years old mine, S: undisturbed soils.

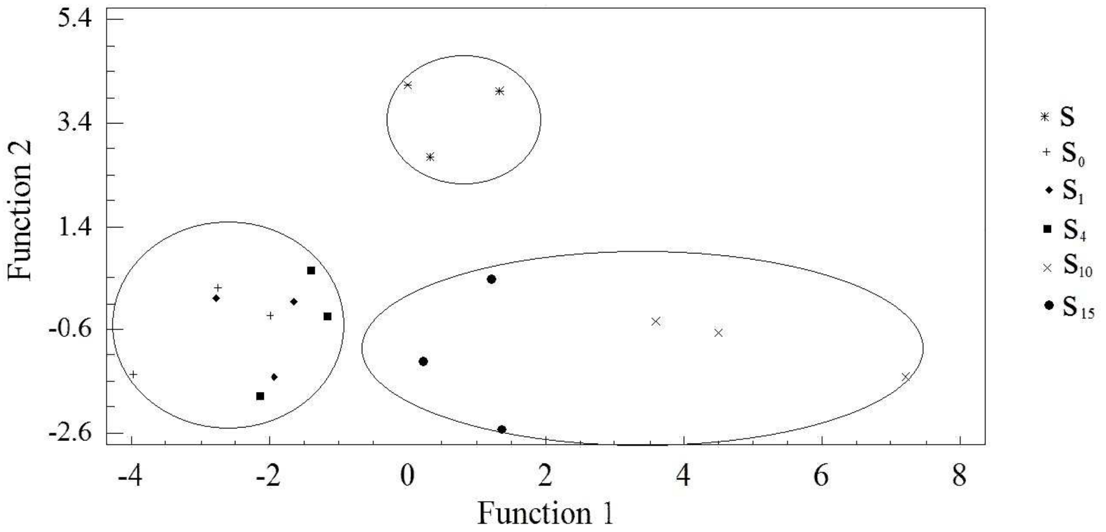

Figure 2. Plot of canonical scores calculated by discriminant analysis for the different age of mine soil. S_0: recently mined, S_1: one year old mine, S_4: 4 years old mine, S_{10}:10 old years mine, S_{15}: 15 years old mine, S: undisturbed soils.