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Geochemical characteristics of soils in Fezzan, Sahara desert: Implications for environment and agriculture

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ABSTRACT

An investigation was conducted to geochemically characterize the soils in Fezzan of the Sahara desert in order to assess (a) the role of the soils as a carbon store, (b) the potential risk of the fine-grained soil fraction as a dust source, and (c) the potential soil constraints for the development of irrigation agriculture. The results show that, on average, there was about 0.7% of carbon stored in the topsoil with approximately 1/3 being inorganic carbon and 2/3 being organic carbon. The fine-grained soil fraction contained 2.13% of Fe and 252 mg/kg of phosphorus, indicating that the Fezzan area could be an important source of ocean iron and phosphorus. Manganese and strontium were identified as the major chemical pollutants potentially present in the dusts. The soils were generally alkaline and saline. Sodium dominated the soluble basic cations with a mean sodium adsorption ratio >16. Calcium dominated the exchangeable basic cations with a mean exchangeable sodium percentage of 6.52, suggesting that most of the topsoils were not sodic. However, there was a tendency that sodicity increased with depth for some soils. Different strategies are proposed for reclaiming the soils using the groundwater from the Great Man-made River Project.

1. Introduction

Sahara has experienced alternate humid and dry periods at least for the past 7 million years (Schuster et al., 2006). The latest wet/dry cycle commenced about 15,000 years BP with the peak African Humid Period (AHP) lasted from approximately 10,000 to 5000 years BP when the low-lying areas were covered by a layer of water, forming the so-called mega-lakes (deMenocal et al., 2000; Drake et al., 2008). The subsequent drying processes led to the disappearance of the mega-lakes, allowing soils to develop on the lake sediments. Due to the present hyper-arid conditions, modern pedogenesis is expected to be very weak. Therefore, the Sahara soils are, to a large extent, of relict nature. On the other hand, the characteristics of the relict soils could have been significantly modified due to wind deflation that is dominated in the Sahara desert under current climate conditions.

Detailed information on geochemical characteristics of the Sahara desert soils is useful for a few reasons. First, desert soils are effective sites to hold inorganic carbon. Knowledge of inorganic carbon storage in the Sahara desert soils is important for global inorganic carbon inventory. Second, the Sahara desert is the world's largest source of aeolian soil dusts (Goudie, 2014; Prospero et al., 2002; Swap et al., 1996). These Saharan dusts are likely to affect the global geochemical cycling and climate (Mahowald et al., 2010). For the past decades, concerns have been raised over the impacts of Sahara desert dusts on air quality and possibly human health in the affected areas (Brunekreef and Forsberg, 2005; Prospero, 1999). There have been increasing researches conducted to evaluate the transport and deposition of aerosols from the Sahara desert (Barkan et al., 2005; Goudie and Middleton, 2001). Most of these researches have used the concentration of total suspended particles (TSP), PM2.5 (particle with a diameter <2.5 μm) and PM10 (particle with a diameter <10 μm) with limited information on major chemical constituents to characterize the dusts (Alastuey et al., 2005; Rodŕiguez et al., 2001). While these physical parameters give indication of dust load and rough elemental signatures of the dusts, it provides no insights into the presence of potentially toxic elements, which is needed for better assessment of environmental risk from the dusts. Third, the development of desert agriculture using the available irrigation water requires a good understanding of soil chemical properties in order to develop appropriate strategies and methods for soil amendment.

So far there has been only limited work reported on the chemical characterization of the Sahara desert soils. Alastuey et al. (2005) presented data on mineral and chemical composition of TSP and PM2.5 in the dust samples collected in Canary Islands during a strong African dust outbreak episode. Borbély-Kiss et al. (2004) investigated some major elements contained in the dusts collected from Hungary during Saharan dust episodes. Moreno et al. (2006) reported the chemical characteristics of a small amount of soil and dustfall samples collected from Algeria, Chad, Niger and Western Sahara and found marked

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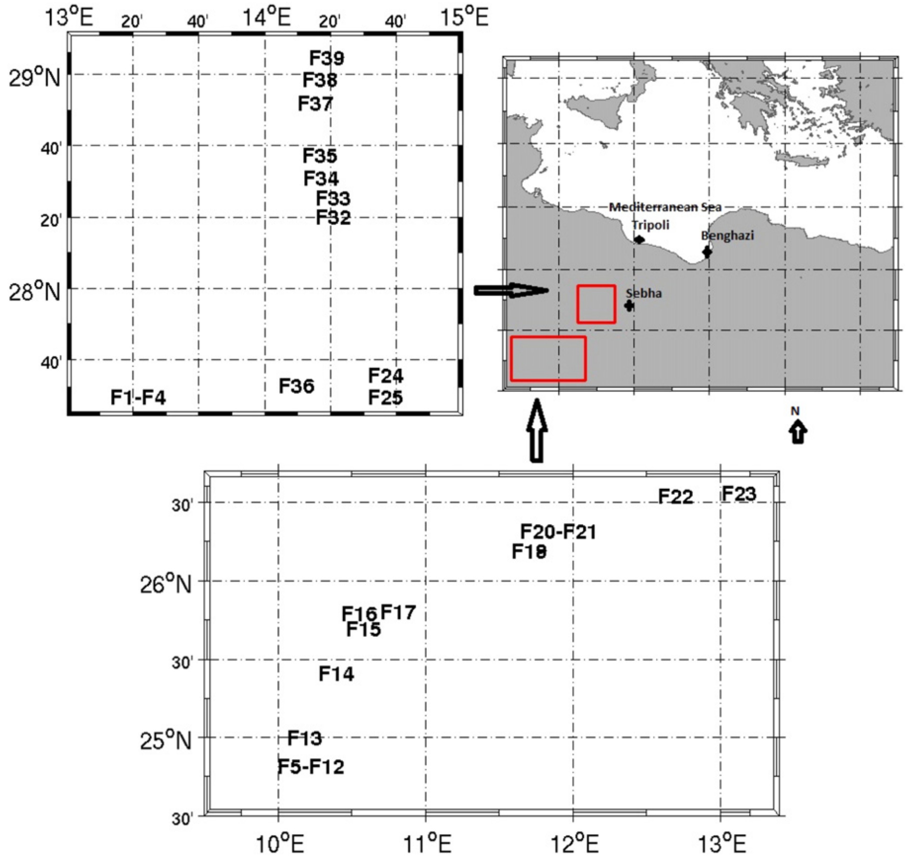

Fig. 1. Map showing the soil sampling locations in the Fezzan region, Libyan Sahara.

variation in the geochemical composition of the soils among these different locations of dust source areas. In spite of these efforts, the available information is still far from sufficient for understanding the geochemical characteristics of soils in this vast desert. Substantial amounts of further work are required to accumulate knowledge that is needed to inform the development of strategies for minimizing the environmental impacts and maximizing the beneficial uses of the desert soils in Sahara.

As part of a larger project to investigate the geochemical processes associated with the formation of alkaline soils in different parts of the world, we present here the results from the Fezzan basin, south-western Libya. This part of the Sahara desert has so far received relatively less attention despite that its role as a dust source is significant (Falkovich et al., 2001). Another reason for selecting this area for the study is its relevance to desert irrigation agriculture. There is a need to enhance agricultural activities in Africa to allow its sustainable development (Valipour, 2014, 2015). The construction of the Great Man-made River in Libya has provided the opportunities for agricultural production in its hyper-arid area (Elhassadi, 2007; Gijsbers and Loucks, 1999). However, detailed soil information covering a large area is lacking though a limited number of small-scale soil investigations with varying purposes were conducted at some locations (*e.g.* El-Ghawi et al., 2005; Salem and Al-ethawi, 2013). To develop sustainable agricultural

Table 1
Average and range of pH, EC, various carbon fractions, soluble and exchangeable basic cations for the upper layer (0–30 cm) of the 33 soils from the Fezzan area, Sahara desert.

Soil Parameter	Average	Minimum	Maximum
pH	8.8	6.92	10.11
EC (dS/m)	4.214	0.145	18.51
Organic C (%)	0.42	0.16	0.67
Inorganic C (%)	0.26	0.00	2.24
Soluble K (mmol/kg)	1.49	0.00	11.8
Soluble Na (mmol/kg)	45.7	0.10	300
Soluble Ca (mmol/kg)	3.81	0.01	12.3
Soluble Mg (mmol/kg)	3.77	0.28	12.3
SAR	16.5	0.03	101
Exchangeable K (mmol/kg)	6.97	0.56	21.8
Exchangeable Na (mmol/kg)	11.7	2.18	53.5
Exchangeable Ca (mmol/kg)	90.9	16.1	192
Exchangeable Mg (mmol/kg)	5.86	1.24	10.4
ESP	6.52	0.87	24.9

Table 2
Vertical variation in pH, EC, organic C and inorganic C along the 5 selected soil profiles in the Fezzan area, Sahara desert.

Sampling site	Depth (cm)	pH	EC (dS/m)	Organic C (%)	Inorganic C (%)
F4	0–10	9.30	1.347	0.34	0.00
	10–20	9.40	1.228	0.51	0.03
	20–30	9.48	2.904	0.33	0.00
	30–50	9.35	4.550	0.40	0.00
F7	0–10	10.1	0.720	0.44	0.00
	10–20	9.51	3.670	0.49	0.02
	20–30	8.76	12.76	0.62	0.55
	30–50	8.78	9.230	0.51	0.35
	50–70	8.94	6.560	0.36	0.44
	70–90	8.81	1.550	0.38	0.15
F12	0–10	9.07	0.960	0.60	0.14
	20–30	9.50	0.247	0.26	0.13
	70–90	8.95	0.758	0.34	0.00
F21	0–10	8.31	10.22	0.38	0.32
	20–30	8.54	9.500	0.49	0.61
	30–60	8.61	15.90	0.59	0.53
F24	0–50	8.60	2.789	0.16	0.00
	150–160	8.61	2.700	0.27	0.06
	190–200	8.54	2.489	0.31	0.00