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# Investigation of desert subsoil nitrate in Northeastern Badia of Jordan

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## HIGHLIGHTS

- ► Elevated nitrate levels were observed under desert pavement in Jordan.
- ► Pavement particle size and cover percent are main factors for nitrate accumulation.
- ► Nitrate and chloride showed similar distribution profiles.
- ► Desert pavement lichens appeared not to contribute significantly to nitrate levels.

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## ABSTRACT

High levels of naturally occurring nitrate were observed under desert pavement surfaces in NE Badia of Jordan. The subsoil nitrate inventory varies from about 24,351 to 28,853 kg $NO_3^-$/ha to a depth of 60 cm which is more than two times greater than nitrate in nonpavement soils, although both soils occurred within similar landscape and microclimate conditions. The results indicated that pavement particle size and cover percent are the primary factors contributing to the observed variations in nitrate accumulation. Desert pavement soils fully covered with fine clasts showed higher nitrate concentrations compared to soils moderately covered with coarse-grained pavements. The results also showed that high levels of nitrate were generally reached between 20 and 30 cm depth before the concentrations decreased. Chloride showed distribution profiles similar to those of nitrate. No observable difference was observed in nitrate level under desert pavement with abundant lichens compared to non-lichen pavement surface.



## 1. Introduction

Deserts account for nearly one third of land area worldwide (Post et al., 1985; Abrahams and Parsons, 1994) and for more than 90% of the land area in Jordan. Desert soils have long been thought to be nutrient poor. However, widespread occurrence of nitrate has frequently been observed in groundwater and soils in arid regions that are distant from potential anthropogenic sources and the soils are characterized by very low organic content (Noble, 1931; Gormly and Spalding, 1979; Hunter et al., 1982; Leatharn et al., 1983; Marrett et al., 1990; Barnes et al., 1992; Walvoord et al., 2003; Graham et al., 2008).

The elevated nitrate concentrations have been largely attributed to long-term atmospheric nitrate precipitation (Böhlke et al., 1997; Walvoord et al., 2003; Michalski et al., 2004a, 2004b) and partly linked to biological fixation processes (Böhlke et al., 1997; Michalski et al., 2004a; Walvoord et al., 2003). Nitrates are formed in the atmosphere, deposited on the surface, leached and accumulated into the subsoil over a long period of time. However, recent investigations (Al-Taani, 2008) have indicated that a portion of these nitrates may have been formed at the soil–atmosphere interface; in particular, through photochemical and thermal transformation reactions that occur on soil surfaces.

One of the main distinct features of deserts is desert pavement which is an armored surface composed of closely packed stones, resting on or embedded in soils (Cooke et al., 1993). Desert pavement mantles are gently sloping landforms and include alluvial fans, basalt flows, pluvial lake benches, and ancient alluvial terraces (Cooke et al., 1993). Wherever found, it plays a fundamental role in geomorphic, hydrologic, pedologic, and ecosystem processes (Wells et al., 1985; McFadden et al., 1987; Abrahams and Parsons, 1991; Cooke et al., 1993; Dunkerley and Brown, 1995; Wood et al., 2002, 2005).

It is believed that pavement covered surfaces are depositional (Wells et al., 1995) rather than erosional surfaces (Cooke et al., 1993). Therefore, it is likely that the roughness of these surfaces helps to trap aeolian deposition of nutrients such as nitrate. High nitrate levels have been observed at shallow depths (<1 m) in soils mantled with desert pavements in the Mojave Desert (Graham et al., 2008), whereas, nearby soils without desert pavement had nitrate of one to two orders of magnitude lower.

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In the northeastern basaltic plateau of Jordan, desert pavement covers an area of about 11,000 km$^2$ (Fig. 1). These pavements were developed on accretionary mantle of soil that overlays different basaltic lava flows of Tertiary to Quaternary age (Al-Qudah, 2003; Al-Qudah and Abu-Jaber, 2009). Desert pavements are of different sizes ranging on average from less than 1 cm up to 25 cm in diameter (Al-Qudah, 2003). The pavement surfaces, in some places, are covered completely or partially with lichens.

Lichens play an essential role in the vegetation of many deserts and contribute substantially to the biomass production in these ecosystems because they are adapted to use the limited resources (Lange et al., 1977) and are able to tolerate high levels of stress conditions such as drought, temperature extremes and low humidity. Lichens growth is a function of latitude, altitude, orientation and size of pavements (Al-Qudah, 2003). Studies in the lichens diversity of the Mediterranean region, showed high species richness compared to other regions with more than 350 species from 16 orders, 52 families, and 117 genera were confirmed (Temina and Nevo, 2009). Lichens have been shown to be a major source for nitrogen fixation from the air (Millbank and Kershaw, 1969).

It is believed that desert pavement acts as a trap that can accumulate aeolian influx and increase the levels of salts in desert subsoil. This study intends to investigate nitrate concentrations under desert pavement surfaces in NE Badia of Jordan. It also aims to determine the relation of subsoil nitrate level to desert pavement characteristics and the effect of pavement morphology and lichen abundance on nitrate accumulation.

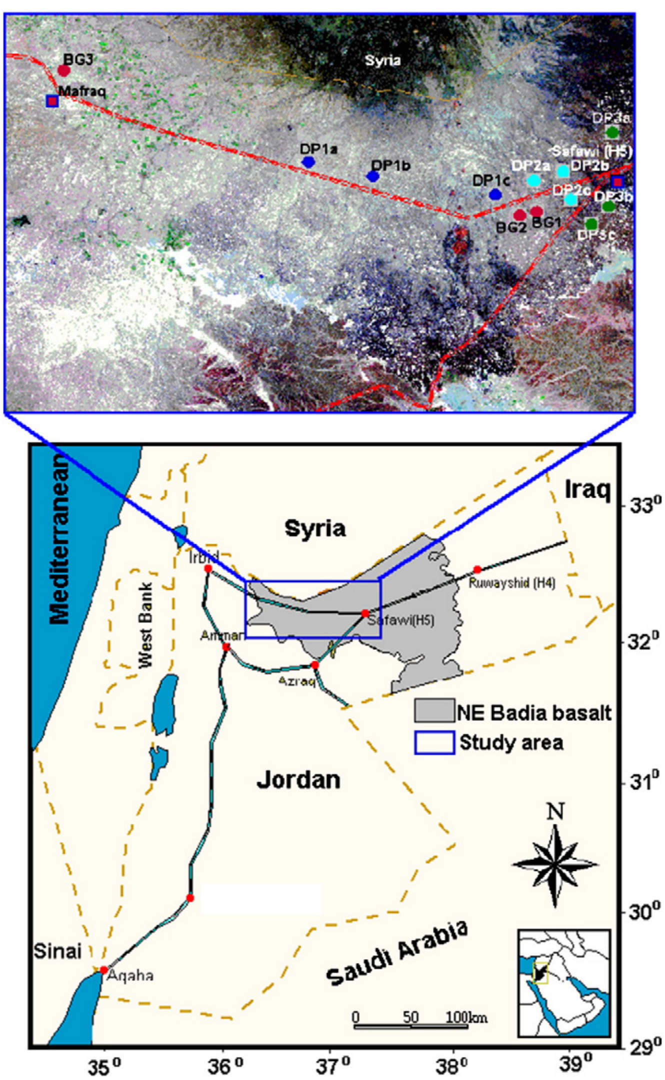


**Fig. 1.** Map showing the study area with sampling locations.

## 2. Material and methods

Subsoil nitrate levels have been determined in the soils of NE Badia of Jordan under pavement and in nearby areas where pavements are absent. Four areas in NE Badia have been selected for the study (Fig. 1), of which three are with nearly well-developed desert pavement. Soils in these sites are almost fully or moderately mantled with desert pavements. All sites are on nearly flat surfaces and occur on lava flows. In areas with pavement surfaces, sampling sites were chosen based on pavement morphology (size and cover percent) and abundance of lichens cover. After characterization of pavement surface, three soil locations have been selected based on pavement particle size (Fig. 2). Pavement types are: large pavement particles (DP1) with average diameter of 230 mm and surface cover of 60%, medium pavement (DP2) with mean particle size of 41 mm and surface cover of 80% and fine pavement (DP3) of 13 mm particle size and nearly 100% surface coverage.

To test for the effects of lichens on subsoil nitrogen levels, three soil pits from each pavement particle size were excavated, two with lichens and another without. In addition, three soils without pavement cover were sampled. Summary of soil sampling is tabulated in Table 1.

Soil profile was sampled at a 10 cm interval from surface to bedrock, where 6 samples have been collected for each soil pit (soil depth in the area is generally < 1 m). Following sampling, soils were packed, sealed and transported to the soil lab for further analysis. Soil samples were characterized for grain size distribution by dry-sieving. The fraction of < 2 mm size was separated, extracted with deionized water (1:5 soil-to-water mixtures), shaken for 90 min, air-dried, centrifuged and filtered through a 0.45μm filter. The extract was analyzed for $NO_3^-$ by spectrophotometer (APHA, 1998), $Cl^-$ by argentometric method (APHA, 1998) and pH (portable meter). Electrical conductivity (EC, μS/cm at 25 °C) was measured for the soil extract and converted to TDS (mg/l) [TDS (mg/l) = 0.67 ∗ Conductivity (EC, μS/cm at 25 °C)].

## 3. Results and discussion

Elevated levels of nitrate under desert pavement (Fig. 3) have been observed, although desert soils in the study area are low in organic matter and are distant from potential anthropogenic sources. The results showed that at each location (except for DP2), high levels of nitrate were reached between 20 and 30 cm depth before the concentrations decreased afterwards.

Desert climate conditions of limited rainfall allow nitrate (formed either biologically or nonbiologically) to accumulate near the surface. Over a long timeframe and during infrequent events of rainfall, nitrate leaches into soil and accumulates as water evaporates and returns to the atmosphere. While desert pavements reduce infiltrated water into soil, limited infiltration promoted nitrate accumulation for thousands of years (Phillips, 1994; Walvoord et al., 2002).

The result also illustrated that the near-surface nitrate levels vary with pavement particle sizes (Fig. 3). Desert soils under pavement cover of fine (DP3) and medium (DP2)-sized clasts showed slightly higher nitrate concentrations compared to coarse-grained pavements (DP1). While fine particles can be closely packed together, they decrease water infiltration and favor accumulation of nitrates by evaporative concentration (Fig. 3). Large particles are expected to trap larger quantities of nitrogen depositions, however, they are likely to contribute less significantly to nutrient accumulation, as water leaching through the soil zone is high. Pavement cover percent seems to have an important effect. In the study area, soils under fine pavement cover often form continuous cover which impedes water percolation into soil and promotes nitrate accumulation.