The Decapolis region (Northern Jordan) as historical example of desertification? Evidence from soil development and distribution

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Abstract

Historic land use was found to impact soil development directly in the Decapolis region in Northern Jordan, leading to re-distribution, not simply erosion and degradation of soils. Several authors proposed that land use had a strongly negative impact on soil development in semi-arid areas, leading to desertification. The term desertification was used to describe erosion, caused by land use, as the reason for an advance of deserts and the abandonment of ancient sites. However, evidence from Jordan shows that erosion is a most unlikely cause for the abandonment of historic sites. Land use lasting over centuries seemingly changed the character of the landscape and can be traced through distinct soil development. Soils may have been degraded since prehistoric times and it seems possible that major erosion in the Decapolis region was not primarily related to land use or increased rainfall, but to more frequent extreme events interrupting prolonged droughts. As global warming seems likely, it is important to consider the impact of climate on landscape development in future management plans.

1. Introduction

The Decapolis region in Northern Jordan is characterised by numerous ruins of once splendid Roman and Byzantine cities, which are very well preserved. No major resettlement took place after their abandonment in the 10th century AD (Hoffmann and Kerner, 2002). It was assumed that the decline of the region was due to mismanagement, neglect and overgrazing after the Muslim conquest in 636 AD, which led to severe soil erosion and desertification (Lowdermilk, 1944; Butzer, 1961; Dregne, 1983; Hillel, 1991). Other authors suggested that climate variations and not land use had an important impact on the settlement history (Huntington, 1911; Issar, 1990; Issar and Zohar, 2004).

A case study in the vicinity of the ancient city of Abila evaluated the role of the proposed land degradation for the abandonment of the site (Lucke, 2003). However, in contrast to the proposal of Lowdermilk (1944), major erosion and land degradation since the Byzantine period were found to be very unlikely. Evidence indicated that land use over centuries led to a heterogeneous pattern of soil development, pointing to long-term transformation of the landscape due to land use, but not to a general devastation or single erosion event (Lucke et al., 2005). As the site of Abila could have been an exception, this paper aims to widen the spatial scope of research and to compare our studies with the database of the National Soil Map and Land Use Project (NSM&LUP) of Jordan (NSM&LUP, 1993; al-Qudah, 2001). In order to obtain a representative picture of soil development in the Decapolis region, soils on distinct relief and source rock types are compared and interpreted with regard to soil genesis and landscape transformation.

2. Soils in Jordan and Israel

A great part of the soils in Jordan and Israel are derived from limestone formations or basalt and show red colours

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(Mediterranean Red Soils or Terra rossa). Reifenberg (1947), Bronger and Bruhn-Lobin (1997), and Bronger and Sedov (2003) state that Terrae rossae date back to the Pleistocene and were formed under moister climate conditions than today, because limestone produces little residue and the red colour is caused by haematite, a product of long and intensive weathering.

According to Yaalon and Ganor (1973) and Yaalon (1997), Terrae rossae in Israel are subject to aeolian deposits, which are brought from the Sahara and Negev wadi fans and deposited with precipitation. This input is too slow and steady to be observed in the profile, as the aerosols are mixed with the solum by bio- and peloturbation, but is most significant for soil development. However, Jahn (1995) examined circum-Saharan soils and found that at humid sites in northeast Israel only 2–5% of the substrata originated from long-distance aerosol input. Dust additions from local sources are even smaller, although Jahn found 20–40% dust input in a paleosol of Pliocene age and assumed the same is valid for most Vertisols (Jahn, 1995). According to Issar and Bruins (1983), aeolian input was limited to the last glacial period (100,000–10,000 BC).

The Mediterranean Red Soils in Jordan and Israel are considered to be degraded (Horowitz, 1979). Several authors postulated that historic mismanagement and erosion were responsible for the abandonment of ancient sites (Lowdermilk, 1944; Butzer, 1961; Dregne, 1983; Hillel, 1991), although it was never proven that the present erosion is man-made and not natural (Geraty and LaBianca, 1986).

3. Study sites and methods

3.1. Soils in the Decapolis region

The Decapolis region consists of different landscape units, including the alluvial plain in the Jordan valley, heavily dissected mountains east of the Jordan valley and a more level plateau further east, which slowly merges with the Arabian desert. The present study focuses on soils in the mountains close to the Jordan valley, around the city of Umm Queis, around the Tell Zera’a in the Wadi el-Arab, and on soils of the eastern plateau around the site of Abila and the modern city of Irbid (ancient Arbela) (Fig. 1). Most soils in the investigation area are derived from limestone formations or basalt and show red colours (Mediterranean Red Soils or Terra rossa). Vertisols, Inceptisols, and Entisols are present; in the eastern part Aridisols, and under forests, Mollisols (NSM&LUP, 1993).

In cooperation with the Ministry of Agriculture of Jordan, our findings were compared with the database of the National Soil Map and Land Use Project of Jordan (NSM&LUP, 1993). The National Soil Map and Land Use Project (NSM&LUP) examined the whole territory of Jordan from 1989 to 1995 to determine the agricultural potential. Pedogenic studies were not the main focus of this project, but were included when possible. The soils were classified according to Soil Taxonomy (USDA, 1990, 1992).

3.2. The sites of Gadara/Umm Quies, the Tell Zera’a in the Wadi el-Arab, Abila and Irbid

Gadara/Umm Quies lies on a saddle between a plateau and a hilly area close to the Jordan valley (Fig. 2). The high land in the west is heavily dissected because rising height differences towards the Jordan valley lead to increasing erosion intensity. According to Bender (1974), the Red Mediterranean Soils around Gadara/Umm Quies developed out of the calcareous sediments of the B.3 and B.4 units of the Belqua group. However, the plateau directly west of the site is level, not dissected and is capped by a basalt sheet from a major eruption in Syria during the Middle Pleistocene (Bender, 1974).

Tell Zera’a is an ancient settlement hill in the middle of the Wadi el-Arab, south of Umm Quies. Several calcareous sediments from the Tertiary and Cretaceous are exposed on the slopes of this wadi (Bender, 1974). It is quite broad and its lower southern slopes are gentle, making them suitable for cultivation. Both the Wadi el-Arab and the highlands at Umm Quies are intensively cultivated with olives, cereals and vegetables. On part of the upper southern slopes of the Wadi el-Arab, a Mediterranean oak forest grows (mainly Quercus ithaburensis and Ceratonia siliqua), while part of
the upper northern slopes was reforested with pine (Pinus halepensis).

Abila is situated in the northeast approximately 16 km north of the modern city of Irbid on a gently sloping limestone plateau. Mediterranean Red Soils have developed in the calcareous sediments of the B.4 unit of the Belqua group (Bender, 1974). Several very steep wadis are cut deeply into the soft rock, partially formed from tectonic activity of the Jordan–Yarmouk fault system. As in the Wadi el-Arab, the upper sections consist of limestone deposited in the Tertiary, while sediments of the Cretaceous are exposed below (Bender, 1974). The valley floor is mostly not suited for cultivation, but rain-fed cereals and vegetables are grown on the plateau. Also large and very productive olive tree plantations are present.

Irbid (ancient Arbela) is situated in a level plain (Irbid–Ramtha basin), which contains some of the most fertile soils of Jordan. Fluvial limestone gravels and basalt are the source rocks in the vicinity of Irbid (Bender, 1974). This plain is not dissected by wadis and springs and streams are absent. Wheat is grown in huge fields.

3.3. Soil analysis

Soil profiles were opened down to the bedrock and excavation trenches, gullies, street cuts and building pits studied. For collection of soil samples, plastic bags were filled from a ca. 5 cm thick strip in the middle of the identified layers/horizons. In existing trenches, the outer 5 cm were removed to exclude influence from material washed down from above. Texture and content of calcium carbonate were compared with the database of the NSM&LUP where analyses were available, chosen as they are well suited to characterise soil development and had been conducted at most profiles studied by the NSM&LUP. Further data, including gravel content, were not fully available or, like the pH-values, showed almost no variations between the different sites to be of significance for interpretation. The content of calcium carbonate was determined using a Scheibler-Apparatus according to Schlichting et al. (1995). The texture was determined using wet sieving according to DIN 19683 (1973), while the smaller particles were measured with a laser diffraction device (HRLD Mode Sympatec) according to ISO 13320 (1999). To ensure that these results can be compared with textures determined using the pipette-method, the clay values were recalculated as proposed by Konert and Vandenberge (1997), given in brackets in the tables. Before sieving, the samples were treated with hydrochloric acid (HCl) to eliminate carbonates. The hydrochloric acid was evaporated and the samples were dispersed with sodium pyrophosphate solution (Na4P2O7). Before measuring with the laser diffraction device, the dispersed samples were also exposed to ultrasound (built-in in the HRLD Mode Sympatec device) for 60 s to destroy any agglomerations.

The samples of the National Soil Map and Land Use Project of Jordan were collected and treated in the same way before analysis. Soils were sampled to 100–150 cm depth or limiting layer, assuming that these depths tied in with rooting depths of most crops. Sand and silt fractions were categorised according to the soil taxonomy (USDA, 1990), and silt and clay contents were determined with the pipette-method according to Köhn (Hartge and Horn, 1989).

4. Results

4.1. The plateau around Abila

The soils on the plateau around Abila can be classified as Entic Chromoxerets, Lithic Xerochrepts, Vertic Xerochrepts, and Lithic Xerothents (NSM&LUP, 1993). However, soils vary widely within small areas, making it difficult to assign these classifications to spatial units covering larger areas of the plateau. Fisher et al. (1968) therefore used the summarising terms “Red Mediterranean Soils”, “Brown Limestone Soils” and “Grey Limestone Soils”. Variations are visible by different colour intensities (ranging at Abila from 5YR4/4 to 7.5YR6/5 on the Munsell scale), varying stone contents, changes of soil depth and distinct archaeological material on the surface. Street cuts revealed depths varying between 30 and 300 cm within short distances (Fig. 3). The texture varies strongly, as well as the content of calcium carbonate (Table 1). Very shallow Entisols resting on bedrock with and without stone-rich transition horizon (Table 1, pits PJ 029 and PM 407; Table 2, pit 3A), Xerochrepts of medium depth (Table 1, pit PD 022; Table 2, pits 1A and 2A, as well
as deep Vertisols (Table 1, pits PM 406 and PD 024) are present (Figs. 4 and 5 show the locations of the sampling places).

The profiles deeper than approximately 1 m were nearly free of stones except for the deepest horizons above the bedrock. The clay content reaches a maximum in the B horizons, also indicated by plasticity and slickensides. Very few (1%) small and soft calcareous concretions were present in the lower part of the deep soils, approximately 50–100 cm above bedrock.

The differences in depth could not be related to land use systems, colour, or the relief, and were not indicated by plant cover. However, texture and calcium content seem to some extent related to field borders and archaeological material on the surface. As found by Lucke et al. (2005), areas bearing Mamluk and older pottery showed a slightly finer texture, brighter colour and higher content of calcium carbonate (Table 2, pit 2A) compared to areas without pottery younger than the Byzantine period (Table 2, pit 1A). As these differences follow field borders and cannot be attributed to changes in the relief or source rock, it seems likely that prolonged land use during the Mamluk period is responsible for the observed distinction. This implies that no great soil translocation took place after the Byzantine period, as it would have erased the differences of soil development (Lucke et al., 2005).

East of Abila, close to the village of Amrawah, a paleosol was found, buried by basalt and re-exposed by tectonic activity (Fig. 6). According to Bender (1974), this basalt is an extension of the Yarmouk-basalt which was deposited in the Middle Pleistocene 700,000 years BP. The buried soil is approximately 372 cm deep and developed on Belqua B.4 limestone. It shows three bands of calcceous concretions: an upper band (50–165 cm, with a maximum at 140 cm) of hard, mature and intense (50%) concretions, a second band (200–260 cm) of soft and medium (25%) concretions, and a lower band (300–360 cm) of hard and intense (45%) concretions. Slickensides and manganese concretions are present throughout the whole profile. On top of the basalt, soil cover varies between 10 and 600 cm. It seems that three bands of gravel were deposited while this soil formed. Small and soft calcceous concretions (30%) are present under the deepest gravel band. Because the basalt as well as the gravel bands all incline in slightly different angles, the soil depth between them varies strongly. It seems that land use finally created a new level surface, cutting the gravel bands at different locations, which is mirrored by the strongly varying stone content on the surface.

Finally, Grey Limestone Soils within the ruins of Abila were compared with the Mediterranean Red Soils in the fields. In ancient Abila, houses were built with limestone from local quarries, which is the same material as the

Table 1
Laboratory analyses by the NSM&LUP (from NSM&LUP, 1993)

<table>
<thead>
<tr>
<th>Sampling pit</th>
<th>Depth (cm)</th>
<th>CaCO₃ (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>cS%</th>
<th>mS%</th>
<th>tS%</th>
<th>vS%</th>
</tr>
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<tbody>
<tr>
<td>PM 407</td>
<td>0–2</td>
<td>15.7</td>
<td>6.2</td>
<td>38.0</td>
<td>55.8</td>
<td>2.3</td>
<td>1.2</td>
<td>0.9</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>2–28</td>
<td>9.7</td>
<td>6.7</td>
<td>38.5</td>
<td>55.8</td>
<td>2.0</td>
<td>1.0</td>
<td>0.9</td>
<td>2.8</td>
</tr>
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<td>36.6</td>
<td>58.5</td>
<td>1.2</td>
<td>0.9</td>
<td>1.0</td>
<td>1.8</td>
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<tr>
<td></td>
<td>18–48</td>
<td>10.5</td>
<td>5.8</td>
<td>33.9</td>
<td>60.3</td>
<td>1.4</td>
<td>1.2</td>
<td>1.2</td>
<td>2.0</td>
</tr>
<tr>
<td>PD 022</td>
<td>0–33</td>
<td>n.a.</td>
<td>7.0</td>
<td>29.1</td>
<td>63.9</td>
<td>2.4</td>
<td>1.4</td>
<td>1.3</td>
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<tr>
<td></td>
<td>33–86</td>
<td>n.a.</td>
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<td>0.4</td>
<td>0.2</td>
<td>1.3</td>
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<td>0.6</td>
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<td>4.6</td>
<td>56.9</td>
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<td>126–163</td>
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<td>0.5</td>
<td>0.8</td>
<td>0.6</td>
<td>1.7</td>
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</table>

The soils of pits PM 406 and PM 024 were not exposed to bedrock. Their total depth is unknown.
Table 2
Laboratory analyses results for our soil sampling places

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<tr>
<th>Sampling pit</th>
<th>Depth (cm)</th>
<th>CaCO₃ (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay %</th>
<th>cS%</th>
<th>mS%</th>
<th>fS%</th>
<th>cU%</th>
<th>mU%</th>
<th>fU%</th>
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<td>38</td>
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<td>19</td>
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<tr>
<td></td>
<td>10–20</td>
<td>20</td>
<td>4</td>
<td>90</td>
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<td>14</td>
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<tr>
<td></td>
<td>20–30</td>
<td>25</td>
<td>10</td>
<td>84</td>
<td>6 (26)</td>
<td>0</td>
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<td>9.3</td>
<td>43</td>
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<td>14</td>
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<tr>
<td></td>
<td>30–45</td>
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<td>5 (29)</td>
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<td>4.5</td>
<td>40</td>
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<td>17</td>
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<td>4 R</td>
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<td>6 (36)</td>
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<td>24</td>
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<td>0.8</td>
<td>21</td>
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<td>24</td>
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</tbody>
</table>

Recalculated values for clay according to Konert and Vandenberghe (1997) are given in brackets. Pit 4R represents soil development out of accumulated debris inside the ruins of Abila.

Fig. 4. Map showing our sampling pits around Abila and the village of Hartha (marked with x) and the profiles examined by the National Soil Map and Land Use Project of Jordan (marked with y). The ancient site of Abila was sampled at locations named with “R”. The map was copied and edited from the 1:50,000 topographic map of Jordan drawn in 1959 (available at http://www.lib.berkeley.edu/EART/jordan/50k.html).
bedrock of the soils on the plateau (Fuller, 1987; Lucke et al., 2005). A site was sampled within the remains of the Umm el-Amad basilica (Fig. 7), assuming that the soils formed out of the debris of the basilica resemble, in principle to soil-forming processes on the plateau since abandonment of the site. Soil cover of the ruined basilica varied strongly, dependent on the character of the debris. While the cover of large limestone blocks was only about 20 cm thick, 60 cm depths were reached on limestone gravel. The soil is characterised by a high content of calcium carbonate, probably due to mortar remains, and shows a texture similar to the plateau soils (Table 2, pit 4R). It seems possible that the soil cover on the limestone blocks comes from aeolian input, however, debris material other than limestone may have contributed to its formation. On the limestone gravel in pit 4R, calcium content increases with depth, indicating that weathering processes are active in the profile.

4.2. Construction pits for houses in Irbid

Three new pits for house construction in Irbid were sampled; these revealed deep and massive Vertisols down to 400 cm and many Roman and Byzantine sherds were present on the surface. In one of the profiles soft calcareous concretions were found at a depth of 50–300 cm with a maximum at about 250 cm depth. Their frequency varied between 2% and 50%. Below the concretions layer, the colour changed to a brighter red, probably indicating a paleosol (Fig. 8). The other construction pits revealed neither calcareous concretions nor colour changes. Slickensides were present in all profiles starting at a depth of about 50 cm.

4.3. Wadi el-Arab

Wadi el-Arab is characterised by steep northern slopes with exposed white rock, while the southern slopes are gentler. White soils are present on top of the gentle ridges, descending into the wadi, and the depressions between are filled with red colluvium (Fig. 9). One pit was opened in the white soil on one of the southern ridges. It proved to be sticky and plastic and showed no profile differentiation, stones or sherds. It appears that the ridges consist of Cretaceous Muwaqqar chalk marls (Bender, 1974) and represent the exposed, very soft source rock, which can well be ploughed and cultivated.

Three pits were dug into the Mediterranean Red Soils present in the depressions between the white ridges. The first reached parent material, a limestone gravel, below 100 cm. The second proved to be 120 cm deep and revealed limestone, while the third was only 30 cm deep and rested on hard limestone elevated 3 m above the surrounding wadi floor. Few Roman and Byzantine sherds were discovered at all locations. Additionally, many erosion gullies were present in the depressions and these gullies showed that soil depth varied from 80 cm to more than 180 cm.
Upward on the southern slopes of the Wadi el-Arab, the versants become steeper and Grey Limestone Soils are present. When exposed to erosion, relict surfaces are clearly visible due to buried A-horizons (Fig. 10), which sometimes still show remains of plants and shrubs.

The Grey Limestone Soils on the upper southern slopes showed varying of colour intensity, ranging from 10YR3/3 to 10YR5/6. Attempts to identify possible sources of these variously coloured soils were unsuccessful. The dark brown colouring was developed only in buried A-horizons. In the higher levels of the southern slopes of the Wadi el-Arab, the slopes change into stepwise arranged natural terraces which are connected over very steep versants. On these terraces, only about 10 cm soil cover is present over limestone, nevertheless olive trees and cereals are grown.

The lower part of the northern slopes of the Wadi el-Arab resembles the stepwise arranged natural terraces of the higher southern slopes. Up at Umm Queis, the angle of the slopes increases and terraces are absent. Instead, a white rock is exposed which was seemingly rearranged by landslides. This was illustrated at a road cutting where a relict surface was covered by a huge mixture of hard and soft limestone material.

4.4. Plateau west of Umm Queis

The topsoil on the plateau west of Umm Queis contains the greatest amount of archaeological material of all the...
soils examined, dating mainly from the Roman and Byzantine period. Pits exposed Entic Chromoxerets, reaching the basalt bedrock in 150–200 cm. Approximately 80% of the basalt cap west of Umm Queis is covered quite homogeneously by these soils (NSM&LUP, 1995a). Although some shallow gullies could be observed, erosion seems to be limited. Slickensides begin at a depth of approximately 30 cm. Soft small calcareous concretions were present within a depth of 80 cm and increased downwards, reaching a maximum around 140 cm. Their extent varied between 1–5%. The plateau west of Umm Queis is estimated to bear some of the best soils of Jordan, and land suitability mapping allocated it the best possible values for cereals (NSM&LUP, 1995a).

5. Discussion

The four areas examined show strong differences in soil properties and distribution. In summary:

- Mediterranean Red Soils around Abila are heterogeneous, ranging from shallow Entisols to deep Vertisols in small areas. A paleosol indicates that soils were eroded and transformed several times;
- the fluvial limestone gravels and basalts around Irbid are covered by deep Vertisols;
- soils in the Wadi el-Arab are heterogeneous, but distributed according to relief; and
- deep and homogeneous Entic Chromoxerets are present on the basalt cap west of Umm Queis.
These findings do not support the proposal that erosion played a significant role in the abandonment of ancient sites. The Decapolis region shows a soil cover that allows today for intensive agriculture at all examined locations. As it is generally assumed that Mediterranean red soils form slowly and date to the Pleistocene (Bronger and Sedov, 2003), it seems unlikely that the present soil cover formed during the last 1000 years since abandonment of the sites. Additionally, relict land surfaces seem to be represented by gravel bands in the soil which developed on the basalt covering the Amrawah paleosol, pointing to several phases of soil formation and erosion since deposition of the basalt. Ongoing research has to clarify the origin of the gravels, the exposure of which may be related to changing stone contents on the fields around Abila. The Amrawah paleosol indicates that soils around Abila are indeed degraded and transformed, but land use seems to have created only a new level surface on long transformed soils. Slight differences of soil development, following field borders, might be attributed to prolonged land use during the Mamluk period, implying that no major erosion took place since the Muslim conquest in 636 AD. The huge amount of archaeological material from the Roman and Byzantine period does not point to sudden catastrophic erosion due to land use, because it should have removed the archaeological material too. A concentration of archaeological material due to deflation can be ruled out, because the soils are rich in clay and calcium carbonate, form hard crusts when drying and are not very susceptible to wind erosion (Lucke et al., 2005; Rösner, 1995). It is interesting to note that the greatest intensities of material concentration of sherds on the surface, seems not very likely—instead, sherd cover in the Decapolis region could be a direct function of land use and manure intensity.

Rapid soil formation could be possible if strong aeolian input took place. However, the soils developed on the ruins of Abila indicate that no more than 20 cm of the soil cover can be attributed to aeolian input since abandonment of the site. The observed small-scale variations in soil development on the plateau should also not be visible after strong aeolian input (Lucke et al., 2005). Soil distribution in the Decapolis region is clearly related to source rock and relief. This is in agreement with the study of Jahn (1995), who attributed only 2–5% of the substrata in present Mediterranean Red Soils in Israel to aeolian input.

Colluvial and alluvial fans mantle almost all hill slopes. Artefacts suggest that the fans are mainly of Middle and Upper Paleolithic Age (NSM&LUP, 1993), attributed to the formation of these fans to enhanced erosion due to moister conditions at the end of the Pleistocene. However, Cordova (2000) suggested that general drought, reduced vegetation and an increased number of extreme precipitation events were responsible. According to Cordova (2000), the Mediterranean Red Soils in Jordan extended further east in the past into what is today steppe or desert. Analyses of magnetic susceptibility of wadi sediments indicate that the Mediterranean Red Soils were eroded mainly between 17,000 and 9000 BP in the upper and middle Paleolithic age. Drought and increased extreme events also led to stronger incision of floodplains in wadis, forcing early inhabitants to abandon these areas (Cordova et al., 2005). Recent measuring of sedimentation in the King-Talal dam in Jordan suggests that a higher frequency of extreme events could be responsible for increased soil erosion (al-Sheriadeh and al-Hamdan, 1999). Compared with the impact of heavy rainstorms, the effect of soil conservation measures seems fairly negligible. Fisher et al. (1968) summarised that erosion in Jordan is limited to a dozen rainy days per year when precipitation intensities are high and soil cover is marginal.

Maher and Banning (2001) found that a Terra rossa paleosol developed in colluvium in Wadi Ziqlab around 20,000 BP, and experienced a phase of intense erosion during the younger Dryas. According to Maher (2005), climate change is the most likely explanation for landscape change in Wadi Ziqlab. Field and Banning (1998) were able to distinguish five types of colluvia in the Wadi Ziqlab and to date them according to archaeological material. Colluviation in Wadi Ziqlab was episodic, related to heavy precipitation events and occurred in the form of earth slumps and landslides. Field and Banning (1998) could not explain the differences of colluvium types, but concluded that the greatest amount of colluvia was deposited earlier than the Bronze Age.

Vita-Finzi (1979) postulated that erosion in the Mediterranean took place in two major phases, essentially at the end of the Pleistocene and during the Medieval period (older and younger fill), and could be attributed to climatic fluctuations. These findings stimulated erosion research and subsequent investigations found different local patterns, but the role of extreme precipitation events gained more and more attention (Bintliff, 1992). Erosion in the Decapolis might be related to a regional development in the Mediterranean: according to Frumkin and Stein (2003), a sharp drop of the level of lake Lisan (today the Dead Sea) in the transition period from Pleistocene to Holocene (20,000–10,000 BP) corresponded with strongly enhanced erosion. It seems likely that soils in the Decapolis region are in the present state since the prehistoric period.

Although anthropogenic horizons are reported around the margins of ancient occupation tells (especially in the Jordan valley), the influence of land use and vegetation on the soils in Jordan is limited, as deduced from a comparison of soils under old and young forests, which are very similar (NSM&LUP, 1993). It is concluded that the effect of forest removal on soils has been fairly limited, as there is insufficient evidence of non-calcareous soils under forest or for persistence of former organic rich horizons (NSM&LUP, 1993). Rock outcrops and shallow soils are described as the result of long periods of
geological erosion, which may have been locally accelerated. Overall erosion is estimated not to exceed the expected geological rate and Jordan is considered to be in the stable state of completed erosion (NSM&LUP, 1993).

Maps of mean annual precipitation and soil distribution show that the patterns are very similar (Fig. 11). According to NSM&LUP (1993), distribution of soils in Jordan shows a correlation of clay content with rainfall and source rock. The highest clay contents are accompanied by very low contents of calcium carbonate. A complete leaching of calcium carbonate was found only where mean annual precipitation exceeded 550 mm. The clay contents decline steadily to the east and south, in accordance with decreasing precipitation. In the arid regions of today, high subsoil clay contents and buried Red Mediterranean Soils are interpreted as indicators for higher rainfall in the past (NSM&LUP, 1993).

According to Geyh et al. (1992) and Geyh (1996), fossil groundwater in east Jordan was formed in varying intensity from 35000 to 24000, 21000 to 15000, 14000 to 6000 and 5000 to 4000 BP, but recharge steadily declined. Distribution of the fossil groundwater corresponds with relict buried red soils and the actual distribution of soils (NSM&LUP, 1993), indicating that groundwater and soils were formed under moister conditions, which is in agreement with the manganese and calcareous concretions in the Amrawah paleosol.

Khresat et al. (1998) and Khresat (2001) attributed clay maxima in the subsoil to Argillic horizons in Jordan’s Mediterranean Red Soils, but the NSM&LUP concluded that the clay maximum cannot be explained by illuviation. Thin section studies proved that Argillic horizons are absent in the profiles studied by the NSM&LUP (1995b). The thin section studies also indicated that basically all soils in Jordan are derived from re-distributed earlier soils. This re-distribution might be shown by the gravel bands at the Amrawah paleosol. Here, human land use finally created a new surface, levelling a slightly inclining terrain and cutting the gravel bands, which seems to be mirrored by the changing stone content on the fields. Therefore, another explanation is offered here for the clay maxima in the subsoil: historic land use. It seems possible that a distribution of soil depth as visible at Abila (Fig. 3) is due to the levelling effect of long-term continuous ploughing since the beginning of agriculture. Impacts of long-term land use on soil development are well known, for example, from England, where Celtic and Roman field systems are still visible in some places both in the soils and on the surface (Bowen, 1961). Former land use technologies, including the wooden plough or the heavy moldboard plough, can be attributed to these relict field structures and soil properties (Fries, 1995; Lucke, 2002).

Land use in Jordan seemingly levelled the surface of a once undulating landscape. The clay maxima could represent ancient surfaces or B-horizons which were covered by topsoil from the surrounding, slightly elevated areas (Figs. 12 and 13). This would be in agreement with small-scale variations of soil development, which were attributed to different periods of land use (Lucke et al., 2005). As the limestone plateau around Abila shows many karst features like caves and sinkholes (al-Farajat, 1997), it seems likely that the original landscape was not as level as it appears today. The contrasting very homogeneous soils on the plateau west of Umm Queis can be explained by the underlying basalt cap.

6. Conclusions

The evidence found in the Decapolis region suggests that land use impacted landscape development, but did not lead to general soil erosion or an advance of the desert. Mediterranean Red Soils close to Abila overlie a limestone plateau with karstic features and show very heterogeneous properties. They were seemingly re-distributed by ploughing over centuries, which levelled a once undulating landscape. To some extent, historic field systems seem to
be traceable according to soil development and material culture, which implies that no major erosion took place since the Muslim conquest (Lucke et al., 2005). Soils in the Wadi el-Arab are heterogeneous and distributed according to the relief. On basalts and fluvial limestone gravels close to Umm Queis and Irbid, deep Vertisols are present. Soils developed out of debris in ruins indicate that aeolian input and soil formation were very limited since the abandonment of the sites, and that no temporary erosion took place which was later replaced by newly formed soil. It is concluded by the authors that there are no indicators for major historic erosion or desertification due to land use. In contrast, it seems possible that soil properties have not changed much since prehistoric times, as most colluvia were deposited during the transition from the Pleistocene to the Holocene (Vita-Finzi, 1979; Field and Banning, 1998; Cordova, 2000; Frumkin and Stein, 2003).

Regarding the settlement history, the argument for the “erosion-theory” seems to be circular: it was assumed that the present land degradation had to be related to the abandonment of archaeological sites because the sites are located in a degraded environment. Based on this assumption, numerous soil conservation projects were launched in order to combat desertification (Mainguet, 1994) and the term “desertification” was first used to describe the devastating effect of land use (Thomas and Middleton, 1994).

Considering the distribution of soils in the Decapolis region, it seems that climate had the greatest impact on soil development. Soils are most strongly developed in the moister regions, either due to stronger weathering of bedrock or increased aeolian deposition. Relict buried soils seem to correspond with fossil groundwater. It seems likely that land degradation in Jordan is not related to increased precipitation, but to periods of prolonged drought interrupted by more frequent extreme events (Cordova, 2000; Maher, 2005).

Up to now, not enough data exist to date erosion precisely in the Decapolis region and to evaluate exactly the impact of land use, but considering desertification, it has to be questioned whether soil conservation measures and a focus on land use technologies alone can be successful. As global warming seems likely, it is possible that the future will witness drier conditions in Jordan and an increase of extreme events (al-Zaad et al., in press). Future strategies to combat desertification may be more successful if not focussed on single measures like soil conservation but on a better understanding of the landscape system and its relationship to climate.

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