THE PAST AS A KEY FOR THE FUTURE: MUTUAL DEPENDENCIES OF LAND USE, SOIL DEVELOPMENT, CLIMATE AND SETTLEMENT

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ABSTRACT

It is of high actual importance to clarify historical climate variations and their impact, because it is not possible to predict future developments and its motors, if the past way of climate is not understood. The Decapolis area in northern Jordan provides excellent opportunities to investigate this question. Environmental change could have been responsible for the abandonment of the area, caused by human activities or climate variation. Recent investigations let the climatic possibility seem more and more likely, because climatic models match very well to the historical development, while mis-management becomes less probable, as it is evident that medieval Arabs were highly skilled farmers. Our investigations revealed a very heterogeneous land use and soil development pattern, and no indicators for a sudden and general erosion event. In contrast, relic surfaces and the soil's genesis point to moister conditions in the past and differences in the soil's development point to diverse land use intensities. While it is evident that land use changed the character of the landscape and can be tracked according to soil development, it did not lead to an advance of the desert. In this context, it merely seems that desertification is related to climate change.

KEYWORDS: Climate change, historical land use, impact of global warming, settlement history, soil erosion, soil properties.

INTRODUCTION

Global warming is feared to lead to climate change, water shortage and advancing desertification. However, it is still discussed whether global warming really takes place, whether it is caused by CO_2 emissions, destruction of rainforests or natural factors which are not related to human activities, and it cannot be determined yet how the exact consequences of global warming may look like (Berner and Streif, 2000).

A way to a better understanding of climate are investigations of past changes. Human influence is supposed to be minimal before industrialisation, while the global atmospheric air circulation is believed to be stable since the last Ice Age (Hare, 1961). Nevertheless, investigations in past climates found fluctuations during the Holocene (Butzer, 1961; Nützel 1975, 1976). As the methodical approaches were greatly improved in recent years, research focussed more and more on shorter time intervals and historic periods (Bar-Matthews *et al*., 1998; Issar 1992, 1998, 2003; Frumkin and Stein, 2003; Bookman *et al.*, 2004). But it was so far not possible to evaluate the exact impact of the discovered variations or to understand their reasons.

The settlement history of the Near East shows periods of abandonment, which seem to be related to these climate fluctuations. A rainfall calculation from Soreq Cave (Bar-Matthews *et al.*, 1998) found decreasing precipitation to about 50 mm during short periods (100 years) which matches the desertion of sites (Lucke *et al.*, 2004a). However, it neither proves causality nor imply the reasons and the exact impact of lowered precipitation. It is possible that the rainfall reductions led to an advance of the desert, reducing agricultural potentials and forcing the abandonment of sites. But it has to be clarified whether a reduction of 50 mm crosses already the threshold to let the desert advance. It is connected with the question whether the rainfall pattern changed as well. The latter is most important for agriculture (Seth, 1978; Lanzendörfer, 1985). Additionally, it is also possible that land use was too intensive and caused desertification. Land use has an effect on climate, too, and the activities of early man may have contributed to the rainfall variations (Claussen, 2003; Claussen *et al.*, 2003).

To cope with possible negative developments caused by global warming, it is of importance to better understand the past. To achieve this goal, important contributions can be made by soil science, archaeology and evaluation of land use. Soils are like a memory which stores changes of the environment and allows for a reconstruction of past landscapes and climate conditions (Bäumler, 2001a, 2001b; Bäumler *et al.* 2002). In combination with archaeology, soil examinations are able to describe historic land use intensity and related transformation of the environment (Lucke *et al.*, 2004a). If the historic land use is evaluated, impacts of climate variations and a possible effect of land use change on local climate can be assessed.

The Decapolis region

The Decapolis region in Northern Jordan and Israel is an excellent place for research on the relationship of settlement history, land use and climate (fig. 1). It is situated close to the desert, which causes strong variations of rainfalls, while the settlement history is fairly well known and past climate data are available as well for the Near East. In antiquity, numerous cities flourished in the Decapolis region. Most sites were settled since the Early Bronze Age. During the Roman, Byzantine and Umayyad periods, the cities grew considerably and many monumental buildings were constructed, demonstrating great wealth of the inhabitants – but during the Abbasid period, the region suffered a sharp decline and the cities were abandoned Hoffmann and Kerner, 2002). Apart from a minor resettlement during the Ayyubid-Mamluk time, no cities were present in the Decapolis region any more and the area was characterised by villages and nomadic tribes until the end of World War II (Walmsley, 1992, 1997).

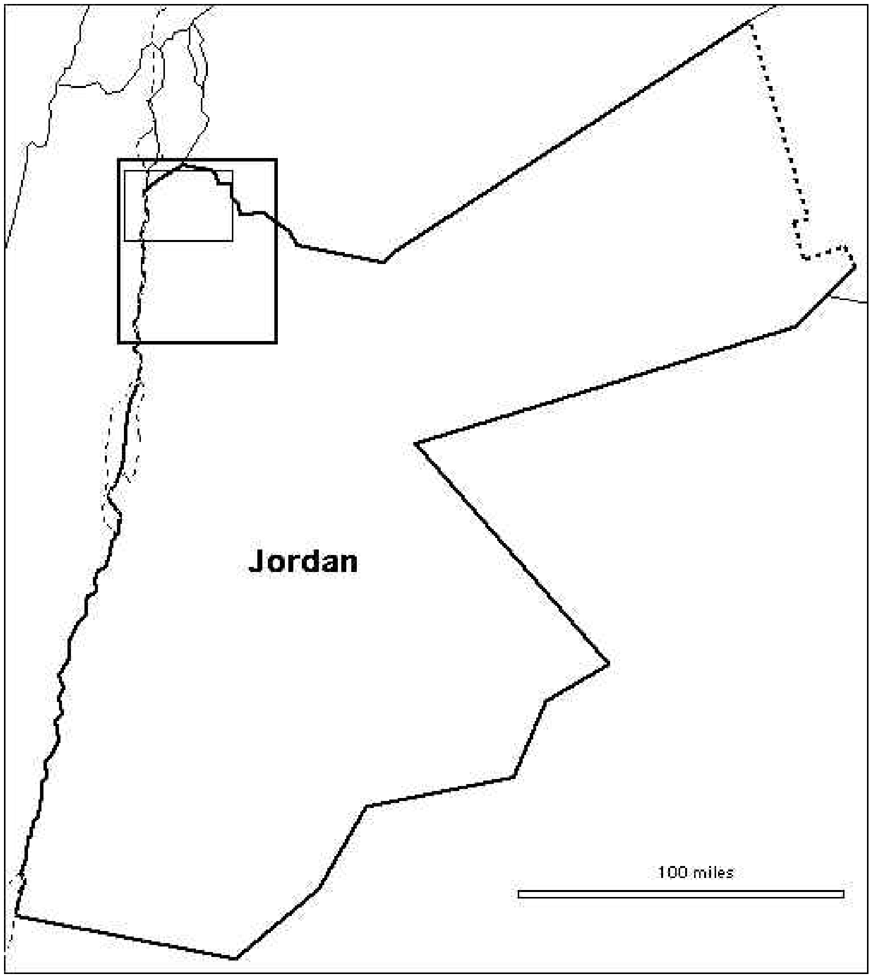

Fig. 1: Location of the Decapolis region (big box) and the investigation area (small box).

The region includes several different landscapes: The Jordan valley is characterised by hot and dry climate, but numerous springs and the Jordan river makes intensive irrigation possible. The heavily dissected highlands further east allow for limited irrigation, as perennial streams are scarce and many valleys deep and narrow, but the plateaux receives sufficient rainfall for intensive agriculture. Further east, the highlands merge with the desert and precipitation variations increase. Despite the heterogeneous landscape, the region was a political unit and the sites experienced a similar historical development.

Several authors suggested climate changes to be responsible for the abandonment of the region (Huntington, 1911, 1915; Issar, 1990, 1998; al-Shorman, 2002). Other authors believe that land use became too intensive inducing desertification and desertion (Lowdermilk, 1944; Butzer, 1961), or that political and economic power shifted away from the area and caused decay (Walmsley, 1992, 1997). Moreover, an earthquake in 747/748 A. D. was also considered to have been responsible for the abandonment of the region (Hoffmann and Kerner, 2002).

The investigation area

Our goal is to achieve a better understanding of historic land use, to clarify whether an over-explotation of resources took place, and to evaluate a possible connection to climate. To include different landscape types, research was carried out at the site of Abila, ca. 16 km north of the modern city of Irbid, and in the Wadi el-Arab, close to the modern town of Umm Queis (fig. 1).

Abila site is situated 16 km north of the city of Irbid and 5 km south of the Yarmouk River which marks the border to Syria. The site was chosen because it is situated on the level eastern plateaus and because of a low rate of disturbances with regard to building activities. The highland around Abila gives the impression of a vast, gently undulating plain of red soils, dissected by several wadis with steep slopes. The wadis were cut deeply into the soft rock, predominantly dry during the summer and too deep and narrow to be used by agriculture to a significant extent. Many wadi slopes are steep with angles of 40 – 80 degrees and nearly bare of vegetation, while a grey and white substratum, mixed with gravels and stones, is present in the valley's bed. Essentially all wadis are very narrow, allowing cultivation only at limited places where the valley floors widen. There, usually unirrigated orchards are grown. These are supplied with abundant water during floods after winter rains. The spring water of a once-perennial stream in one of the wadis at the site of Abila is pumped for the supply of nearby villages, leaving the wadi dry in summer. In contrast, the plateaus are under intense cultivation. Due to gentle slope degrees, there are no terraces. Except for large olive tree plantations, no other trees or forests are present. On the fields, rain-fed cereals and vegetables are grown.

The Wadis el-Arab and Umm Queis lie further west where the plateaus are more heavily dissected and start to descend to the Jordan valley. In the Wadi el-Arab, the perennial stream dried out as pumping of the springs started approximately 20 years ago for the supply of the modern city of Irbid. The Wadi was dammed and is now partially covered by a lake, which also provides drinking water for Irbid. The valley's southern slopes are quite gentle and intensively used for agriculture. In comparison, the northern slopes are very steep and do not allow for agricultural land use, but the plateau north of the wadi, close to the ancient city of Gadara (today Umm Queis), provides one of the most fertile soils of Jordan (Lucke *et al.*, 2004b).

METHODS

Soil samples were collected both from the vicinity and from the debris in the ruined sites of Abila and Tell Zera'a. In the vicinity, profiles were opened up to the bedrock to clarify the development process of soils and to get the in situ parent material. To assess the influence of cultivation, culture material was collected with the soil samples which gave clues for the intensity and periods of historic land use. To evaluate the land use, air photos and maps were examined for relict structures and land use changes. The present agriculture was investigated using data from the Ministry of Agriculture of Jordan and interviewing farmers.

For collection of the soil samples, small plastic containers were filled with soil material from a 5 cm thick stripe in the middle of a defined layer/horizon. On the plateaus and in the wadis, pits were dug and the samples collected from freshly opened profiles. In existing excavation trenches, the top 5 cm of substrate were removed to exclude influence from material washed down from above. As it was occasionally impossible to determine the exact depth in the excavation trenches, the sampling layers were numbered and their thickness was measured. Determining the correct depth of an excavation trench is sometimes difficult due to the excavation practice not to dig one hole, but rather several with different depths. The samples were analysed for texture, pH value, as well as for nitrogen, calcium, carbonate, sulphur and phosphorus content. The phosphorus content was analysed in those soil samples for which an agricultural land use seemed likely. As the agricultural test areas were examined after heavy rains, the water content was also analysed by weighing the samples before and after

72 hours of drying at 105 °C. The pH value was measured potentiometrically with a glass electrode in distilled water at a soil:solution ratio of 1:2.5. The calcium content was determined using a Scheibler-Apparatus according to Schlichting and Stahr (1995), while the content of carbon (C), nitrogen (N) and sulphur (S) was measured with the elemental analysis apparatus Vario El. For analysis of the phosphorus (P) content the samples experienced pressure decomposition according to Loftfield (Bock, 1972), allowing photometric measurement with the molybden-blue method according to Murphey and Riley (Schlichting and Stahr, 1995). The texture was determined using wet sieving according to DIN 19683, while the smaller particles were measured with a laser diffraction device (HRLD Mode Sympatec) according to ISO 13320. Before sieving, the samples were treated with abundant hydrochloric acid (HCl) to eliminate carbonates. The hydrochloric acid was evaporated again and the samples were dispersed with natriumpyrophosphate solution ($Na_4P_2O_4$) to eliminate binding matter. Before measuring with the laser diffraction device, the samples were additionally pretreated by 60 seconds of ultrasonic to destroy any agglomerations.

RESULTS AND DISCUSSION

Land use

As Lucke *et al.* (2004a) found, present land use in Jordan is quite similar to historic land use and has similar problems. Crops are highly dependent on rainfall patterns. Therefore, farmers usually decide after the first rainfalls which crops to sow (Lanzendörfer, 1985). If there are no well-distributed rains at the beginning of the rainy season a hard drought crust is likely to form in the summer heat, impeding germination of most crop seeds. Additionally, harvest is endangered if there are no late rains with regard to the growing season. As well, excessive rains are reported to be of disadvantage, since the soils get elastic and hence make the field work difficult (Lucke *et al.*, 2004a). Agriculture on the plateaus is fully dependent on rainfall, as there are no other water sources than cisterns, and irrigation is very difficult even today. While on the one hand the dependency on winter rains prevents salinization, shallow soils rich in calcium carbonate are very vulnerable to drought on the other hand.

Soils

Our research at Abila revealed strong variations of soil depth in the area, although the highland looks like a vast, homogeneous plain. While the evaluation of air photos gave no clues for varying soil depth, soil and rock openings along streets and our own diggings on the fields revealed a strong variation of the soil's depth. It varied between 30 cm to 3 m. These differences seem partially to be related to the relief, but could also be observed on the same terrain units. Reifenberg (1947) assumed that these differences are caused by different weathering behaviour of the source rocks. Although chemical analyses of the bedrock were not yet carried out, this explanation seems not very probable as the observed differences in soil development are too big to be solely explained by different weathering behaviour of the parent material. At Abila, soils are derived from the B.1 unit of the Belqua limestone group (Bender, 1974). Yaalon and Ganor (1973) postulated that soil development in Israel and neighbouring countries is influenced by aeolian deposition during rainstorms. Although the extent of aeolian deposits is still discussed, it can be concluded that the differences in soil development at Abila would be even more distinct if part of the parent material is derived from aeolian input, as the level highland around the site should have received the same amount of aeolian deposits. Thus the observed differences in soil development may largely root from land use.

Walking over the fields close to Abila, the soil colour varies slightly at many places according to field borders. To examine this observation, samples were collected from two neighbouring pits which were dug in a distance of approximately 200 m (fields 1A and 2A). The sampling plot on field 2A was characterised by enrichment of nutrients, very high calcium content and stronger weathering of bedrock (table 2). Differences due to the parent rock or relief can be excluded for both sampling plots. Both field 1A and 2A revealed many ancient sherds, mostly from the Late Roman and Byzantine-Umayyad period. On field 2A a cistern was constructed in antiquitiy. Ayyubid-Mamluk sherds are reported from there by Fuller (1985), indicating a medieval farmstead which fits well to the more intensive weathering and nutrient enrichment of the soil of field 2A.

Table 1 (from Lucke *et al.*, 2004a, modified) Soil properties of sampling place 1A. The sand- and silt-fractions are shown in total and divided in coarse, medium and fine material. The carbon content represents the total carbon (Ct).

Sample depth	No.	H_2O [%]	pH	Ca [%]	Ct [%]	N [%]	S [%]	P [mg/g]	Gravel [%]	Comment
5cm	A1	14,4	7,7	22,5	1,7	0,06	0,03	0,94	1,2	ploughed
15cm	A2	8,5	7,9	20	3,5	0,11	0,04	0,92	17,2	crust
25cm	A3	8,1	7,8	25	4	0,10	0,03	0,73	57,4	
40cm	A4	29,2	7,9	21	3,6	0,11	0,03	0,75	15,9	

Sample depth	No.	Sand [%]	Silt [%]	Clay [%]	Coarse Sand [%]	Medium Sand [%]	Fine Sand [%]	Coarse Silt [%]	Medium Silt [%]	Fine Silt [%]
5cm	A1	4	89	7	0,4	0,5	3,1	38	32	19
15cm	A2	4	90	6	0,3	0,2	3,5	48	28	14
25cm	A3	10	84	6	0	0,7	9,3	43	27	14
40cm	A4	5	90	5	0,3	0,2	4,5	40	33	17

Table 2 (from Lucke *et al.*, 2004a, modified) Soil properties of sampling place 2A.

Sample depth	No.	H_2O [%]	pH	Ca [%]	Ct [%]	N [%]	S [%]	P [mg/g]	Gravel [%]	Comment
5cm	A5	9,2	7,9	45,9	6,6	0,16	0,04	1,35	21,4	ploughed
15cm	A6	5,3	7,9	40,3	6,3	0,13	0,04	1,18	46,6	crust
30cm	A7	6,6	7,9	47,3	6,4	0,13	0,04	1,29	4,5	
50cm	A8	7,5	7,9	47,4	6,3	0,10	0,03	1,29	3,2	

Sample depth	No.	Sand [%]	Silt [%]	Clay [%]	Coarse Sand [%]	Medium Sand [%]	Fine Sand [%]	Coarse Silt [%]	Medium Silt [%]	Fine Silt [%]
5cm	A5	2	91	7	0,5	0,4	1,1	30	40	21
15cm	A6	2	91	7	0	1	1	37	37	17
30cm	A7	2	93	5	0	0,4	1,6	41	36	16
50cm	A8	2	92	6	0	0,8	1,2	48	31	13

The soil in the debris of the ruins of Abila was investigated for comparison with the relict soils (plot 11R, table 3). Here, we found a relict surface developed out of Early Bronze Age debris which was preserved in an animal's cave, and remains of mudbrick stones. They were quickly covered with sediments and thus conserved while remains of the city walls prevented erosion.

Table 3 (from Lucke *et al.*, 2004a, modified) Soil properties of sampling location 11R. The samples were numbered and their thickness added, because it was not possible to measure their exact depth. The trench is in total 7,50 m deep. The samples are listed as they are positioned in the trench.

Sample/Thickness	No.	PH	Ca [%]	Ct [%]	N [%]	S [%]	P [mg/g]	Gravel [%]	Comment
11R 8 / 60 cm	A46	8,5	64,4	7,8	0,08	0,04	5,86	12,4	surface today
11R 7 / 25 cm	A47	8,3	39	5,1	0,08	0,03	5,59	4,9	brownish substr.
11R 6 / 1,75 m	A48	8,4	39	5	0,07	0,06	5,13	6	grey debris
11R 3 / 15 cm	A51	9,1	24	1,9	0,04	0,03	2,69	4,5	mudbrick stone
11R 2 / 5 cm	A52	8,6	20	1,9	0,05	0,04	1,30	15,7	animal's cave
11R 1 / 2 m	A53	8,6	53	7	0,08	0,06	6,38	13	grey debris
11R 0 / 30 cm	A54	8,4	48,8	6	0,08	0,8	5,56	11	soil over bedrock

Sample/ Thickness	No.	Sand [%]	Silt [%]	Clay [%]	Coarse Sand [%]	Medium Sand [%]	Fine Sand [%]	Coarse Silt [%]	Medium Silt [%]	Fine Silt [%]
11R 8 - 60 cm	A46	3	87	10	0,2	1	1,8	12	42	33
11R 7 - 25 cm	A47	8	83	9	0,5	2	5,5	29	31	23
11R 6 - 1,75cm	A48	7	86	7	0,5	2,1	4,4	23	40	23
11R 3 - 15 cm	A51	12	82	6	0,2	0,2	11,6	39	27	16
11R 2 - 5 cm	A52	15	79	6	6,7	0,3	8	40	26	13
11R 1 - 2 cm	A53	6	86	8	0,5	1,8	3,7	25	38	23
11R 0 - 30 cm	A54	8	84	8	0,6	1,6	5,8	23	38	23

The red soils on the plateaus can be described as degraded Terrae rossae (Rhodochromic Cambisols). As the weathering of calcareous rocks produces minimal residuals, the development of a Terra rossa (Rhodochromic Cambisol) occurs very slowly. The red colour usually arises due to the clay mineral of haematite, which emerges after long and intensive weathering processes of the silicates (Horowitz, 1979). Therefore Terrae rossae are in general counted as old soils, dating from the Tertiary or the Pluvials of the Ice Ages (Horowitz, 1979; Scheffer and Schachtschabel, 1998). A relic surface under Basalt, close to the village of Amrawah, indicated that the soils reached depths up to 3 m before cultivation started (Lucke *et al.*, 2004b). It can be concluded that a considerable amount of soil was lost since cultivation of the fields which are now around 60 cm deep, as most soils at Abila. However, no tracks of intensive mismanagement forcing the abandonment of the site could be detected. Today agriculture is applied on this ancient land surface (Horowitz, 1979; Lanzendörfer, 1985). This matches the natural reforestation observed by travellers in the 19th century (Seetzen, 1854; Schumacher, 1890) and is in disagreement with Lowdermilk's theory of insufficient land use (Lowdermilk, 1944). He assumed that Arab mismanagement produced barren lands and malaria-infested swamps in the wadis. Newer historical investigations also mediate against the theory of insufficient land use, because they could show that Islamic Conquerors were not uncultivated Bedouins, destroying the agricultural systems, but highly developed agriculturists (Waston, 1981). The similarity of the relict substrates of Tell Abil to the present agricultural surfaces indicates that soils were probably already eroded in the Bronze Age, as the inhabitants usually used local mudbrick for the construction of their houses. Re-weathering of source rock or aeolian deposition prevented the landscape to change into barren rock. The relict surface in the animal's cave on the other hand points to more intensive weathering in the Bronze Age, as present debris surfaces did not develop the red colours (Lucke *et al.*, 2004a) which matches the climate reconstructions of Butzer (1961) and Bar-Matthews (1998).

Investigation of the soil in the Wadi el-Arab around the Tell Zera'a revealed a different picture (Lucke *et al.*, 2004b). In the wadi, on the one hand deep red soils are present which are dissected by many erosion gullies. On the other hand, a uniform greyish-white substrate could be observed which extended down on ridges from the top of surrounding slopes. These greyish-white soils seem to be the typical marl soils which Reifenberg (1947) described. Both the ridges and the red soils in the depressions in-between are intensively cultivated (fig. 2). Construction of a farm on one of the ridges revealed that the marl substrate is deeper than 4 m, but it is difficult to draw a distinction between the very soft parent material and soil. It is possible that these ridges are products of weathering and land slides of the exposed rocks at the wadi slopes. Although the soils on the depressions of the wadi were crossed by many deep erosion gullies, we assume that these material losses are replaced by sediments carried down from the ridges and plateaus. Otherwise, they could not have maintained depths of 2 m and more, while the level plateaus around Abila carry soils of a depth of only 60 cm. As the greyish wadi substratum has similar characteristics as the greyish debris soil (table 3), we assume that it represents slightly weathered products of the soft limestones. In comparison, the red soils of the plateaus and wadi depressions must have experienced a much longer and more intensive weathering process to develop their colour.

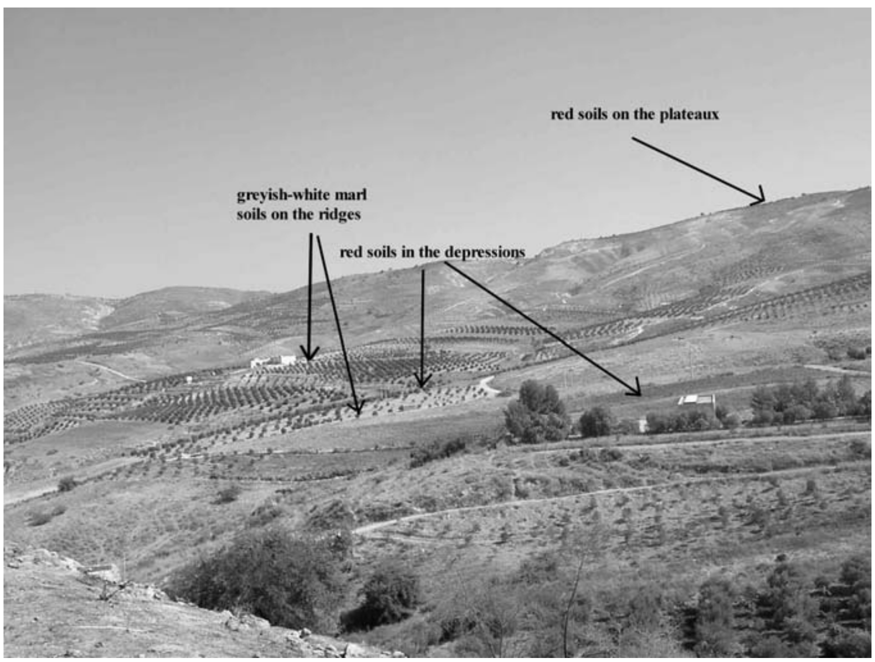

Fig. 2: The southern slopes and soil characteristics of the Wadi el-Arab.

Comparing the soils on the plateaus, it is remarkable that we found a depth of approximately 2 m on the plateau close to Gadara/Umm Queis, while a very dense coverage with material culture (mainly from the Roman and Byzantine-Umayyad periods) indicated that land use was not less intensive than close to Abila (Lucke *et al.*, 2004b). Because of its depth, the soil close to Gadara/Umm Queis is today one of the best in Jordan. The difference in depth in comparison to Abila may root from different bedrock, as basalt is present at Gadara/Umm Queis, or from higher aeolian deposition. This has to be investigated further, but speaks also against the theory of catastrophic erosion as proposed by Lowdermilk (1944).

CONCLUSIONS

Agriculture in Jordan today strongly depends on rainfall, as the greater part of the cultivated area lies on plateaus, where only rain-fed agriculture is possible. The shallowness of soils and the high content of calciumcarbonate cause a high vulnerability to drought. On the one hand, relict mudbrick stones preserved in the debris at Tell Abil indicate that ancient soils looked not much different from the present ones. On the other hand, differences in soil development on the same source rock within an identical relief position point to a strong impact of land use on soil genesis. It is evident that land use changed the landscape, as the observed differences of soil development can only come into being after long periods of land use. It further indicates that the theory of catastrophic erosion after the Arab conquest has to be rejected. It merely seems that the present character of the landscape does not differ much from the landscape present during the abandonment of the Decapolis cities. A relict soil developed out of Early Bronze Age debris points to increased precipitation during the Bronze Age, which matches climate reconstructions.

According to Khresat *et al.* (1998) and Khresat (2001), the soils of Jordan developed in a humid climate that shifted gradually towards more arid conditions. According to Cordova (2000), the red soils extended further east in antiquity than today. Our results match these findings and indicate that there was no sudden catastrophic erosion due to overexploitation of the land. According to Frumkin and Stein (2003), periods of increasing aridity as during the drying of lake Lisan at the end of the last glacial period led to quick and strong soil erosion and degradation. In this context, it seems possible that soil degradation is more related to climate than to the activities of man, because the latter transformed the landscape but did not produce barren lands.

If this proves true and if global warming leads to increasing aridity in the Near East, it can be expected that soil degradation will increase even if countermeasures are undertaken to combat desertification and to promote a sustainable land use. Further losses of soil will have an negative impact on groundwater and vegetation, too. In this context, it seems most important to investigate the relationship of local climate and land use. It might be possible that the intensive historic land use, cutting the forest, contributed to the intensity and negative effect of climate variations (Seth, 1978). To cope with the effects of global warming, it might be more promising to focus on the land use's influence in local climate than on soil preservation measures. The latter may be doomed to fail if soil degradation is inevitable due to changing climate conditions.

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