Chapter 29
Sensitivity of a Sandy Area to Climate Change Along a Rainfall Gradient at a Desert Fringe

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29.1 Introduction

Global climate change has become a strongly and frequently addressed issue in the last decades. The aspect is crucial in dry-land areas, which cover approximately one third of the globe's total land area. The relationship between average annual rainfall and environmental variables has attracted the attention of many scientists. Climatologists use aridity indices to express relationships between climatic and environmental variables (Köppen 1931; Budyko 1974; Wallen 1967; Bailey 1979). These indices, based on purely climatic variables such as annual precipitation, temperature, evaporation and radiation, tend to imply that the acuteness of aridity is inversely related to annual precipitation. Although aware that soil water content depends on local soil type and precipitation regime, Walter (1939, 1960) asserted that at a larger, global scale, standing biomass is positively correlated to average annual rainfall. This approach is still followed by many researchers who assume a positive relationship between average annual rainfall and environmental variables such as water availability for plants, vegetation cover, productivity, species diversity, soil properties, human activity, and erosion rates for sub-humid to arid areas (Issar and Bruins 1983; Shmida 1985; Seely 1991; Lavee et al. 1991; Kutiel et al. 2000; Meron et al. 2004). This approach is certainly correct at the global scale, as well as for non-irrigated annual crops in dry-land areas. It is, however, questionable for arid and semi-arid areas, usually regarded as highly sensitive to climate change, especially for perennial plants.

With decreasing annual rainfall, the number of rainstorms and storm rain amounts decrease. Under such conditions, water availability for plants may be highly dependant on the relationships between rainfall and surface properties which greatly influence the degree to which water will percolate or will be transformed into runoff, thereby significantly affecting the spatial redistribution of water resources. For example, it is well known that rocky hill slopes devoid of extensive soil and vegetation cover are characterized by extremely low infiltration rates, and quickly develop surface runoff. Due to the short duration of most individual rain showers, flow distances are short, resulting in water concentration and deep water percolation at nearby down-slope positions (Yair and Danin 1980; Yair 1983, 1994,

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1999). Under given rainfall conditions, the degree of water concentration is expected to be more limited in sandy soils devoid of topsoil crusts, where infiltration depth is quite high due to the low water-holding capacity, and the high porosity of unconsolidated sand. However, due to the latter properties of sand, water preservation in sandy areas is generally good. The poorest water regime is to be expected in fine-grained soils (loess or silty-clayey soils) characterized by their high water-absorption capacity which limits the depth of water percolation, and enhances evaporation losses during the hot time intervals between consecutive rainstorms. Under such conditions, we contend that, in dry-land areas, surface and rainfall characteristics which encourage water concentration and water preservation can be considered as the main component in water availability, rather than the absolute average annual rain amount. We therefore postulate that semi-arid and arid ecosystem characteristics will not necessarily correlate with the actual amount of rainwater, but rather with the degree of water concentration and water preservation. In other words, a given climatic change in dry-land areas would be expected to have differential effects in a rocky area, in a loess-covered area, and in a sandy area. Furthermore, a non-uniform effect should be expected within each of the above physiographic units, due to spatial differences (over short distances) in percolation and water redistribution by surface runoff.

The common assumption regarding the positive relationship between annual precipitation and water resources disregards the fact that a climatic change in semi-arid areas, especially at the desert fringe, is not limited to purely climatic variables such as precipitation, temperature or wind regime. It is almost always accompanied by a parallel change in surface properties, such as associated with sand deposition during a transition to a dry climatic phase, and loess deposition during a wetter phase. The new surface properties can be expected to exercise a strong effect on infiltration, surface runoff, and water availability for plants. This raises an interesting question: does the alteration of surface properties enhance the expected positive effect of rainfall increase, or reduce it or even eliminate it? Earlier studies, conducted in the northern Negev desert, had shown that loess deposition on top of rocky surfaces resulted in a substantial decrease in runoff generation, coupled with rainwater absorption at a shallow depth by the loess mantle (Yair 1983, 1994). Furthermore, a laboratory experiment (Yair and Bryan 2000) showed that slight changes in surface properties may have a dramatic effect on the hydrological regime associated with sand or loess deposition. A sand layer 1–2 mm thick deposited on a fine-grained substratum is sufficient to eliminate surface runoff generation, whereas a fine-grained layer 1–2 mm thick deposited on sand has a reverse effect. Such results lead to the idea that, following a transition to a dry climatic phase, sand deposition may improve water availability because of deep infiltration of all rainwater, and because of good water preservation resulting from limited evaporation losses. A reverse situation may develop where loess is deposited when passing from a dry to a wet climatic phase. The loess mantle, characterized by a high water-absorption capacity, would be expected to limit the depth of rainwater penetration. Infiltrated waters would be completely lost via evaporation, leading to salt accumulation at a shallow depth and, with time, to soil salinization (Yair and Shachak 1987; Yair 1994).

Finally, the term resilience is often used to describe the degree to which an ecosystem can be disturbed or affected by climatic change, and yet revert to its initial composition and structure. A system disturbed beyond its level of resilience will develop into a new ecosystem. Such a dramatic change can be triggered by human activity. For example, the introduction of heavy grazing into a grassland area is often responsible for the replacement of grass cover by shrubland, with severe bush encroachment (Jeltsch et al. 1997). The same has been predicted for semi-arid areas, due to increasingly warmer and drier climatic conditions (Schlesinger et al. 1990). However, semi-arid and particularly arid ecosystems are regarded by some ecologists as being resistant to drought (Thiery 1982; Holling 1983; Wiens 1985). Perennial plants in these ecosystems are adapted to extreme variability in climatic conditions from year to year, and over a timescale of decades. Under such conditions, a rather extreme climatic change, mainly rainfall, would be required in order to seriously affect natural semi-arid and arid ecosystems.

The sandy area along the Israeli-Egyptian border offers quite unique conditions for the analysis of the possible effects of climatic change on a sandy arid ecosystem, characterized by semi-stable to stable dunes (Chap. 2, this volume). The whole area is composed of uniform quartzitic sand. However, the rainfall gradient is very sharp, passing from approx. 170 mm average annual rainfall in the north to approx. 90 mm in the south, over a distance of 35 km. The northern area is classified as arid and the southern area as hyper-arid (Chap. 6, this volume). In view of the specific sand properties introduced above (limited water absorption by sand grains, and high porosity), one would expect deeper water penetration and water preservation with increasing annual rainfall. Such a view would be in accordance with the prevailing idea regarding the positive relationship between average annual rainfall and environmental variables. This view may be valid in the case of unconsolidated sand but it is questionable for sandy areas stabilized by a thin topsoil crust rich in fine-grained particles and biological elements. Earlier studies conducted in the southern part of the area, within the Nizzana research site (Yair 1990, 2001; Kidron and Yair 1997) had already shown that the topsoil biological crust plays an important role in the local water regime, strongly affecting rainwater infiltration, runoff generation, and the spatial redistribution of water resources (Chaps. 6, 16 and 17, this volume). Field observations show a differential development of the topsoil crust from north to south along the rainfall gradient. The topsoil crust is thicker and darker in the northern than in the southern part of the sand field, pointing to differences in the composition and properties of the crust which may affect its hydrological behaviour and, consequently, the water regime along this rainfall gradient (Almog and Yair 2007). In addition, the area covered by the topsoil crust increases from south to north.

29.2 Aim of Study

Contrasting views exist on how topsoil biological crusts affect infiltration, runoff generation, and soil moisture regime. Some authors (Booth 1941; Loope and Gifford 1972; Perez 1997; Eldridge and Tozer 1997) contend that the cohesive and flexible biological elements of the crust absorb raindrop energy and prevent the development of a rain crust conducive to surface sealing and runoff generation. Such soil crusts would be expected to increase infiltration and soil moisture content. Other authors (Bond 1964; Avnimelech and Nevo 1964; Roberts and Carson 1971; Yair 1990; Dekker and Jungerius 1990) adopt a reverse view. They claim that water absorption, and the swelling of microorganisms and fine-grained elements forming the crust limit infiltration rate and, under suitable rainfall conditions, develop surface runoff, resulting in spatial differences in the soil water regime.

The major aim of this study is to check the validity of existing models regarding the positive correlation between annual rainfall and environmental variables in a sandy area with an extensive cover of a topsoil biological crust. The following aspects will be dealt with along the rainfall gradient described above:

1. Spatial distribution pattern of rain amounts at the annual and individual rainstorm scales.
2. Vegetation cover and plant species diversity in different habitat types along the gradient.
3. Spatial variability of topsoil crust cover and properties (Chaps. 10 and 11, this volume).
4. Spatial distribution of dead and living perennial shrubs.
5. Effects of topsoil crust properties on infiltration, runoff generation, and soil moisture regime (Chaps. 17, 18 and 20, this volume).

29.3 Methodology

The data collected cover the rainfall years 1998–2000 and 2001–2003. The study is based on five monitoring sites (Fig. 29.1). Sites N1, N3 and N5 were equipped with rain recorders, and sites N2 and N4 with rain gauges. Investigations of vegetation cover and species diversity were limited to sites N1, N3 and N5. Plots of 5–5 m were located along three parallel lines at sites covering the different ecotopes (Chap. 2, this volume) along a transect incorporating the following: the dune crest, north-facing dune slope, dune slope, dune base, interdune area and south-facing dune slope. In addition, a field survey of the cover of dead and living perennial shrubs was conducted along three transects (100×1 m) at sites 1, 3 and 5, following the approaches of Bauer (1943), Barour et al. (1987) and Kent and Coker (1992). The vegetation transects were located at the dune base where, for topographical and hydrological reasons, the density of the vegetation is highest in the area (Chap. 18, this volume). It is assumed that the survival and mortality of the perennial vegetation is a good indicator of the effect of water availability at the decadal timescale.

Runoff plots, located at the base of north-facing slopes and equipped with stage recorders and runoff and sediment collectors, were established at the five sites. Runoff plots had a uniform area of 8 m^2. Soil water content was measured after each rainstorm down to a depth of 80 cm. At each site, the topsoil crust (Chap.10, this

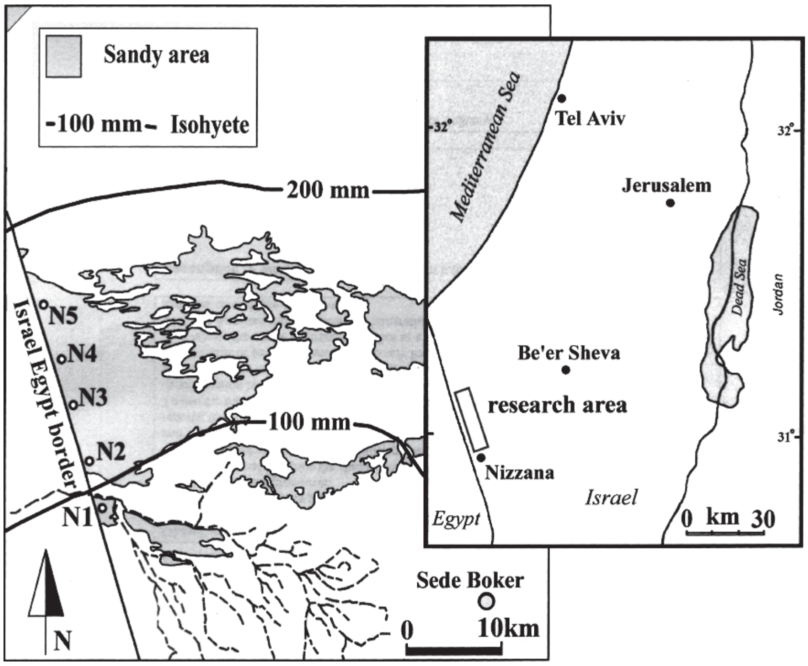

Fig. 29.1 Research area and location of monitoring sites

volume) was analyzed for its thickness, particle size distribution, organic matter content, and water-absorption capacity. Scanning electron microscope photographs provided an insight into the appearance of the biological crust elements.

29.4 Results

29.4.1 Rainfall

Annual rain amounts recorded during the monitoring period are presented in Table 29.1. During the 4 years of this study, annual rain amount was below the long-term average. However, it is interesting and important to note that the long-term trend of rainfall decrease from north (site N5) to south (site N1) is not evident in all years. Rain amounts followed the long-term trend in 1998–2000 and 2001–2002, but deviated from the long-term trend the year after. In 2002–2003, the southern site (N1) showed a rain amount slightly higher than the long-term average, while the northern site (N5) showed only half of the long-term average. This is due to the synoptic patterns prevailing in the eastern Mediterranean region (Chap. 4, this volume). Rainfall can penetrate the area from the northwest, northeast,

Table 29.1 Annual rain amounts along the climatic gradient

	Annual rainfall (mm)			
Site	1998–1999	1999–2000	2001–2002	2002–2003
N5	49.8	55.3	146.5	82.7
N3	30.3	53.1	76.2	95.1
N1	28.8	27	57.7	99.3

Table 29.2 Spatial distribution of selected rain events

Storm rain amount (mm)	N1	N3	N5
30 Nov. 2001	2	11.5	20.9
28–30 Jan. 2001	6.1	8.7	8.7
9–12 Dec. 2002	14.2	11.1	4.1
17–22 Dec. 2002	24.4	8.8	0

southwest and southeast. Furthermore, during many storms the rain-bearing clouds are limited in their dimensions, do not cover the whole north-western Negev dune field, and often split into localized, patchy and spotty rain cells. Table 29.2 displays some examples of the spatial rainfall pattern described above.

Needless to say, the non-uniform and non-systematic spatial distribution of rain amounts at the annual and rainstorm timescales must affect spatial vegetation patterns, without even considering the possible effects of the biological topsoil crust and other factors on spatial differences in water resources.

29.4.2 Vegetation Changes Along the Rainfall Gradient

Vegetation cover and plant species diversity were investigated in different habitat types. In total, 90 plant species (see list in Veste et al. 2005) were identified along the gradient within the study plots: 64% (57 species) are annuals and 36% (33 species) are perennials (Fig. 29.2; site N1, Chap. 7, this volume). No significant difference in the number of perennial species is observed in the area investigated (Fig. 29.2A). Plants occurring at all sites are *Artemisia monosperma, Asthenaterum forsskalii, Atractylis cuneata, Erodium crassifolium, Moltkiopsis ciliata, Retama raetam* and *Thymelaea hirsuta* (Veste et al. 2005). *Stipagrostis scoparia* and *Cornulaca monocantha* have their most extensive distribution at the most southern site, N1, where the area with mobile sand is relatively extensive. When annual plants, highly sensitive to annual rainfall amount and timing of rainfall, are considered, the highest number of species is found in the central site N3, the lowest at the wetter northern site N5 (Fig. 29.2A). The lowest mean vegetation cover of perennials is found at the southern site N1. A sharp increase is observed at site N3, with no difference between latter site and site N5 (Fig. 29.2B). When annual plants are considered, there is no difference between sites N1 and N3, but the mean cover of annuals is slightly higher at site N5.

Figure 29.3 displays the percentage cover of perennial shrubs in the four major ecotopes, namely the crests, interdunes, and the north- and south-facing slopes. Apart from the crest, where the percentage cover increases from site N1 to site N5 with increasing annual rainfall, no clear systematic trends can be detected along the rainfall gradient for any of the other ecotopes. However, increasing surface stability from south to north

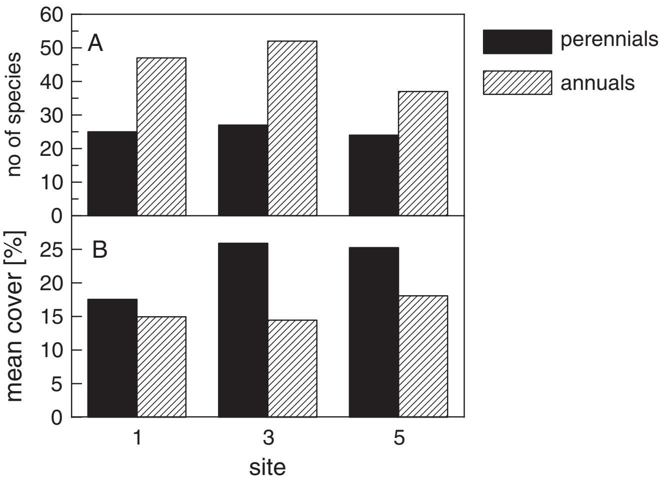

Fig. 29.2 Species diversity (**A**) and mean vegetation cover (**B**) along the rainfall gradient

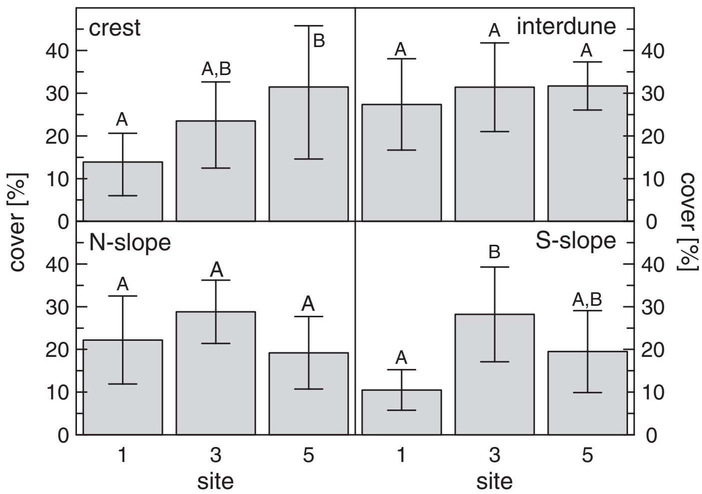

Fig. 29.3 Vegetation cover at the major geo-ecological units

enables more perennial plants to establish on the dune crests. The highest cover (27–32%) is found in the interdune corridors, with no significant differences along the gradient. Of special interest is the fact that, at site N5, no difference exists between the crest and the interdune area. At this site, almost the whole dune from top to bottom is stabilized and covered by the topsoil crust. Site N3 has a similar, quite high cover on both the north- and south-facing slopes. The percent cover of north-facing slopes is slightly higher at the southern site N1 than at the northern site N5. This trend is, however, reversed for south-facing slopes at sites N1 and N5.

Figure 29.4 displays the percent cover of the topsoil crust along the gradient. An increase in percent cover is observed from south to north for the crests of the dunes (Chap. 10, this volume). Crust cover in the interdune corridors is quite uniform throughout the area, with a very slight increase from site N1 to site N5 (from 93 to 97%). Crust cover increase from south to north is not gradual. It is approximately 50% at site N1, 90% at site N3 and 93% at site N5.

Figure 29.5 presents the percentage of living and dead perennial shrubs at the dune base at sites N1, N3 and N5. The data obtained clearly show a linear increase in the percentage of dead shrubs with increasing average annual rainfall. A reverse trend is observed for the living shrubs. Such a pattern is indicative of the negative long-term trend in water availability with increasing annual rainfall (Chap. 19, this volume).

29.4.3 Hydrological Aspects

Table 29.3 presents the data on rainfall–runoff relationships for sites N1, N3 and N5 during the years 2001–2003. As could be expected, due to the fluctuations in rainfall, the trends in the spatial distribution of annual rainfall are not similar for the 2 years.

However, a clear trend appears in both years for runoff generation. The runoff volumes collected decrease with increasing annual rainfall. In 2001–2002, rainfall

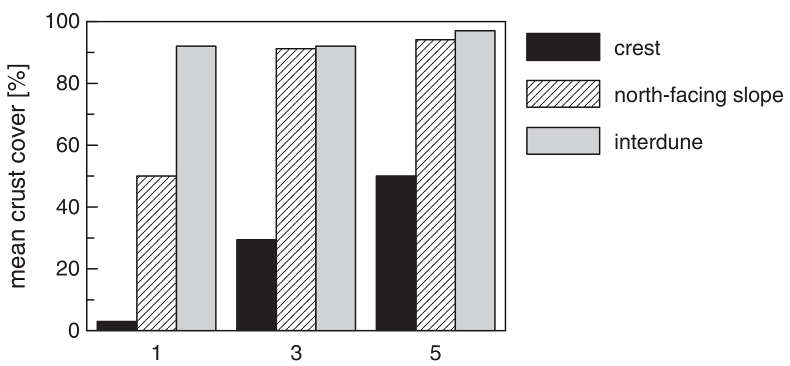

Fig. 29.4 Mean topsoil crust cover along the rainfall gradient

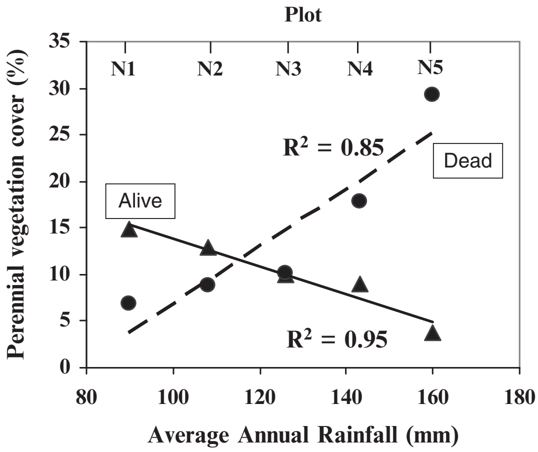

Fig. 29.5 Dead and living perennial vegetation along the rainfall gradient (March 2002)

Table 29.3 Rainfall–runoff relationships (2001–2003)

Rainfall year	Plot	Annual rainfall (mm)	Annual runoff (l)
2001–2002	N5	146.5	4.4
	N3	76.2	7.5
	N1	57.7	14.4
2002–2003	N5	82.7	1
	N3	95.1	8.5
	N1	99.3	28.8

at the northern site N5 was three times higher that at the southern site N1. However, the runoff volumes collected at site N1 were 3.7 times higher than those at site N5. The year after, annual rain amounts were quite uniform all over the area, yet the ratio of runoff to rainfall for plots N1/N5 is almost 30 times higher. The runoff data obtained are supported by data collected during sprinkling experiments conducted in the area. Under wet surface conditions, the rain threshold required for runoff generation was 10–12 mm h^{-1} at plot N1, 19–22 mm h^{-1} at plot N3, and above 40 mm h^{-1} at plot N5. These findings may be indicative of two opposing processes: (1) an increase in infiltration and deep rainwater penetration with increasing rainfall, or (2) high water absorption by the topsoil crust with increasing annual rainfall, which limits infiltration depth.

In the case of high infiltration rate with increasing annual rainfall, one would have expected an increase in infiltration depth, particularly for the wet, first rainy season. However, the data presented in Fig. 29.6 show a reverse trend for both years. In the first rainy season, despite the differences in rainfall and runoff, depth of water percolation is negatively correlated with annual rainfall. Water percolation reached 50 cm at site N1, 30 cm at site N3 and only 15 cm at site N5. Soil moisture

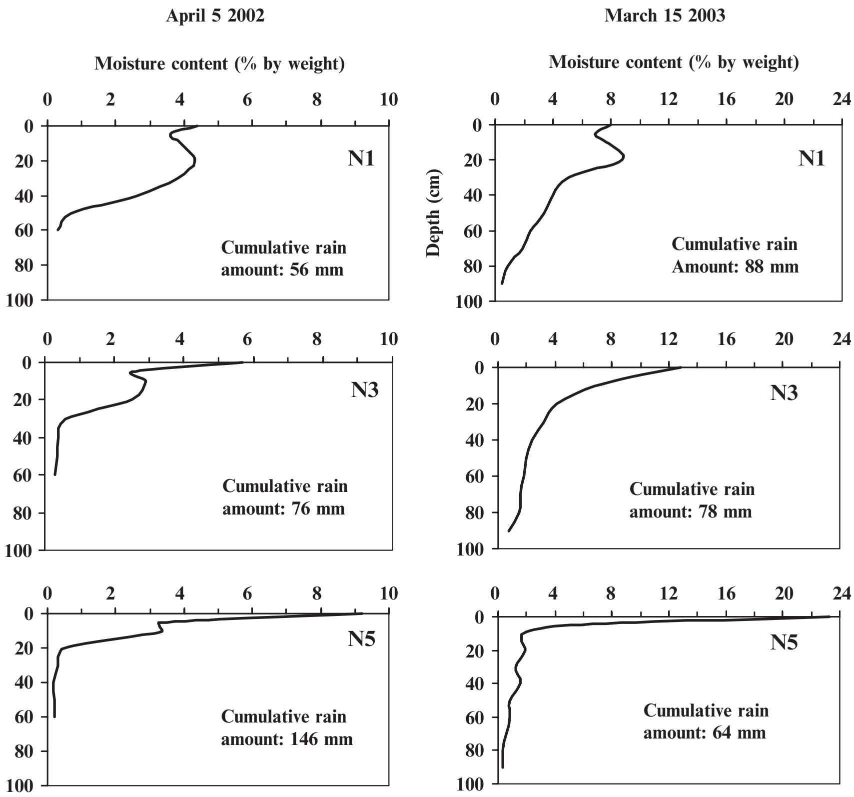

Fig. 29.6 Soil moisture profiles along the rainfall gradient (two rain events at three sites, 2002–2003)

graphs show an additional interesting fact. Water absorption by the topsoil crust is always highest at site N5, and decreases southwards along the rainfall gradient.

The runoff and moisture data obtained draw attention to the important role that should be attributed to differences in surface properties along the rainfall gradient considered. A gradual change in the properties of the topsoil crust is observed, for all variables, along the rainfall gradient (Table 29.4). Crust thickness (Figs. 29.7 and 29.8), organic matter content, and percent of silt and clay increase with increasing annual rainfall. Such trends explain the significant increase in the field capacity of the crusts from the southern drier to the northern wetter area. An additional factor contributing to the increase in water absorption by the topsoil crust with increasing rainfall is related to the composition of the biological elements of the crust (Fig. 29.8). The biological crust in the climatologically drier area is composed of a thin microbial film, with a dominance of cyanobacteria, and many voids between the sand grains (Chap. 20, this volume). The crust in the northern wetter area is quite different. It is very rich in large mosses known for their high water-absorption capacity (Kidron 1995).

Table 29.4 Properties of the topsoil crust along the rainfall gradient (average of 20 samples)

Site location	Silt and clay content (%)	Organic matter content (%)	Crust thickness (mm)	Field capacity (% by weight)
N5	49.2	11.2	7.6	19.5
N3	37.8	7.1	4.2	11.9
N1	27.7	5.3	2.7	6.1

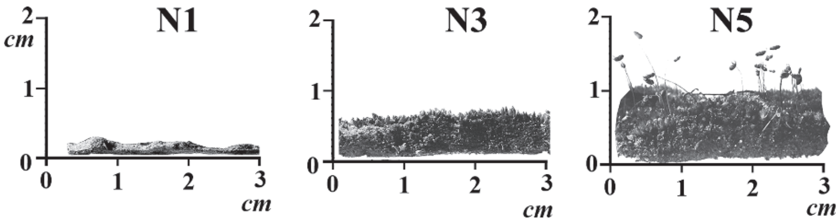

Fig. 29.7 Topsoil crust thickness along the rainfall gradient, sites N1, N3 and N5

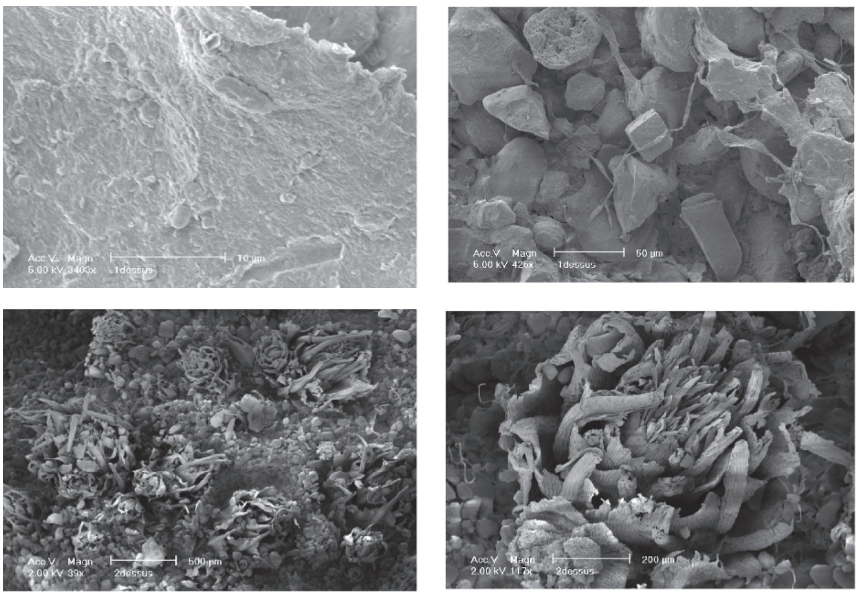

Fig. 29.8 ESEM images of the crust. *Top* Topsoil crust at the southern plot (N1). Thin and compacted sheet of biological elements (*left*), with many voids between the sand grains (*right*). *Bottom* Topsoil crust at the northern plot (N5). High concentration of large mosses acting as a sponge (*left*) and close-up view of one of the mosses (*right*)

29.5 Discussion

The data presented above clearly demonstrate the complex relationships among average annual rainfall and environmental variables. Despite the fact that the sandy substratum is uniform all over the area, spatial variability along the rainfall gradient is not gradual and not systematic. Some aspects show a positive relationship with annual rainfall, while others show no clear relationship or even a negative relationship. The difference in long-term average annual rainfall from north to south resulted in a differential development of the topsoil crust. The crust is better developed and more extensive in the wetter area where it is thicker, and richer in organic matter, fine-grained particles and mosses than is the case for the southern topsoil crust (Table 29.4 and Fig. 29.8). This may be regarded as a positive environmental effect of rainfall increase. However, the better developed topsoil crust plays a negative role when the higher vegetation is considered. The crust in the wetter area (site N5) is able to absorb all rainfall during most rainstorms, strongly limiting the depth of rainwater penetration, subsurface flow water movement, surface runoff generation and, consequently, water availability for perennial shrubs (Fig. 29.6). At the same time, the thin crust in the drier area (site N1) absorbs less water, allows deeper water penetration and surface runoff generation during some of the rainstorms. Runoff generated over the crust infiltrates at the dune base. The overall result is deeper water penetration and higher water availability for vegetation in the crusted area. Water availability at the dune base, and at local concavities, is further enhanced by the process of subsurface flow.

The processes described above explain why the survival of perennial plants is lower in the wetter than in the drier area (Fig. 29.5). Nevertheless, in this case the non-uniform spatial distribution of rainfall at the annual and rainstorm timescales also plays an important role. The quite uniform species diversity at the regional scale may be regarded as indicative of a low sensitivity of the perennial vegetation of the sandy area to climate change along the rainfall gradient considered (90–170 mm). The three aspects discussed above show different trends at the regional scale. Topsoil crust properties change positively with increasing rainfall; water availability, biomass (Chap. 25, this volume) and survival of the perennial vegetation show a negative correlation with average annual rainfall; species diversity and number of species show no correlation with increasing rain.

A similar complexity is observed at the smaller, local scale of representative eco-geomorphic units within the dune system (Fig. 29.3). Vegetation cover increases with increasing annual rainfall for the crest of dunes, is quite uniform for the interdune corridors, but irregular and non-systematic for north- and south-facing slopes. Different factors may explain these results. The quite uniform cover in the interdune corridors may be explained by a combination of two factors: (1) these represent the most stable environment in the whole area; (2) the increase in water absorption by the topsoil crust with increasing annual rainfall eliminates the expected positive effect of rainfall increase. Surface runoff and subsurface flow are not regarded as important factors in the soil moisture regime of interdune areas. The positive relationship between vegetation cover and annual rainfall for the dune crests may be explained by the surface stability factor. Surface stability enhances the extent of vegetation and topsoil crust covers. However, surface stability is highly dependant on wind speed. A positive relationship exists between the relative elevation of dunes and wind speed, leading to decreased stability of elevated dunes and increased stability of low dunes. As the relative elevation of the sandy ridges is higher in the southern than in the northern part of the area, surface stability increases with increasing rainfall (Fig. 29.4), resulting in a more extensive vegetation cover on dune crests from south to north.

The role of surface runoff and subsurface flow is evident for north-facing slopes. Water concentration by these two processes at the dune base is considered responsible for the dense vegetation belt observed at the base of north-facing slopes at site N1, where runoff frequency and magnitude are highest (Table 29.3). This high density explains the higher vegetation cover observed at the southern and drier site N1, contrasting with the northern wetter site N5 where runoff frequency and magnitude are extremely low. A reverse trend is observed at sites N1 and N5 for the south-facing slopes. This result may be explained by the combination of the limited frequency and magnitude of runoff generation at site N1 (Chap. 17, this volume), and the more extensive topsoil crust cover and surface stability at site N5. In view of the arguments presented above, it appears that the central site N3, where many of the characteristics are less extreme than at sites N1 and N5, on the whole enjoys the best water regime prevailing along the rainfall gradient considered (Figs. 29.2, 29.3 and 29.4).

29.6 Implications for the Sensitivity of the Sandy Area to Changing Climatic Conditions

The results obtained cast doubt on the generality of the prevailing assumption that an increase in average annual rainfall, especially in semi-arid areas usually regarded as highly sensitive to climate change, should always have a positive effect on the ecosystem. For some aspects, the relationship with annual rainfall is positive and, for others, negative or inexistent. Quite often, a single factor has a strong and determinant influence on the outcome. For example, a thick topsoil crust, able to absorb all rainwater during most rainstorms, seriously limits infiltration depth and water availability for the perennial vegetation, and counteracts the expected positive effect of a relatively high annual rain amount. On the other hand, the high frequency and magnitude of surface runoff in the drier part of the area has a positive effect on water resources via the process of water concentration (Chaps. 24, 25, 27 and 28, this volume).

The data presented above bear some importance in view of the expected climate change related to global warming. In terms of the response of the sandy area considered to the foreseen increase in aridity, any attempt to project the results of the present study at a larger scale needs to consider changes and effects in both rainfall and wind regimes. The following scenarios may be advanced.

- Along the gradient considered, a decrease in the average annual rain amount may have negative effects in the southern part of the area (site N1), due mainly to a decrease in the frequency and magnitude of runoff events responsible for the creation of "wet belts" at the base of the sandy ridges and at local concavities. In addition, it is quite possible that the spatial extent of the topsoil crust will decrease, further limiting runoff frequency and magnitude, while increasing the extent of the area with mobile sand. This scenario may be regarded as a desertification process due to rainfall decrease. Desertification will be greatly enhanced if, parallel to the reduced rainfall, wind velocities increase. Such a combination would be expected to increase the extent of the unstable and mobile sand surfaces. The scenario presented above is consistent with prevailing views on the positive relationship between average annual rainfall and environmental variables.
- A reverse situation – improvement of the water regime – may develop in the northern wetter part of the study area (site N5). A decrease in rain amount may lead to a change in the composition of the topsoil crust (Chaps. 10 and 13, this volume). Under drier conditions, the composition of the topsoil crust will change. Mosses, dominant under present-day conditions at site N5, may be replaced by a crust rich in cyanobacteria, fungi and lichens, similar to the crust prevailing, at present, in the southern area. Under such conditions, the frequency and magnitude of runoff and of subsurface flow will increase, leading to a positive effect of water concentration. The overall result may be regarded as a positive effect despite the transition to a drier climatic phase. However, in the case of an increase in the frequency of strong winds, one would expect an increase in surface instability which would, nevertheless, be limited to the dune crests. A positive aspect of this scenario is that, due to the spatial shift in topsoil crust types, and of their effects on the water regime, a transition into a drier phase may not result in a reduction in species diversity for the sandy area as a whole. Species found today in the south would be sustained in the north.

29.7 Conclusions

The scenarios described above lead to the conclusion that any climatic change in the area will not be limited to purely climatic variables such as rainfall or wind regimes. It will be accompanied by a parallel change in surface properties, including changes in the extent of the topsoil biological crust, the composition and properties of the topsoil crust, and the extent of bare sand surfaces. These would be expected to have positive or negative effects in different sectors along the rainfall gradient considered, as well as within each of the sectors. Moreover, this would be expected to change the effects of perennials and shrubs on other life forms (Chaps. 27 and 28, this volume).

Finally, the conclusions derived from the present study should not automatically be extrapolated to all other sandy arid areas. For the time being, this should be limited to sandy areas with similar conditions, namely a winter rain climate and an extensive occurrence of topsoil biological crusts indicative of stable surface conditions. The results obtained may not be applicable to sandy areas with strong winds or high-intensity summer rainstorms which prevent or limit the development of biological topsoil crusts.

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