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Cover photograph: Giraffes on the game farm Omatako Ranch (Observatory S04 Toggekry) in the Namibian Thornbush Savanna.
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Soils along the BIOTA transects

Andreas Petersen, Alexander Gröngröft*, Anthony Mills & Günter Miehlich

Summary: Soil analytical and taxonomic data of 27 Observatories, being distributed along the BIOTA transects from Northern Namibia to the Cape Peninsula and produced with a standardised procedure for each site have been evaluated with respect to overarching factors for the soil genesis and pedodiversity. Of twelve soil reference groups found, Arenosols and Leptosols were dominant. Significant trends between topsoil median values (pH, electric conductivity, organic carbon content) and annual precipitation could be described; nevertheless for all distributions some Observatories exhibit special conditions. For both rainfall regimes (summer and winter rainfall) the total organic carbon stored within the soil profiles seems to have the same positive correlation to annual rainfall, however for identical rainfall amounts the carbon pools are varying by a factor of three, among other factors controlled by soil clay content. The pedodiversity of the studied sites varies strongly (2–20 types of 25 possible). In general, soilscapes predominantly build up by aeolian sands are mostly homogenous whereas soils in mountainous areas exhibit the highest richness. Plains and salt enriched areas are of medium pedodiversity.

Introduction

The description of the Observatories in Part II has offered a detailed insight into the individual areas including their soil communities and soil properties. Each of the observatories exhibits special features and thus by focusing on individual sites it is not evident whether there are overarching relationships between the areas or along the transects. With regard to the factors relevant for soil genesis (see concept of Jenny 1941), the differences between the studied areas may result i) from the climate gradient, ii) from the parent material or iii) from the type and intensity of landuse. With the exception of the southernmost observatories all sites can be classified as semiarid to arid, but with differing rainfall regimes, some sites have developed on aeolian sands and many on weathered acid rocks, and most sites are used as more or less intensively grazed rangelands.

This chapter summarises the results of the soil classification as well as the pedodiversity and the parametric behaviour of selected soil properties by focussing on the overall pattern of soil units and selected soil properties. This enables both an overview of the predominant soil units and a comparison of the variability of soil properties along the transects. The soil properties can be used to analyse patterns of plant species richness along the transects, as has already been done by Medinski et al. (2010) for selected soil features and Petersen et al. (2010) for pedodiversity in general.

Methods

As described in Part II, soils on the BIOTA Observatories were investigated with a standardised procedure. The general characteristics of the methodological approach were: site selection by a stratified random procedure, soil description and classification acc. to FAO (2006a, b), profiles at 4 m south of ha-centre points, sampling of all horizons, laboratory analyses of numerous soil variables (details are given in Jürgens et al., submitted, and Petersen 2008). Here, the data of 27 Observatories were included (Fig. 1), normally investigated with 25 profiles each. For the balancing of soil contents across the profile depth, the analysed concentrations of each horizon (weight %) were multiplied by the thickness, the bulk density and the volumetric share of the fine earth (100% minus percentage of rock fragments). The total soil content was the sum of all horizons. The taxonomic pedodiversity was determined according to Petersen et al. (2010).

Results and discussion

Soil distribution and properties

Fig. 2 exhibits the frequency distribution of the soil reference groups—the highest level of classification—summed up for the transects. The great variety is highlighted by the occurrence of 12 out of 32 reference groups possible in the worldwide valid system. With regard to their distribution, two groups can be distinguished: i) Arenosols, Leptosols, Regosols, Cambisols, Calcisols, and Solonshaks, recorded with 49–122 cases each and being widely distributed, at least on eight observatories each, and ii) the group of Solonetz, Durisols, Luvisols, Podzols, Fluvisol, and Gypsisols recorded with only 2–39 cases each on one to five observatories. Due to the subjective selection of observatories and resulting substrate dominances, this overview cannot provide a representative pattern of the occurrence of reference groups in the entire study area, but will summarise the results for the transects. Calcisols for instance show a relatively high abundance, which is most likely due to the regional setup of the observatories Narais (S39) and Duruchaus (S40) in a calcrete-dominated landscape, while on the remainder of the transects Calcisols occur only sparsely. Also, the relatively high number of sites with aeolian sand deposition (5) in the observatories favours the dominance of Arenosols. Leptosols are the most commonly distributed across the

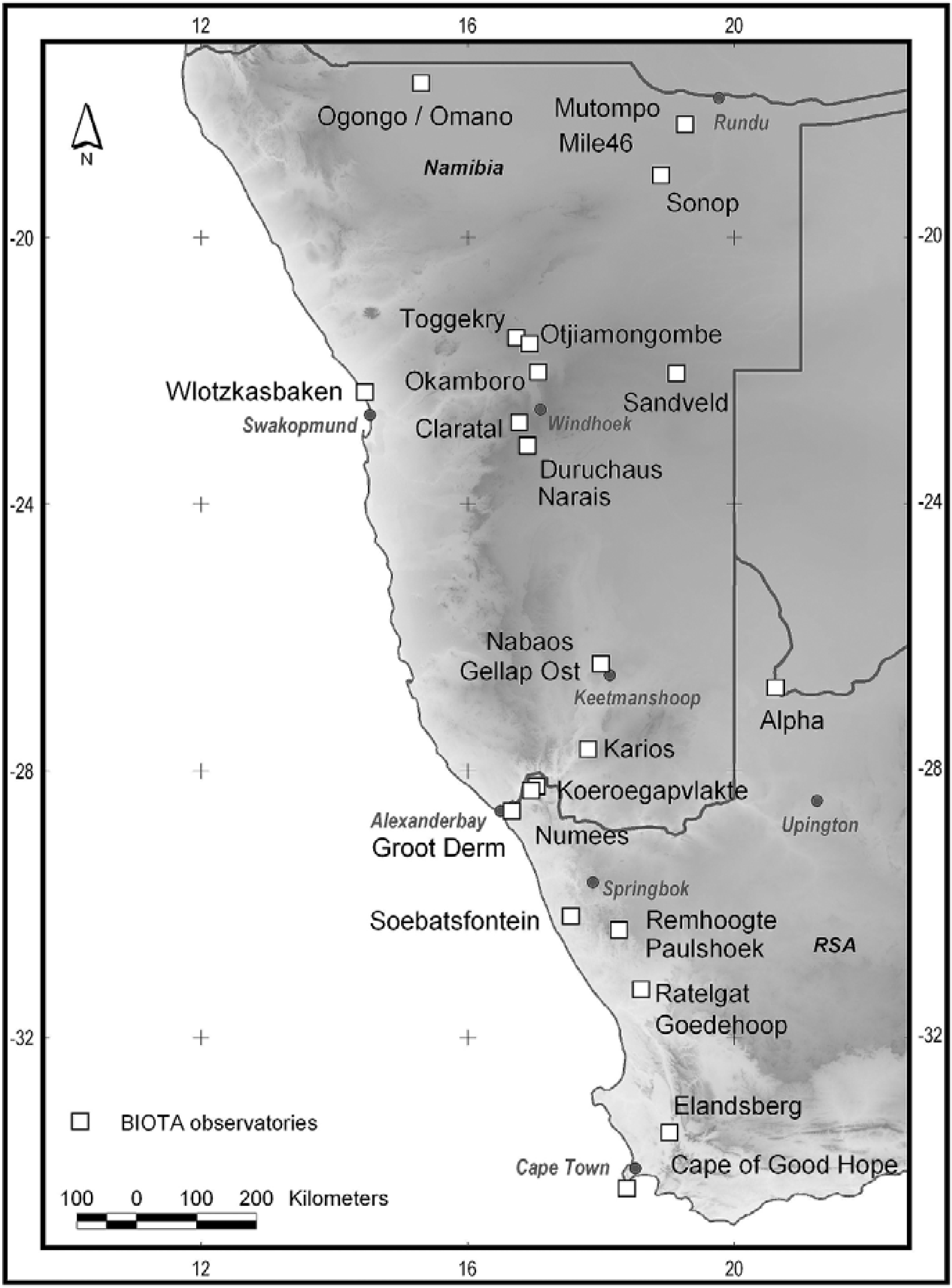

Fig. 1: Map of the Observatories included in the study.

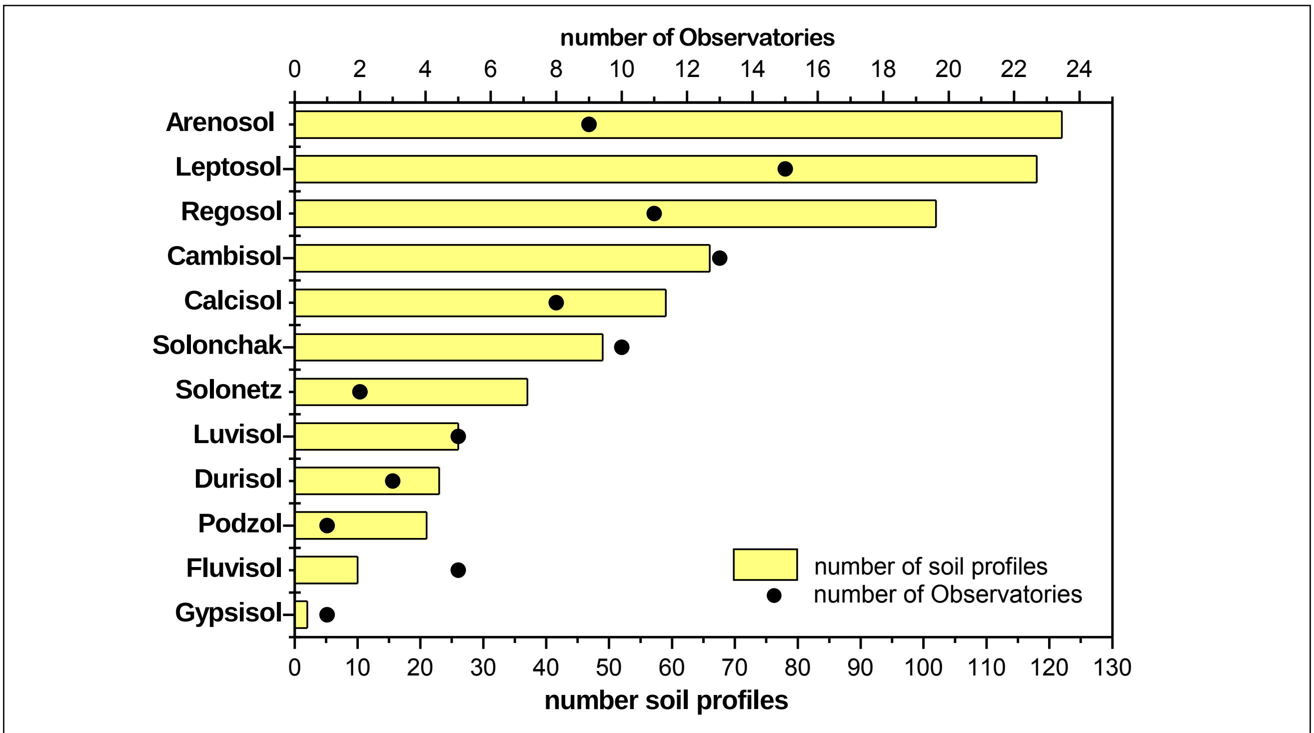

Fig. 2: Frequency distribution of soil types (WRB 2006) in all studied observatories.

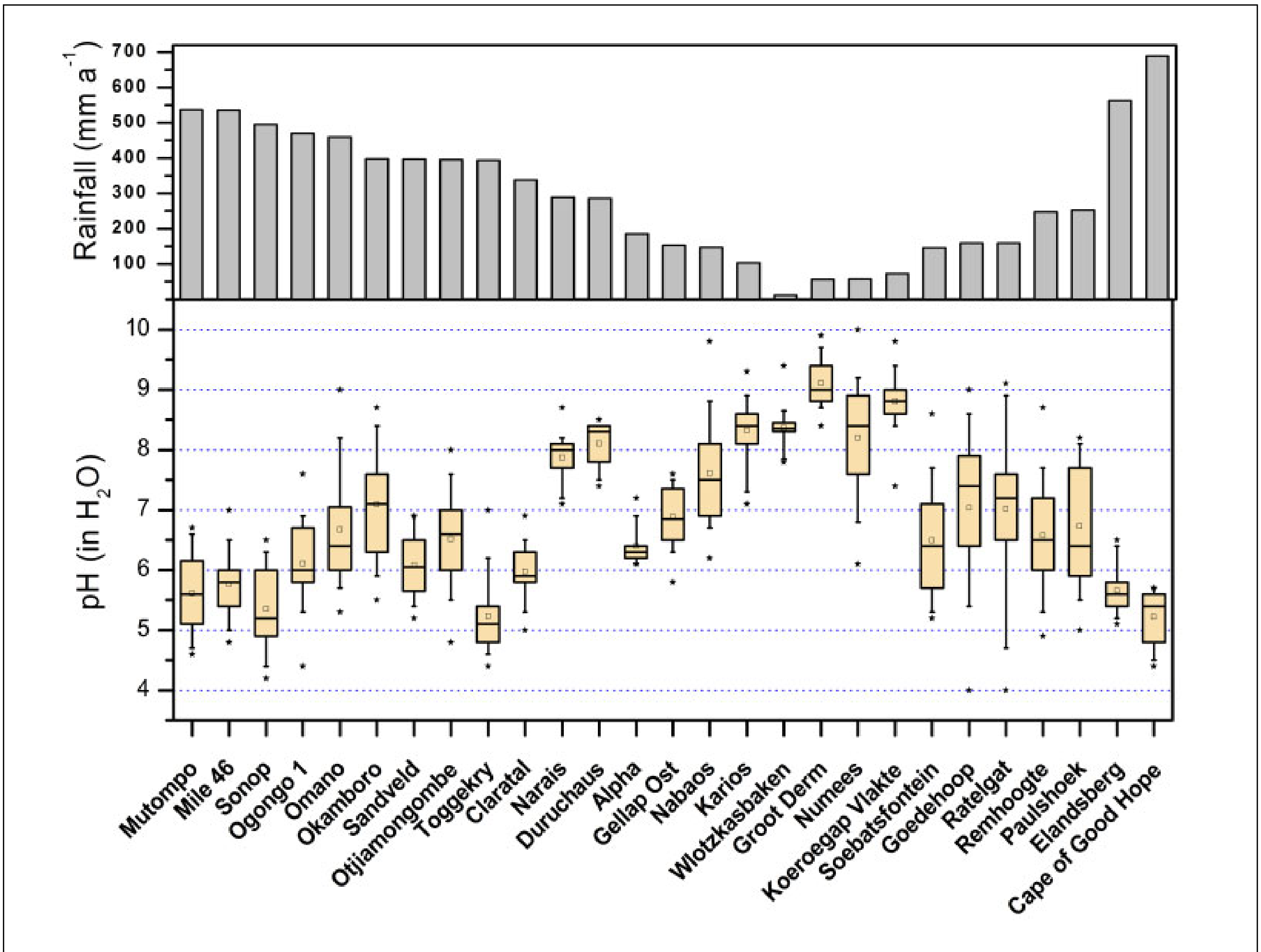

Fig. 3 : Distribution of topsoil pH along the rainfall gradient.

observatories, achieving a high frequency due to a large number (7) of observatories located in mountainous regions of the escarpment, especially in South Africa. A few reference groups occur exclusively in individual observatories such as Solonetz, typical for the Oshana region, Gypsisols, which are prominent in the coastal desert, and Podzols occurring on the Cape Peninsula. These examples illustrate that regional aspects strongly affect the depicted frequency distribution of soil groups.

Examples of range and variability of selected topsoil properties along the transects are shown in Fig. 3, 5, and 7. Within these graphs, all Observatories were arranged along the natural rainfall gradient—decreasing summer and increasing winter rainfall—with sites from the main transect being integrated climatically and not by latitudes. The most evident trend is shown with the pH-value (Fig. 3) and the amount of soluble salts (Electric conductivity value, see Fig. 5). The pH-values exhibit a reciprocal trend compared to the mean annual rainfall. The highest pH-values are found in the arid border zone between summer and winter rainfall and the costal desert on site S16 Wlotzkasbaken (Fig. 4). The within-site variability is largest in the central Namibian savanna and the winter rainfall dominated Namaqualand in South Africa. Here on the Observatories Soebatsfontein (S22) to Paulshoek (S24), significantly wide ranges of pH-values are related to small scale patterns of salt accumulation. Additionally sampled small-scale transects revealed that on these Observatories the higher pH-values are restricted to areas of former termite nests ("Heuweltjies", see Chapter IV.4), which are characterised by higher concentrations of calcium carbonate than the adjacent soils.

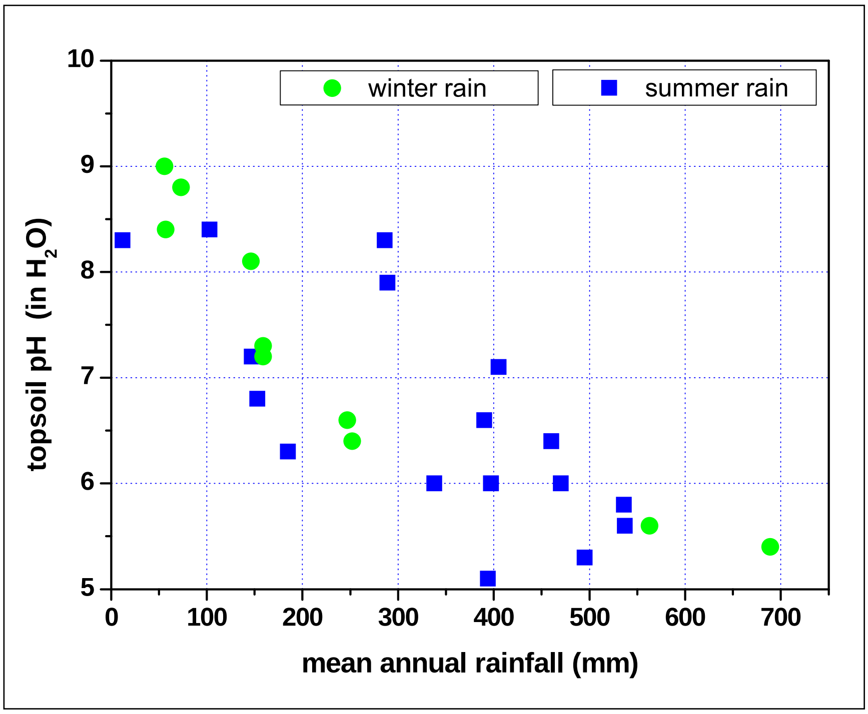

Fig. 4 : Median topsoil pH in relation to mean annual rainfall.

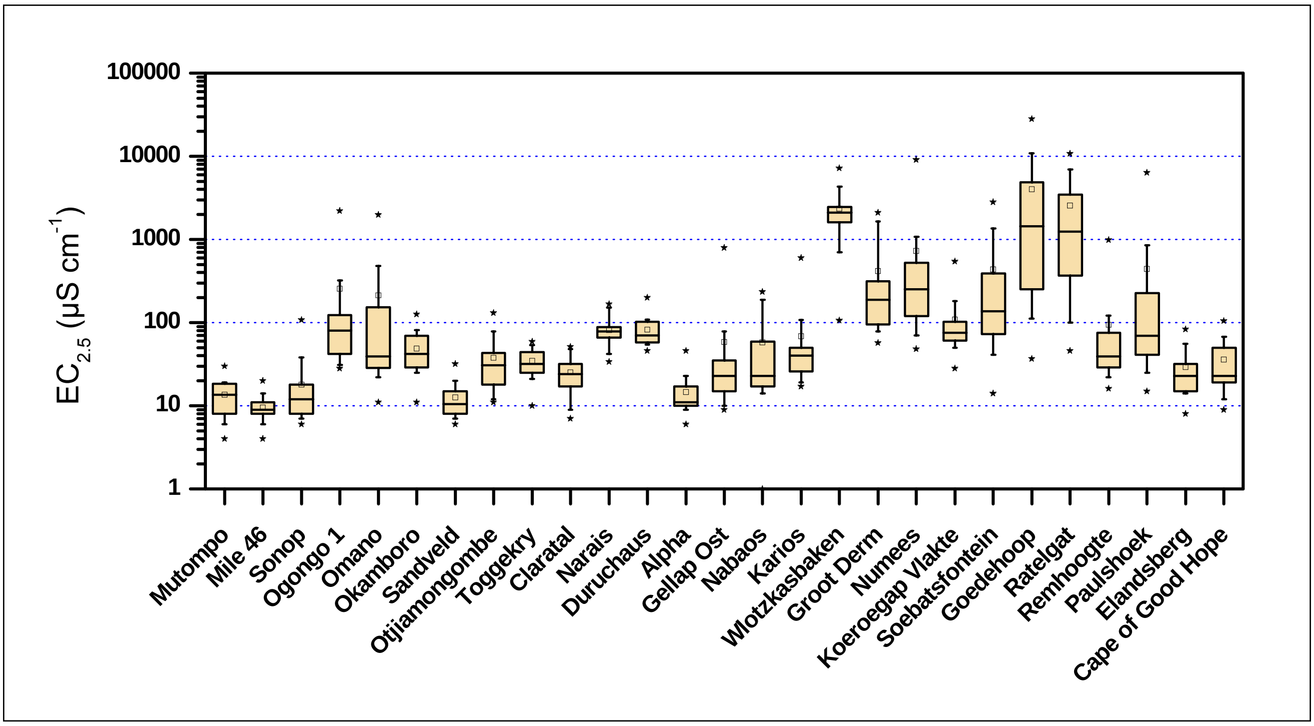

Fig. 5 : Distribution of topsoil electric conductivity (EC) along the rainfall gradient. Rainfall gradient see Fig. 3.

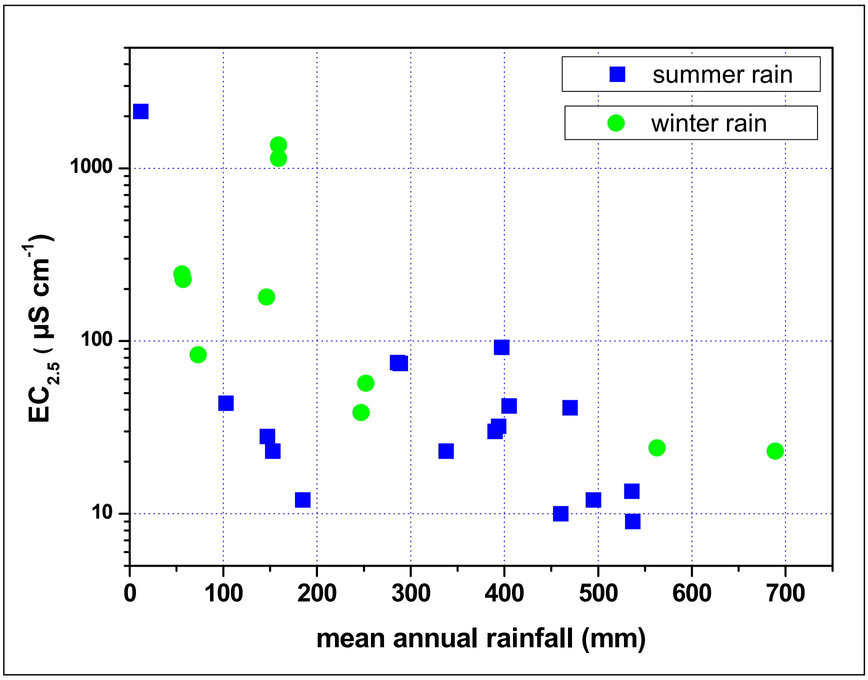

Fig. 6 : Median topsoil electric conductivity (EC) in relation to mean annual rainfall.

The alkalisation of soils is related to the accumulation of strong cations (i.e. sodium) in combination with the loss of strong anions (i.e. chloride and sulphate). The dominance of $NaHCO_3$ and Na_2CO_3 leads to pH-values of 8.3 to 11 (Thomas 1996). The potential to accumulate cations in the soils is correlated to the rainfall for example, the winter rain events in Namaqualand tend to be of low intensity and thus are unable to effectively leach ions.

The trend of electrical conductivity values along the transects is less closely related to the amount of rainfall as is the case for the pH-value (Fig. 6). The electric conductivity shows low values and small ranges in the summer rainfall affected sites and the widest range and highest values in the drier parts of the winter rainfall area. Besides other salt accumulation affecting parameters such as coastal distance, location in an evaporative landscape with water run-on (Oshana region: Observatories S42 Ogongo and S43 Omano), soil texture, clay dispersibility (Mills et al. 2006) etc., here the rainfall regime rather than the rainfall amount seems to have an impact on salt accumulation. Compared to sites with the same amount of rainfall but higher intensities of rainfall events, drainage of accumulated soluble substances is probably reduced by low intensity rainfalls and less drainage. This difference is especially obvious within the annual rainfall amount of 100–200 mm. Additionally, the accumulative effects of ancient termite activity led to patches with higher concentrations of in salts. The results of the electric conductivity values lead to the hypothesis that in the summer rainfall driven ecosystems drainage occurs regularly, although these might occur only every few decades within the drier regions. The fact that very low electrical conductivity values are evident in soils up to a depth of 1 m provides the basis for this hypothesis, which implies drainage over at least 1 m depth. Otherwise, the accumulation of salts, at least of chloride from atmospheric deposition, would exceed the analysed values. These findings are supported by the fact that in the sampled soils often marginal differences in texture go along with differences in electric conductivity values, i.e. higher electric conductivity values in loamier soils of Observatory Otjiamongombe. This also underlines the described drainage effect, which is stronger on sandier soils.

For most dryland areas, the amount of soil organic carbon (SOC) in the topmost soil layer is very low (0.1–0.4%). Fig. 7 shows an overarching decreasing trend running from the higher summer rainfall areas in the north to the arid areas in Southern Namibia. With the transition to the winter rainfall area, the SOC increases again and remains relatively stable with a median of 0.6–0.8% with ranges indicating a high variety of microhabitat conditions. Three exceptions exist in the overall trend: i) higher concentrations of SOC (median 1.08%) on site S38 Claratal, here associated with high altitude (about 2000 m), strong erosive processes and shallow profiles, ii) elevated SOC values on the sites S39 Narais and S40 Duruchaus (0.58, 0.80%), which are combined with very stable conditions of high pH-values in a calcium carbonate rich environment, a situation favouring the persistence and sequestration of organic carbon, and iii) an intensive accumulation of SOC median (2.63%) in a strongly acid nutrient poor and water logging environment on the Cape Peninsula, a situation, which hinders the decomposition of organic carbon. In contrast to the demonstration of SOC in the first horizon, Fig. 8 shows the total amount of SOC in the profiles. The results are substantially different to just the concentration of topsoil SOC, because the profile thickness and their contents of coarse fragments in these areas vary significantly.

The general correlation of SOC to mean annual precipitation is obvious (Fig. 9). Here, both rainfall regimes seem to overlap. The high topsoil SOC values reported for site Claratal above is unremarkable with regard to the total SOC storage, because the low soil depth and the high contents of coarse fragments reduce the storage potential. Irrespective of the overall regression, there are variances of SOC storage with the same rainfall amount of about a factor of three. The sites S06 Okamboro and S05 Otjiamongombe for instance, just 48 km apart and with the same rainfall of nearly 400 mm a^{-1} are quite different in total carbon storage with median values of 1.4 and 4.1 kg SOC m^{-2}, respectively. This example shows, that even a correlation with an aridity index (see Jenny 1941, Donkin & Fey 1993), which generally seems to be a more appropriate

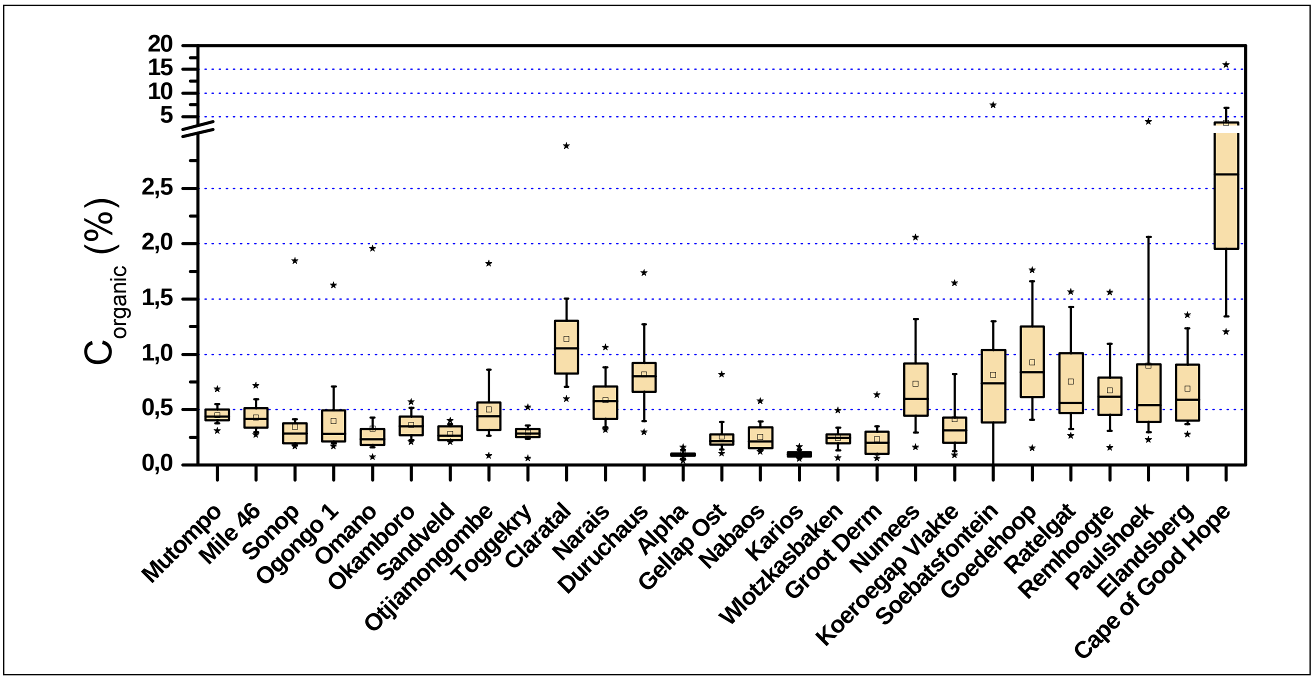

Fig. 7 : Distribution of topsoil soil organic carbon (SOC) along the rainfall gradient. Rainfall gradient see Fig. 3.

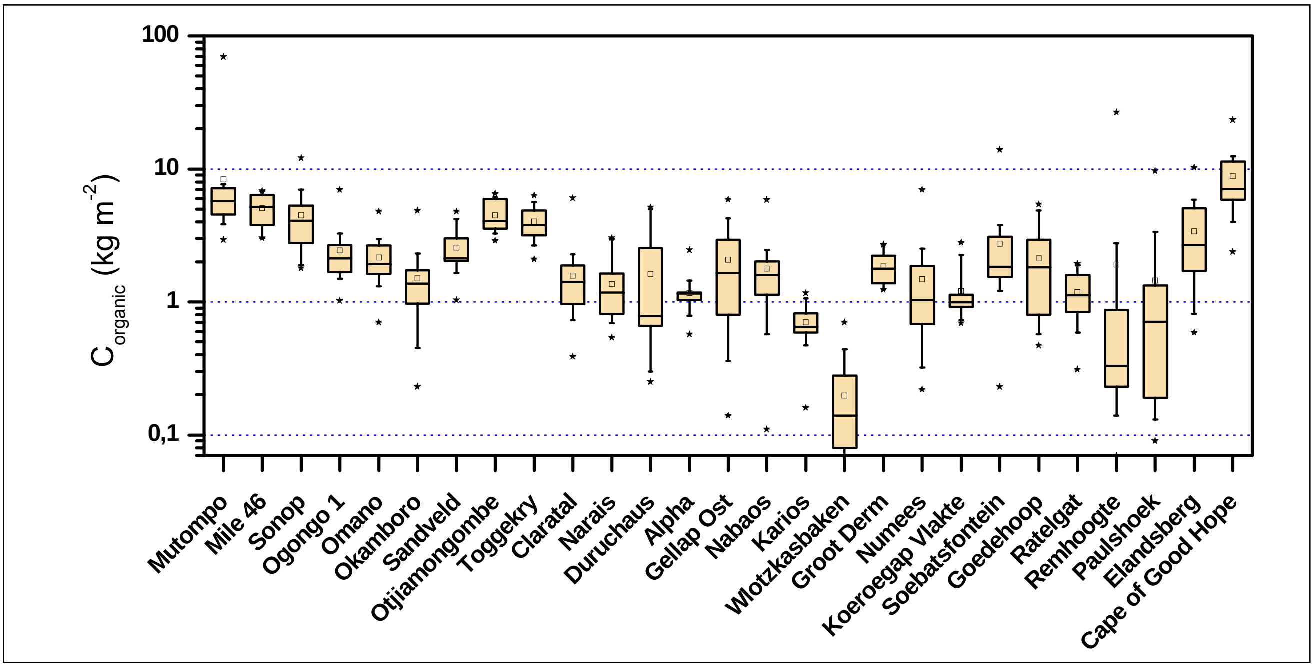

Fig. 8 : Distribution of total soil organic carbon (SOC) along the rainfall gradient. Rainfall gradient see Fig. 3.

variable to describe the complex climatic influence, will result in some variation of SOC storage with identical external impacts. One factor controlling the total SOC is the amount of clay in the soils, which is known to stabilise the organic fractions (Oades 1988) and is about four times larger on the Otjiamongombe site compared to Okamboro.

Pedodiversity

According to McBratney (1992) pedodiversity is "the variation of soil properties or soil classes within an area". After the introduction of the term in the early 1990s, the concept of pedodiversity has been applied with varying meanings and aims. However, since the early approaches by Ibanez et al. (1990) until today (see literature overview in Petersen 2008) no consistent approach to compare the pedodiversity of small-sized areas on the basis of detailed and standardised soil profile descriptions and analyses has been published yet.

Fig. 10 depicts the taxonomic richness (R) and the Shannon evenness (E) based on the classification of soil profiles with

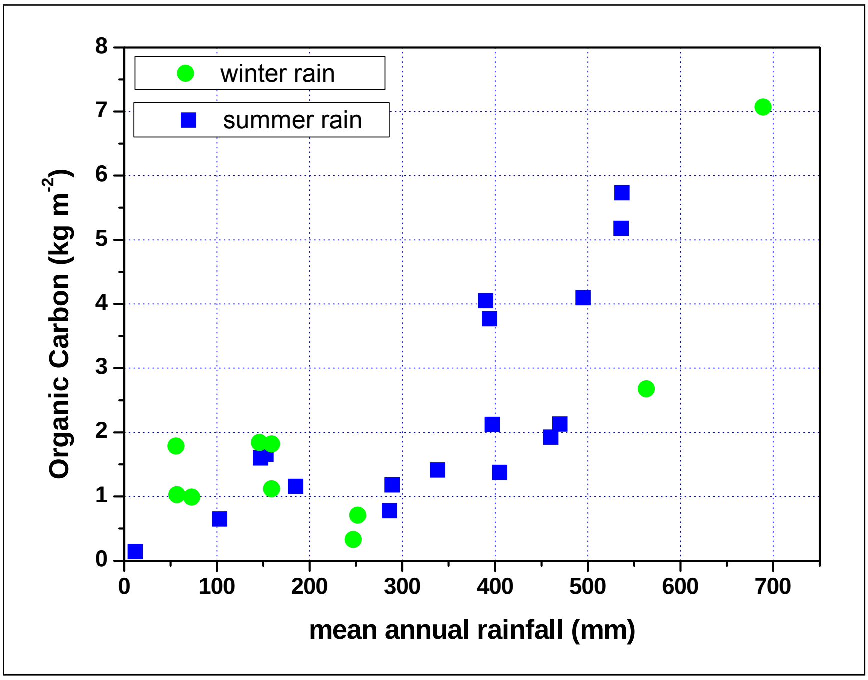

Fig. 9 : Median total soil organic carbon (SOC) in relation to mean annual rainfall.

the WRB (FAO 2006a) on the two-qualifier level. Considering a potential richness of *R* = 25, which means that all profiles belong to different soil units, the Observatories vary between *R* = 2 and *R* = 20, thus indicating a broad range of pedodiversity along the transects. The general trend along the precipitation gradient gives indications for a symmetrical relation with lowest values at the wet ends of the transects, a tendency for high pedodiversity in the intermediate range and a central minimum at smallest rainfall amounts. However, as the differences in pedodiversity with similar rainfall amount indicate, there have to be other controls of soil unit richness on the Observatories. Fig. 11 exhibits the pedodiversity richness with respect to rough landscape characteristics. Therefore the Observatories have been classified to four subunits: i) areas formed by aeolian sands (within the Kalahari basin: S02 Mutompo, S01 Mile 46, S03 Sonop, S41 Sandveld, S17 Alpha; coastal dune veld: S21 Groot Derm), ii) mountainous areas with steep slopes and rock outcrops (S06 Okamboro, S38 Claratal, S10 Gellap Ost, S11 Nabaos, S20 Numees, S22 Soebatsfontein, S25 Remhoogte, S24 Paulshoek), iii) areas with dominating salt enrichment (S43 Omano, S42 Ogongo, S16 Wlotzkasbaken, S26 Goedehoop, S27 Ratelgat), and iv) the remaining sites, mostly plains (S05 Otjiamongombe, S04 Toggekry, S39 Narais, S40 Duruchaus, S12 Karios, S18 Koeroegap Vlakte, S32 Elandsberg, S33 Cape of Good Hope).

With this clustering, some factors controlling pedodiversity become clearer: Soilscapes predominantly build up by aeolian sands as parent material, in general are mostly homogenous (*R* = 2–10). The comparatively high pedodiversity on the Observatory Sonop (*R* = 10) results from the inclusion of the patchy and extended interdune part of the area, where Cambisols of different pH and Calcisols are mixed with the predominant Arenosols of the region. The five salt enriched areas have a medium to high pedodiversity. Especially the two neighbouring sites in

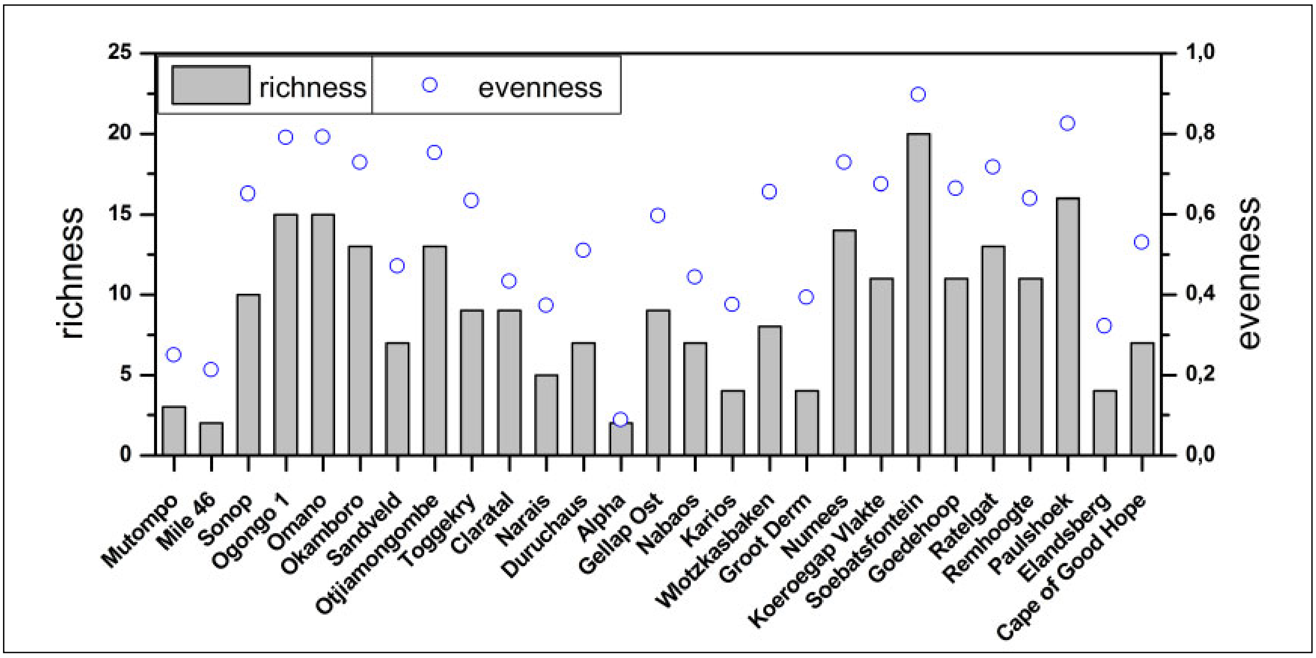

Fig. 10 : Distribution of taxonomic soil richness (R) and Shannon evenness (E) along the rainfall gradient. Rainfall gradient see Fig. 3.

the Oshana region (Ogongo, Omano) are rich in soil units (R = 15), based on the spatial variation of sodium dominance, total salt contents and carbonate enrichment, all three further varied by their vertical distribution within the soil. Here, the applied classification system is rather sensitive and even profiles with similar morphology may be differing on the upper level of soil reference group. On-site topographic variability may have a strong influence on the pedodiversity, but for the same annual rain amount, in some cases the richness is only 7 (Nabaos) whereas on other areas the highest pedodiversity for all sites was found (Soebatsfontein, R = 20). Plains exhibit a medium range of pedodiversity (R = 4–13). From the comparison it can be concluded, that even by introducing the rough landscape qualifier, the richness of comparable sites has a variation in pedodiversity of about a factor three. The topographic variability, which in case of missing other information is regarded as a dominant factor for geodiversity, thus explains part of the pedodiversity, but other factors are of same significance. A decrease in pedodiversity with annual rainfall > 500 mm, which could be explained by the intensification of soil genetic processes, seems to be unlikely. At the wettest region at the Northern end of the transects, the study sites are developed in degraded dunes and thus present low pedodiversity, while the southernmost sites on the Cape Peninsula are developed in weathered material of nutrient poor sandstones, and thus of low pedodiversity as well.

The Shannon evenness has a strong and nearly linear correlation to the richness (Fig. 12). This indicates an increasing similarity of the frequency distribution of soil units with increasing pedodiversity. Two areas are remarkable with E below the trend, which means a strong dominance of one soil unit (Alpha, Claratal) and one area (Wlotzkasbaken) with E above mean trend, meaning a rather similar distribution of found soil units.

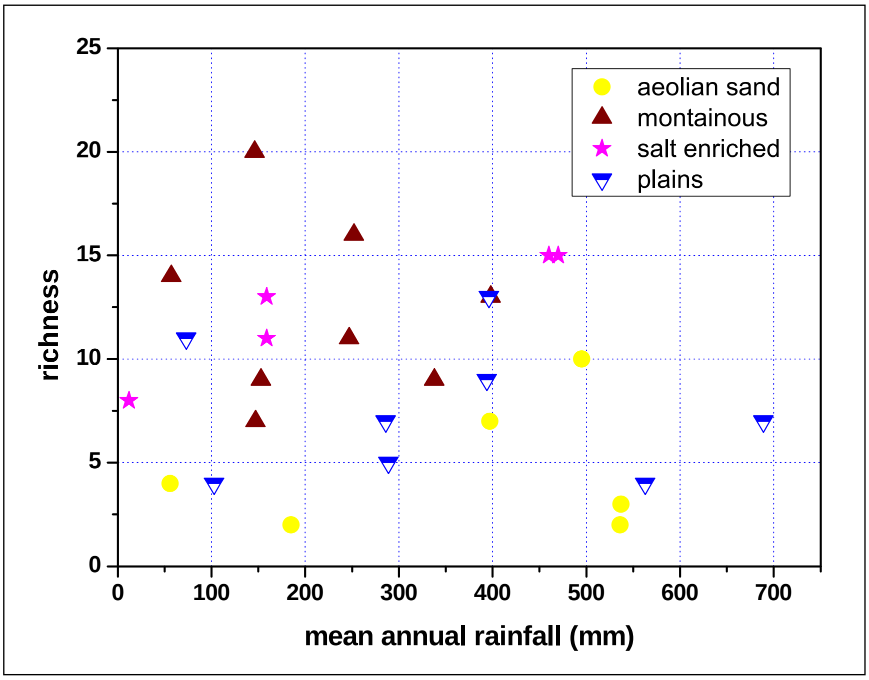

Fig. 11 : Soil richness (R) in relation to mean annual rainfall.

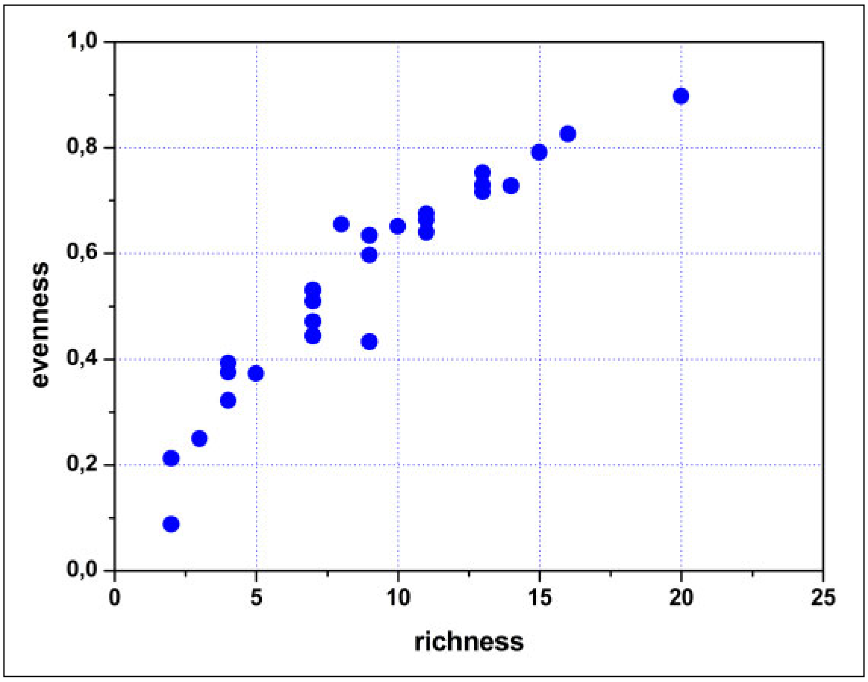

Fig. 12 : Relation between soil Shannon evenness (E) and richness.

Conclusions

In summary, it can be stated that the variability of soil properties in the studied drylands is high for both the overall transects and within the observatories. Looking at the different scales of soil patterns along the transects, distinct differences were evident. Whereas the main substrate-driven changes in the northern part of the transects occurred at a distance level of 100–300 m, the southern part of the transects was additionally small-scale structured (1–100 m). Examples are Observatory Soebatsfontein with a high impact of heuweltjie structures and the Observatories Ratelgat and Goedehoop with small-scale changes in pH-values and salt content. These changes occurred within few meters. Additionally, the small-scale changes and structures of bedrock in mountainous and shallow developed sites seem to be a major factor for ecological niches driven by soil physical factors. This 'flower pot' principle is very obvious on steep slopes in Numees but missing on the morphologically comparable site Claratal. Here, the weathering structure of the bedrock and the intensity of soil erosion control the occurrence of the small scale structuring of the soilscape.

The diversity of soil properties on the studied Observatories is a valuable proxy for the phytodiversity of areas (Petersen et al. 2010). This knowledge is especially relevant for the restoration and protection of degraded landscapes (e.g. mining or strongly overgrazed areas). Here, as proposed by Eviner & Hawkes (2008), in the re-construction of cover soils the diversity of site properties should be taken into account to substantially improve the future diversity of the vegetation.

Acknowledgements
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