Journal of Arid Environments (1997) 35: 29–38

Survey of soil chemical properties across a landscape in the Namib Desert

M.M. Abrams*, P.J. Jacobson†, K.M. Jacobson‡ & M.K. Seely‡

**Department of Environmental Science and Engineering, Oregon Graduate Institute of Science and Technology, P.O. Box 91000, Portland, OR 97291-1000, U.S.A.*
†Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, U.S.A.
‡Desert Research Foundation of Namibia, Gobabeb, P.O. Box 1592, Swakopmund, Namibia

(*Received 29 July 1995, accepted 10 October 1995*)

A selection of soils were sampled in the Central Namib Desert to investigate the importance of landscape and associated plant communities on soil nutrient status. Soils were sampled in an ephemeral river, a wash, and at two dune sites. The soils in the lower landscape positions, the Kuiseb River and an associated wash, had significantly higher nutrient levels than those at the dune sites. These lower landscape positions also had the most stable plant communities, *Faidherbia albida* and *Welwitschia mirabilis*, respectively. The two dune soils, which both support perennial herbaceous species, had extremely low nutrient levels. Only the wash showed nutrient enrichment of the soil under plants, as measured by a relative enrichment factor. This community is the most established, with plants being hundreds of years old; this time factor may be crucial for nutrient accumulation by plants in this extremely arid system. The lack of enrichment under the *F. albida* community suggests that the fluvial inputs and exports, both organic and inorganic, tend to homogenize the nutrient levels within this system. These results indicate that soil nutrient levels in the Namib Desert are closely linked to landscape position and less so with the associated plant communities.

Keywords: *Welwitschia mirabilis*; *Faidherbia albida*; ephemeral rivers; Namibia; soil nutrients; relative enrichment

Introduction

Resource availability for primary productivity in arid systems is often limited by two primary factors — low soil water content and nutrient-poor soils, particularly N and P (West & Skujins, 1978; Lathja & Schlesinger, 1988). In addition, limited water movement in soils can lead to localized saline accumulations (U.S. Salinity Laboratory Staff, 1954). The stresses imposed on plants by these three factors, i.e. low moisture

0140–1963/97/010029 + 10 $25.00/0/ae9560139

availability, low soil nutrient levels, and salinity, are probably the most important edaphic factors affecting plant establishment, growth, and reproduction in arid lands.

The Namib Desert, along the coast of Namibia in Southern Africa (Fig. 1), is one of the most arid sites in the world (Seely, 1978, 1984). It extends north–south roughly

2000 km from South Africa to Angola and inland 160 km at its widest point. It is dissected by a series of ephemeral rivers including the Kuiseb River, which passes through the Central Namib. There is a strong east–west gradient in rainfall, increasing from the coast inland (Lancaster *et al.*, 1984). The presence of the cold Benguela Current off the coast produces coastal fog that extends up to 60 km inland. This fog, in addition to the < 100 mm of mean annual rainfall, provides moisture for the flora and fauna in this part of the Namib.

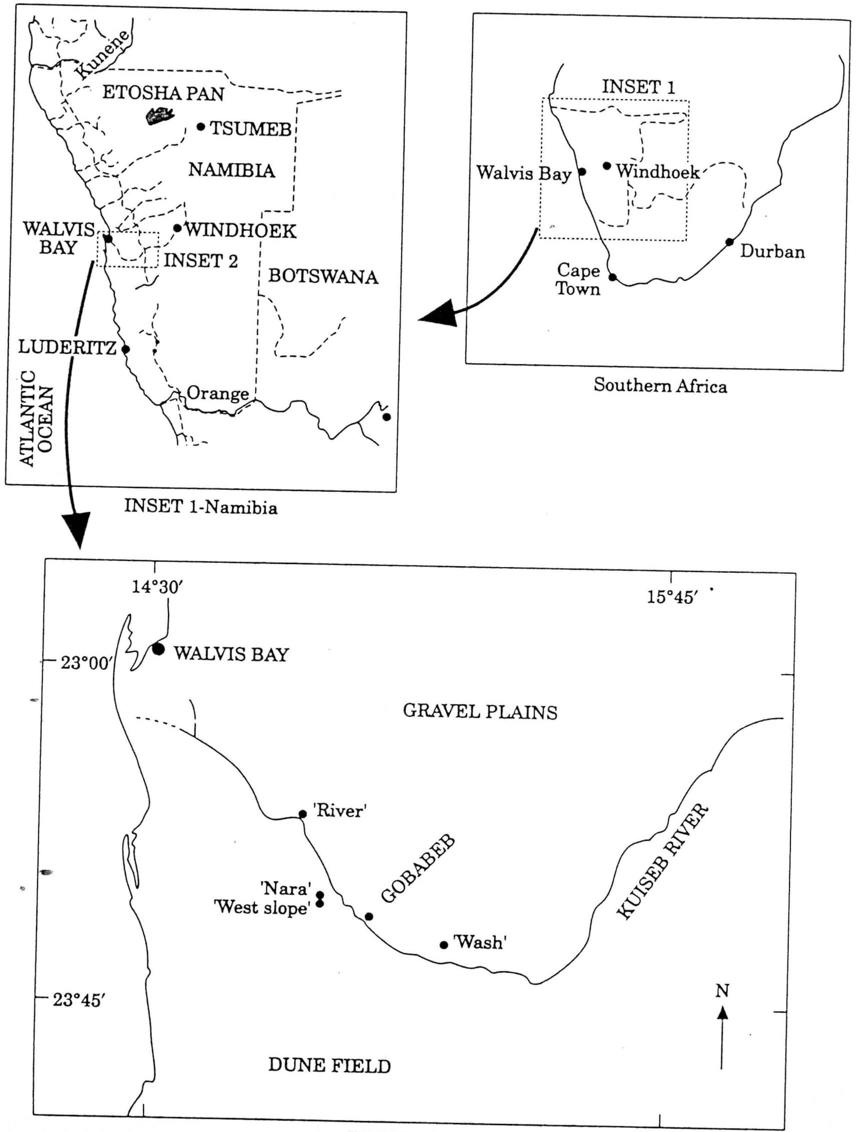

Figure 1. Map of Namibia and the four sampling sites near Gobabeb, Namibia.

Much work has been conducted on the fauna and flora of the Namib Desert (Theron *et al.*, 1979; Seely *et al.*, 1980; Seely, 1990; Schulze *et al.*, 1991; Jacobson *et al.*, 1993). There has also been work on the geomorphology and geology of the Namib (Lancaster *et al.*, 1984; Ward, 1987), however extremely little is known about the soils of the Namib, especially their chemistry, which represent the ultimate nutrient resource base. A brief morphological survey of soils around Gobabeb was conducted by Scholz (1972) but little subsequent work has been done on soils and the link between soil nutrient status and accompanying plant communities. In one study of the VA-mycorrhizal fungal communities of the area, Jacobson (1997) found soil nutrient levels were quite low, with the maximum available P level being 1·53μg g^{-1} and soil organic matter content ranging from 0·013–0·062%.

The soil is the ultimate source of nutrients in the system and plays an important role in capture and retention of water and energy (in the form of plant-fixed carbon (C)). Therefore, a basic understanding of the movement of nutrients, water and energy through this system is incomplete without an analysis of the soil.

One paradigm of soil chemistry in arid lands has been the occurrence of 'islands of fertility', i.e. the accumulation of resources under perennial shrubs and trees (Tiedemann & Klemmedson, 1973; Virginia & Jarrell, 1983; Belsky *et al.*, 1989; Abrams *et al.*, 1990). The existence of such resource accumulations is an indicator of the balance between the resource inputs and exports from a system. In the Namib, the majority of nutrient inputs and exports are tied to wind (aeolian deposits on the dunes and plains) or water (ephemeral rivers and washes) movement. The climatic extremes, the energy associated with resource inputs and exports, and the biological N_2-fixing capabilities within the system should control the resource accumulation in this hyperarid system. Therefore, resource accumulation under perennial plants in such an extreme environment should depend on both plant community type and age as well as landscape position.

The aim of this brief study was to survey the soil chemical properties in a series of landscape positions in the Namib Desert, each representing a different important plant community found in the desert. The question was not only the fertility status of the different sites, but also the role of the plant communities in nutrient accumulation and retention at each landscape position. Therefore, this study presents the nutrient status of several landscape positions in relation to the dominant flora at each site.

Materials and methods

Study sites

The focal point of the study was the central Namib Desert in the vicinity of Gobabeb on the Kuiseb River (latitude 23°34' S, longitude 15°03' E). The first site was approximately 20 km down river from Gobabeb, near Swartbank, on the channel edge of the Kuiseb River flood plain (Site designation = 'River'). The second site was approximately 15 km east of Gobabeb in a wash where the predominant plant species is *Welwitschia mirabilis* Hook. f., a Namib Desert endemic (Herre, 1961; Jacobson *et al.*, 1993) (Site = 'Wash'). The third and fourth sites were approximately 15 km south-west of Gobabeb at the Khommabes Depression (Ward, 1987). The third was located within a !Nara (*Acanthosicyos horridus* Welw. ex Hook. f.) stand in the centre of the Depression (Site = 'Nara') and the fourth was along the toe-slope of the west-facing dune at the edge of the Khommabes Depression (Site = 'West slope').

The River site is representative of the middle section of the ephemeral rivers that dissect the Namib Desert. These ephemeral rivers provide a relatively high energy and resource environment that supports, directly and indirectly, a large number of the flora and fauna found in the Namib (Wharton & Seely, 1982). Soils at this site were sampled at the interface of the channel and flood plain and are in the Fluvent suborder (Abrams, pers. obs.), with alternating layers of fluvial deposited silts and fluvial and aeolian deposited sands. The dominant plant community in this area is a mix of *Faidherbia albida* (Del.) A. Chev. and *Acacia erioloba* E. Mey. (Seely *et al.*, 1980), both N_2-fixing trees (Hogberg, 1986). The principal individuals at the immediate study site were all *F. albida* which were at least 5 m in height.

The Wash site is one of many washes draining the gravel plains to the north of the Kuiseb River. The soils at this site are also Fluvents (Abrams, pers. obs.) but derived from a different parent material than that in which the Kuiseb flood plains are developing (Ward, 1987). The most prevalent plant growing in the wash bed is *W. mirabilis*, an extremely slow growing and long-lived species (Herre, 1961). Individuals under which soil samples were collected were at least 1·5 m in diameter and 0·5 m in height. Although these exact individuals have not been dated, their size suggests they are on the order of 500–1000-years-old (Seely, pers. obs.).

The Khommabes sites are located in the dune sea that extends through a large portion of the desert and is comprised of aeolian sands (Lancanster, 1984). The soils at both Khommabes sites are in the Psamment suborder (Abrams, pers. obs.). The dominant plant at the Nara site is the !Nara plant, a perennial which collects aeolian sand, forming mounds under and immediately around the plants. The !Nara mounds sampled were all approximately 1·5 m in height. The only plants growing along the West slope were a grass species, *Stipagrostis sabulicola* (Pilg.) De Winter, and a leaf succulent, *Trianthema hereoensis* Schinz. Both of these species are perennials and have formed small mounds (< 25 cm in height) around their bases at this site. The establishment of these particular plants probably occurred following the large rains of 1976 or 1978 (Seely, pers. obs.) making them considerably younger than the *W. mirabilis*.

Sample collection and analysis

Four replicate soil samples were collected under and between each of the dominant plant species at a given site. The samples were collected with an 8 cm diameter sand auger to a depth of 16 cm and sieved through a 2 mm mesh screen. They were then dried for 16 h in an oven at 105°C for gravimetric moisture measurements and stored for later chemical analysis.

Each sample was extracted with ammonium bicarbonate-DTPA (AB-DTPA) at a ratio of 1:2 soil:extractant. Extracts were then analysed by atomic absorption spectrophotometry for Ca, Mg, K, Na, Cu, Fe, Mn and Zn (Soultanpour & Schwab, 1977). In addition, extracts were analysed for available P using the molybdate method (Olsen & Sommers, 1982) on an Alpkem rapid flow analyser. Effective cation exchange capacity (ECEC) was calculated for each sample as the sum of the macrocations, Ca, Mg, K and Na. Exchangeable Na percentage (ESP) was calculated as the ratio of exchangeable Na to the sum of exchangeable Na, Ca and Mg (Bohm *et al.*, 1979). A subsample of each soil sample was mixed with distilled, deionized water at a ratio of 1:2 soil:water and the pH and electrical conductivity (EC)

dried again at 105°C for 24 h and analysed on a Carlo Erba NA 1500 series elemental analyser.

Relative enrichment factors (REF) (Zinke, 1962) were calculated for all nutrients at each site. The REF = (U–B)/B; where U is the nutrient concentration under a plant and B is the concentration between plants. This allowed a normalization of the relative increase in nutrients under plants across the landscape positions.

The significant differences in measured soil parameters at the landscape positions and intra-site sample location, i.e. with respect to the plants at each site, were evaluated using an analysis of variance (ANOVA). The inter- and intra-site means of any parameters showing a significant difference were then compared using a paired t-test. Mean differences were considered to be statistically significant at the $p < 0{\cdot}05$ level. All statistical analyses were made using Statview 4·01 (Abacus Concepts, Inc; Berkeley, CA, U.S.A.)

Results and discussion

All soil chemical parameters measured were statistically different ($p < 0{\cdot}05$) at the different landscape positions (Table 1). The two sites that receive the majority of their inputs through fluvial inputs (River and Wash) had significantly higher levels of most nutrients measured than those found in the soils of the two dune sites (Nara and West slope) (Table 2). Both sites receive pulses of fine inorganic material, and both coarse and fine organic material with seasonal floods, but are relatively protected from resource removal by wind erosion that is common on the dune sites (P. Jacobson, unpublished data). The OC content of the River site is quite high for a desert soil (West & Skujins, 1978; Virginia & Jarrell, 1983), demonstrating the importance of this ephemeral river system for energy retention, as fixed C, in this desert landscape. The higher OC in the River is accompanied by higher levels of trace elements, which are predominately chelated by OC, and a lower pH, within the range of optimum nutrient availability for P and trace elements (Bohn *et al.*, 1979). The more regular pulse inputs probably allow more successful plant establishment, which, combined with their protected landscape position, results in a greater net resource accumulation and retention than that possible in the more exposed dune sites.

River

Table 1. *Statistical significance of plant and landscape position on the nutrient status of soil samples collected at four sites in the central Namib Desert*

Parameter	Under/between	Landscape position	Interaction
P	0·0004	<0·0001	<0·0001
OC	0·1575	<0·0001	0·0177
N	0·1861	<0·0001	0·0062
Ca	0·1526	<0·0001	0·9603
Mg	0·0008	<0·0001	<0·0001
Na	0·0341	0·0477	0·0005
K	<0·0001	<0·0001	<0·0001
Cu	0·0780	<0·0001	0·0108
Mn	0·0136	<0·0001	<0·0001
Fe	0·2788	<0·0001	0·2087
Zn	0·2714	<0·0001	0·0033
ECEC	0·0004	<0·0001	<0·0001
ESP	0·0539	<0·0001	0·0281

Table 2. *Effects of landscape position on soil chemistry at four sites in the Namib Desert*

	Units	River	Wash	Nara	West slope
OC	%	3·77 a	0·96 b	0·05 c	0·05 c
N	%	0·32 a	0·04 b	0·00 c	0·00 c
P	mg·kg^{-1}	29·28 a	23·78 a	1·32 b	1·47 b
Ca	cmol·kg^{-1}	1·68 a	1·70 a	0·45 b	0·36 b
Mg	cmol·kg^{-1}	1·06 a	0·69 a	0·06 b	0·08 b
Na	cmol·kg^{-1}	0·33 b	0·93 a	0·58 a	0·73 a
K	cmol·kg^{-1}	0·49 b	1·72 a	0·50 c	0·42 c
ECEC	cmol·kg^{-1}	3·56 a	5·04 a	1·60 b	1·59 b
ESP	%	9·49 c	14·63 c	36·97 b	46·73 a
Cu	mg·kg^{-1}	7·00 a	0·18 b	0·03 c	0·04 c
Mn	mg·kg^{-1}	72·81 a	4·36 b	0·16 c	0·20 c
Zn	mg·kg^{-1}	1·56 a	0·31 b	0·03 c	0·04 c
Fe	mg·kg^{-1}	134·13 a	3·27 b	1·10 d	1·51 c
pH		7·8 c	8·4 b	9·19 a	9·24 a
EC	µS·cm^{-1}	1799 a	1667 a	82 b	95 b

Values in a row followed by different letters are statistically different at $p<0·05$ level.

dunes

Although the soluble salts were higher in the River and Wash sites than in the dune soils, the opposite was true for the ESP. These soils, with high ESP (>15%), combined with the high pH values (>8·5), could be considered sodic soils (U.S. Salinity Laboratory Staff, 1954). The very low nutrient status of these soils in addition to their sodicity may, after water limitations and stability (Yeaton, 1988; Jacobson, 1997), be the limiting factor on types of plants that can grow in these dunes. No information is available on the relative Na tolerances of the three plants found at Khommabes but their growth in such soils suggests they are Na-tolerant.

There were no significant differences in nutrient concentrations between the two dune sites except in ESP and Fe. Both of these factors were significantly higher in the soils from the West slope compared with those from the Nara site. Typically, salts accumulate in lower topographic positions due to runoff accumulations and proximity to perched water tables (Buol *et al.*, 1973). Thus, the Nara site, rather than the West slope, would be predicted to have a higher salt concentration. However, the reverse is observed in these dunes, perhaps due to the influence of wind-blown salts and particles from the coast. While the OC and extractable P at this site was similar to that found by Jacobson (1997), the pH was considerably higher (pH 9 in this study compared to neutral pH values in Jacobson), indicating this site may be unusually high in Na. This is the site of an ancient inland marsh (Ward, 1987) which may account for the long-term Na accumulation.

The plant–soil interaction effect on nutrient accumulation varied among landscape sites. There was no significant intra-site differences for any of the parameters at the River, West slope and Nara sites. This is of particular note at the River site because *F. albida* and its associated rhizobia have been shown to fix atmospheric N_2 (Hogberg, 1986), although the extent to which this occurs at this site is not known. In addition, this lack of an increase in soil nutrient levels under *F. albida* is in sharp contrast to the nutrient accumulation found at other sites in Africa (Dancette & Poulain, 1969; Jung, 1969) as well as that noted for other woody perennials in arid and semi-arid systems (Tiedemann & Klemmedson, 1973; Virginia & Jarrell, 1983; Belsky *et al.*, 1989; Abrams *et al.*, 1990). This indicates that flood inputs into the system are more important than the effect of the tree on nutrient accumulation. Therefore, the sampling position becomes critical because the channel receives almost annual inputs while, further up the flood plain, flooding only occurs on a decade time scale. The sampling site for this study was at the interface between the active channel and the flood plain so it would be more stable than the channel but have more frequent inputs than the flood plain. The shift in nutrient dynamics (import *vs.* export) across the river channel and flood plain is an area that needs further investigation. The lack of an understory community at the sampled location, as would be found in more upland *F. albida* communities in eastern and northern Africa, also might minimize the retention of nutrients under these trees.

Wash

There were, however, many significant differences between soils under and between plants at the Wash site. In general, there were no differences between the soils sampled under the male and female *W. mirabilis* plants but both had significantly higher $p<0·05$ nutrient levels than the soils between plants (Fig. 2(a–d)). Exceptions to this were concentrations of N, EC and OC. In the case of the first two, soil under the female plants was not significantly different to either the soil under the male plants or in the wash; however, soil under the male plants had higher levels than the soil in the wash between plants. Soil under the male plants contained significantly more OC than soil under the female plants or soil in the wash, but there was no significant difference between the latter two. The majority of litter appears to be due to shedding of the reproductive parts of the plants because the leaves are leathery and massive. The males produce flowers while the females produce cones that are relatively much larger and therefore presumably less rapidly decomposed. This difference in the structure of the

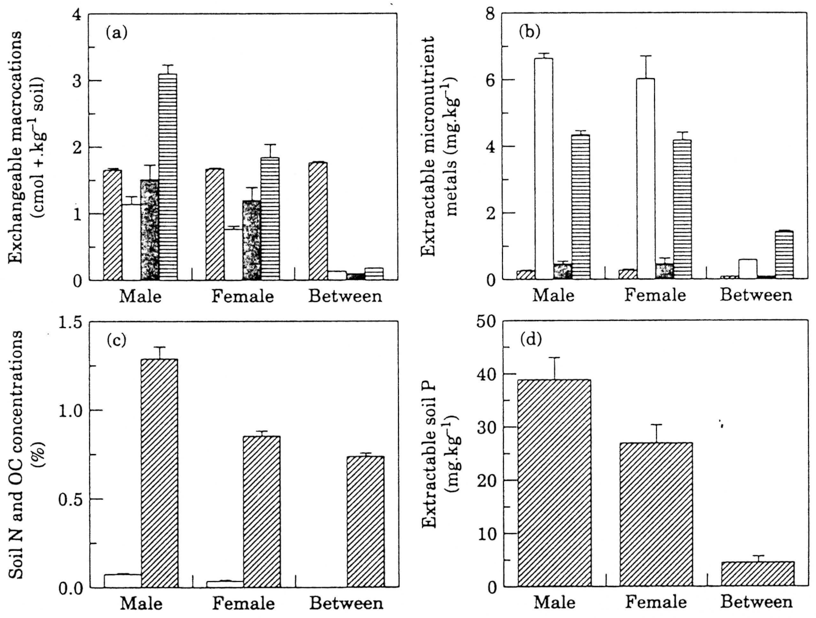

Figure 2. (a) Mean macrocation concentration in relation to *Welwitschia mirabillis* plants at the Wash site. (bars = SE). (▨) = Ca; (☐) = Mg; (■) = Na; (▤) = K. (b) Mean concentration of four trace elements under and between *Welwitschia mirabilis* plants at the Wash site (bars = SE). (▨) = Cu; (☐) = Mg; (■) = Zn; (▤) = Fe. (c) Mean OC (▨) and N (☐) concentrations in relation to *Welwitschia mirabilis* plants at the Wash site. (bars = SE). (d) Mean P concentration in relation to *Welwitschia mirabilis* plants at the Wash site (bars = SE).

litter probably explains the difference in OC accumulation under the plants as the cones would be more slowly incorporated into the soil than the flowers, allowing time for possible export by associated fauna.

The REF for the nutrients at each site provided similar information (Fig. 3(a–c)), with a significantly higher REF found at the Wash than at the other sites. The exception to this was the REF for OC, Ca and Cu. The first two showed no enrichment at any of the sites, while Cu was enriched at all sites except the River. The magnitude of the REF values varied considerably at the Wash with N being the most enriched (Fig. 3(c)). The general lack of enrichment at the dune sites is similar to that found for the River site, the difference being wind, rather than water, as the principal exporting mechanism in the dunes (Yeaton, 1988; Jacobson, 1997). The low REF values, even for N, in the River reflect the relative importance of the uniformly spread flood inputs compared to those from individual plants. The high enrichment of N under *W. mirabilis* without a concomitant OC enrichment may indicate an extremely low C:N ratio in these plants.

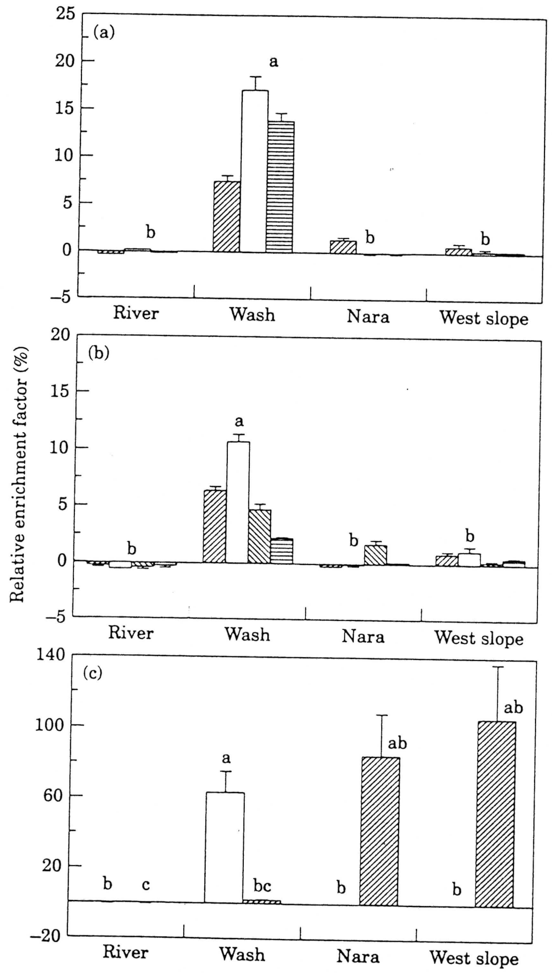

Figure 3. Relative enrichment factors (REF) for (a) microcations ((▨) = Mg; (□) = Na; (▤) = K; Ca not included because it had a REF near 0 at all sites), (b) three trace elements ((□) = Mn; (▧) = Zn; (▤) = Fe) and P (▨), and (c) N (□) and Cu (▨) (OC not included because it had a REF near 0 at all sites), under the dominant plant species at four landscape positions in the Namib Desert (bars = SE). REF values with different letters are significantly different at the different sites.

The results of this limited sampling of Namib Desert soils highlight the importance of ephemeral inputs (higher nutrient and salinity levels at the River and Wash sites) and the uniqueness of the plant–soil interaction in this arid system as a whole. Accumulation of resources under a 500–1000-year-old *W. mirabilis* plant would be predicted, even in such a resource-poor system as the Wash site. However, the lack of this familiar pattern under *F. albida* in the River and in the !Nara mounds is more unexpected. Because the ephemeral waterways are critical for flora and fauna of the entire area, the processes that control their basic nutrient resources, the soil, need to be better understood. Further studies on the movement, cycling, retention and spatial distribution of nutrients in this system need to be undertaken to elucidate the processes controlling resource availability.

This project was funded by an International Planning Grant from the National Science Foundation (#INT-9321925). The authors wish to thank the Ministry of Environment and Tourism of Namibia, the Desert Research Foundation of Namibia, and the Swedish International Development Authority (SIDA) for their support of this project.

References

Abrams, M.M., Jarrell, W.M., Smith, H.A. & Clark, P.R. (1990). Nitrogen accretion in soil and biomass production by three *Prosopis* species. *Agroforestry Systems*, **10**: 93–97.

Belsky, A.J., Amundson, R.G., Duxbury, J.M., Riha, S.J., Ali, A.R. & Mwonga, S.M. (1989). The effects of trees on their physical, chemical, and biological environments in a semi-arid savanna in Kenya. *Journal of Applied Ecology* **26**: 1005–1024.

Bohn, H.L., McNeal, B.L. & O'Connor, G.A. (1979). *Soil Chemistry*. New York, NY: John Wiley & Sons. 329 pp.

Buol, S.W., Hole, F.D. & McCracken, R.J. (1973). *Soil Genesis and Classification* (1st Edn), pp. 116–124. Ames, Iowa: The Iowa State University Press. 329 pp.

Dancette, C. & Poulain, J.F. (1969). Influence of *Acacia albida* on pedoclimatic factors and crop yields. *African Soils*, 14: 143–184.

✓Herre, H. (1961). The age of *Welwitschia bainesii* (Hook.f) Carr.: C14 research. *South African Journal of Botany*, 27: 139–140.

Hogberg, P. (1986). Nitrogen-fixation and nutrient relations in savanna woodland trees (Tanzania). *Journal of Applied Ecology*, 23: 675–688.

Jacobson, K.M. (1997). Moisture and substrate stability determine VA-mycorrhizal fungal community distribution and structure in an arid grassland. *Journal of Arid Environments*, 35: 59–76.

✓ Jacobson, K.M., Jacobson, P.J. & Miller Jr., O.K. (1993). The mycorrhizal status of *Welwitschia mirabilis*. *Mycorrhiza*, 3: 13–17.

Jung, G. (1969). Cycles biogéochimiques dans un écosystème de region tropical sèche *Acacia albida* Del. sol ferrugineux tropical peu lessive (Dior.) *Oecologia Plantum*, 4: 195–210.

Lancaster, N. (1984). Aeolian sediments, processes and land-forms. *Journal of Arid Environments*, 7: 249–254.

Lancaster, J., Lancaster, N. & Seely, M.K. (1984). Climate of the central Namib Desert. *Madoqua*, 14: 5–61.

Lathja, K. & Schlesinger, W.H. (1988). The biogeochemistry of phosphorus cycling and phosphorus availability along a desert soil chronosequence. *Ecology*, **69**: 24–39.

Nelson, D.W. & Sommers, L.E. (1982). Total carbon, organic carbon, and organic matter. In: Page, A.L. (Ed.), *Methods of Soil Analysis*, Part 2, pp. 539–580 Madison, WI: American Society of Agronomy. 1188 pp.

Olsen, S.R. & Sommers, L.E. (1982). Phosphorus. In: Page, A.L. (Ed.), *Methods of Soil Analysis*, Part 2, pp. 403–430. Madison, WI: American Society of Agronomy. 1188 pp.

Scholz, H. (1972). The soils of the central Namib Desert with special consideration to the soils in the vicinity of Gobabeb. *Madoqua*, **1**: 33–51.

Schulze, E.-D., Gebauer, G., Ziegler, H. & Lange, O.L. (1991). Estimates of nitrogen fixation by trees on an aridity gradient in Namibia. *Oecologia*, **88**: 451–455.

Seely, M.K. (1978). The Namib dune desert: an unusual ecosystem. *Journal Arid Environments*, **1**: 117–128.

Seely, M.K. (1984). The Namib's place among the deserts of the world. *South African Journal of Science*, **80**: 155–158.

Seely, M.K. (Ed.) (1990). *Namib Ecology: 25 years of Namib research*. Pretoria, South Africa: Transvaal Museum Monograph, No. 7. 230 pp.

Seely, M.K., Buskirk, W.H., Hamilton III, W.J. & Dixon, J.E.W. (1980). Lower Kuiseb River perennial vegetation survey. *Journal of South West Africa Science Society*, **35**: 57–86.

Soultanpour, P.N. & Schwab, A.P. (1977). A new soil test for simultaneous extraction of macro- and micro-nutrients in alkaline soils. *Communications in Soil Science and Plant Analysis*, **8**: 195–207.

Theron, G.K., van Rooyen, N. & van Rooyen, M.W. (1979). Vegetation of the lower Kuiseb River. *Madoqua*, **11**: 327–345.

Tiedemann, A.R. & Klemmedson, J.O. (1973). Effect of mesquite on physical and chemical properties of soil. *Journal of Range Management*, **26**: 27–29.

U.S. Salinity Laboratory Staff (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. US Department of Agriculture Handbook 60. Washington, DC: US Government Printing Office. 160 pp.

Virginia, R.A. & Jarrell, W.M. (1983). Soil properties in a mesquite-dominated Sonoran Desert ecosystem. *Soil Science Society of America Journal*, **47**: 138–144.

Ward, J.D. (1987). *The Cenozoic succession in the Kuiseb Valley, Central Namib Desert*. Memoir 9. Windhoek, Namibia: Geological Survey, Southwest Africa. 124 pp.

West, N.E. & Skujins, J.J. (Eds) (1978). *Nitrogen in desert ecosystems*. US/IBP Synthesis Series 9. Stroudsburg, PA: Dowden, Hutchinson & Ross. 307 pp.

Wharton, R.A. & Seely, M.K. (1982). Species composition of and biological notes on tenebrionidae of the lower Kuiseb River and adjacent gravel plain. *Madoqua*, **13**: 5–25.

Yeaton, R.I. (1988). Structure and function of the Namib dune grasslands: Characteristics of the environmental gradients and species distribution. *Journal of Ecology*, **76**: 744–758.

Zinke, P. (1962). The pattern of influence of individual forest trees on soil properties. *Ecology*, **43**: 130–133.

14575

Journal of Arid Environments (1997) 35: 39–58

The near-ubiquitous pedogenic world of mesquite roots in an arid basin floor

L.H. Gile*‡, R.P. Gibbens† & J.M. Lenz†

**Soil Survey Investigations, USDA-NRCS, Las Cruces, New Mexico, U.S.A.*

†Jornada Experimental Range, USDA-ARS, Las Cruces, New Mexico, U.S.A.

(*Received 3 January 1996, accepted 26 January 1996*)

A major invasion of grassland by shrubs began about 1850 A.D. in many desert areas of southern New Mexico. Mesquite (*Prosopis glandulosa*) is the most numerous of these invading shrubs in a studied basin floor. Mesquite roots readily penetrated all soil horizons except for continuously indurated petrocalcic horizons. However, roots grew along the top of petrocalcic horizons and in places found locations for penetration, such as cracks and pipes, with numerous, often upward-growing roots enroute to utilize the sparse precipitation. At another site, mesquite roots descended to a depth of at least 5·5 m. Although the spread of mesquite seed by cattle was a major factor in the spread of mesquite, its successful establishment over large areas is apparently due to the ability of mesquite roots to adapt to a wide variety of soils and soil conditions to take advantage of the sparse precipitation; to their ability to greatly proliferate while spreading laterally over long distances; to grow upward and take advantage of small precipitation events that only wet the soil to depths of a few centimeters; and to descend to great depths along cracks and other openings in the soil, down which soil water also penetrates, and thus to their ability to utilize available water at all depths.

Keywords: coppice dunes; petrocalcic horizons; pipes; Haplargids; Calciargids; Torripsamments; Petrocalcids; Haplocalcids

Introduction

Widespread invasion of grassland by shrubs in desert areas of southern New Mexico since about 1850 A.D. has been documented by a number of authors, e.g. Gardner (1951), Buffington & Herbel (1965), and York & Dick-Peddie (1969). Major shrub invaders cited were creosotebush (*Larrea tridentata*), tarbush (*Flourensia cernua*), and mesquite (*Prosopis glandulosa*). In transects along the Rio Grande Valley, Gardner (1951) found creosotebush to be dominant, with small amounts of mesquite and tarbush. In a study on the Jornada Experimental Range, most of which is in a broad

---

‡Present address: 2600 Desert Drive, Las Cruces, New Mexico 88001, U.S.A.

0140–1963/97/010039 + 20 $25.00/0/ae960157