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# MUBARAK'S GARDEN. LAND IMPROVEMENT ON A DRY TROPICAL ISLAND IN THE ARABIAN SEA

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## ABSTRACT

Inhabited dry tropical regions are principally seen as vulnerable areas, especially if people have limited access to suitable land, fresh water and crop seeds. From the traditional, but also from the scientific point of view in some cases, it might be considered to be exceptional, indeed pointless, for people to try to improve land in such an arid environment. But for people living directly on a hypersaline coastline, experiments in crop cultivation are necessary to produce additional fruits and vegetables, using either traditional or adapted techniques of land cultivation. Soil investigations in a kitchen-garden situated on the northern coast of Soqotra Island, Yemen, show that one year of cultivation increased $C_{org}$ contents from 0 up to 0.7%, and $P_{av}$ contents from 100 mg $kg^{-1}$ up to 230 mg $kg^{-1}$ in the garden beds. A general decrease in slightly soluble salts – explained by irrigation with fresh water – is already obvious after only one year: decreasing from 6.7% slightly soluble salt in marine sand, to 0.3% slightly soluble salt in cultivated beds. A vertical increase of clay content in sediments and soils, and also an inland increase of clay content, was observed. It is hoped that this example will encourage future research on kitchen-gardens, since they have a beneficial effect on society as well as having positive environmental consequences, as seen in the present case of land improvement on Soqotra Island in the Arabian Sea.

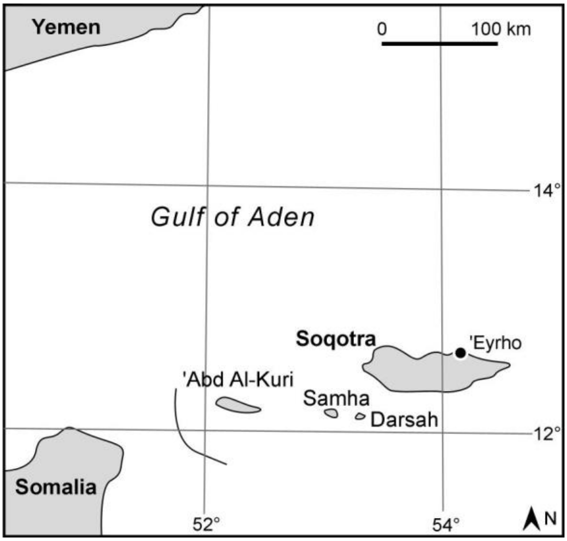
**Keywords**: Soqotra Island, hypersaline environment, soil melioration, crop cultivation

## INTRODUCTION

Cultivating plants in an arid environment is an immense challenge. The intensification of land use and the increase in production by different management practices depends on the degree of land preparation, the choice of species, the use of nutrients and the use of irrigation water (Gregory et al., 2002). A study of land improvement in the form of desert cultivation in Iran shows that irrigation and intensive crop production led to improved soil quality (Fallahzade & Hajabasi, 2012): the comparison of desert soils with cultivated soils showed the latter to have demonstrably higher soil organic carbon content, decreased slightly soluble salt content due to leaching, and a higher soil aggregate stability.

Another marvellous example of land improvement, but in a hypersaline arid marine environment, is the application of adapted irrigation techniques in 'Mubarak's Garden' located on Soqotra Island, Yemen. Based on channel-irrigation systems known from Hadramaut, South Yemen (Caton-Thompson & Gardner, 1939; Serjeant, 1964), and using dried and burnt fish material and sheep dung as fertiliser, Mubarak Walid Eesa, created a kitchen-garden, located at ‘Eyroh on the northern coastline of Soqotra (Fig. 1).

**Fig. 1: Location of the investigated site at ‘Eyrho**




Along the coast on Soqotra the mean annual precipitation during the SW-trade wind season is around 80 mm, which is not enough for rain-fed agriculture. Maximum temperatures of 40°C allow cultivation of fruits, vegetables and herbs only if shade is provided by planting shrubs and trees. Wind speed can reach 100 $km \cdot h^{-1}$ (Bruggemann, 1997), which causes soil desiccation and salinisation, even more so in areas close to the vegetation-poor coastline (Pietsch, 2006). Since the arid climate is interrupted by the wet SW-monsoon in summer (Sirocko et al., 1993; Fleitmann et al., 2007), wadi catchments in the mountains provide fresh groundwater which discharges in the direction of the shoreline. Groundwater levels decrease as the shoreline is approached.

Because of the high water consumption of non-traditional plants, especially in arid and hypersaline environments, either well irrigation or other irrigation systems have to be established. In South Yemen fresh water from wadis or, today, pumped fresh water from wells, is led to fields and garden beds by channels in order to avoid salinisation both of soil and groundwater. Irrigation with freshwater – if available – allows the cultivation of hypersaline soils, even to grow vegetables and fruits which have originally a low salt tolerance, such as radish (*Raphanus sativus*) or lemon (*Citrus aurantifolia*) (Landon, 1993). Land improvement in arid regions also occurs in the form of soil melioration, resulting in the enrichment of soil organic matter necessary for crop cultivation: it is traditional in the Middle East to put animal dung on the fields in order to supply nutrients such as phosphorus (P) and potassium (K): e.g. one date palm needs around 300 g $P_{av}$ and 250 g $K_{av}$ per year (Rehm & Espig, 1991).

In contrast to modern research on land degradation occurring as a result of intensive agricultural land use (Hudson & Alcántara-Alaya, 2006; Nyssen et al., 2008), this study demonstrates how improvement of land in a hypersaline environment is possible without degradation. It also discusses whether or not gardening inevitably leads to (1) increased plant diversity, (2) decreased salinisation and (3) an inappropriate increase/decrease in exchangeable cations and Ca:Mg ratios, which are important for plant growth (Landon, 1993). The information given here documents the fact that plant cultivation and fertilisation in a kitchen-garden on the northern coast of Soqotra had resulted in land improvement. This kitchen-garden was not developed in the frame work of a ‘development project’, but was the work exclusively of the land owner, using his own knowledge and understanding of the environment. Although new approaches to active co-operation between land users, development agents and scientists emerged in the 1990s, few projects have considered traditional expertise and experimentation undertaken by the owners of the land themselves (Critchley, Reij, Willcocks 1994; Pietsch & Morris, 2010). The need to increase production raises questions about positive environmental consequences, in the present case land improvement in a hypersaline marine environment of Southern Arabia.

## THE NORTHERN COASTAL PLAIN OF SOQOTRA ISLAND

### Environment and soils

The island is in a convergence zone of three marine bio-geographical areas: the Red Sea, the Arabian Sea and the Indian Ocean (Klaus et al., 2003). Soqotra displays different coastal environments which develop as a result of the monsoon, the rising and falling of tides, fluctuating salinity, the intensity of sunlight as well as the occurrence of coral reefs (Cheung & DeVantier, 2006). Coastal sedimentation is related to changing sea levels and uplift (Birse et al., 1997; Leroy et al., 2004). Confirmed by shell malformation and bio-erosion on foraminifers such as *Amphistegina sp.*, the northern coast of Soqotra can be defined as a “stress environment with changing conditions” (Toler & Hallock, 1998). Especially in the areas adjacent to the sand-dominated beach, Cenozoic conglomerates, limestone and Quaternary sediments occur; further inland Granite, Basalt and Gabbro are common (Beydoun & Bichan, 1970; Geological Survey and Mineral Resources Board 2003). In the coastal plain Haplic and Calcic Cambisols and Arenic Fluvisols are distributed (Pietsch, 2006). While Fluvisols are common in wadis and delta areas, Cambisols extend more widely towards the coastline and can contain up to 60% clay. Clay content increases inland, while sand content decreases offshore. Coarse fragment content of cambic soils account for 0% to 78%, along the coastline the soil skeleton is often composed of coral remains and pebbles. XRD data of Cambisols near the coast show mainly quartz, calcite, albite and sanidine (Pietsch, 2006). Coastal non-cultivated cambic soils often hold hyposodic properties (> 15% exchangeable Na), sodic properties (> 15% exchangeable Na-Mg) or salic properties (> 1% to 2.5% slightly soluble salt contents; FAO 2006; IUSS-Working Group WRB 2007). If $CaCO_3$ is available, soils are strongly influenced by secondary calcification (Pietsch & Kühn, 2009). PH values of soils are between 7.5 and 8.5. Calcaric Arenosols with a sand content of more than 60 % occur at the coastline, containing a large amount of mollusc shells and foraminifers. Original beach sand is composed mainly of quartz and feldspars. Rock fragments originate from magmatic or metamorphic rocks which are rich in quartz and feldspars (Beydoun & Bichan, 1970). Beach sands are mainly hypersalic (Pietsch, 2006; hypersalic > 5% slightly soluble salts after IUSS-Working Group WRB 2007).

## The vegetation of the coastal plains of Soqotra Island

The coastal plains present a mosaic of low succulent shrubs and wood-based herbs with patches of shrubland. Dominant plants include *Limonium* species, *Tamarix nilotica*, *Suaeda* species and *Atriplex* species (Miller & Morris, 2004). The NE coastal plains on which Mubarak's Garden lies contain the rapidly expanding island capital, Hadiboh, the port and the airport, and are particularly threatened by rural development and land degradation (Miller & Morris, 2004; Pietsch, 2006). Any attempt to increase production within this environment needs to take into account the protection of endemic plants and the island's unique biodiversity (Van Damme & Banfield, 2011). Various trials to cultivate and meliorate beach sands will have to be conducted in order to make use of different management practices, methods of land preparation, choice of species to be planted, use of nutrients and irrigation water (Gregory et al., 2002)

## Traditional agriculture

Historically, agriculture in the form of kitchen-gardens on the Island of Soqotra is not reported before the Common Era (Beyhl & Mies, 1996), and, maybe, only became important in the 19$^{th}$ century. On agricultural practices, Balfour's notes in his book state; "They cultivate small tracts of ground near their houses" (Balfour, 1881). Later, Brown discussed the cultivation of beans, tobacco, sweet-potatoes, tomatoes, melons, onions, pumpkins, chillies and cotton in kitchen-gardens, as well as finger millet (Brown, 1966).

In some parts of the island people worked rain-fed terracing (finger millet and cotton), often at some distance from their homes (Pietsch & Morris, 2010), an ancient and well-known practice on the Yemen mainland (Critchely Reij & Willcocks, 1994; Varisco, 2000; Wilkinson, 2003; Pietsch & Mabit, 2012). Much of the cultivation on Soqotra was – and remains – largely rain-fed: preparation of the ground and sowing of seed being timed to coincide with the short winter rainy season – the second half of November to early January – the time when most rains fall (Bruggemann, 1997). In areas with more water, from springs, streams or hand-dug wells, some cultivation was possible over a longer season, but nearly all cultivation – except from the growth of sweet potatoes – ceases with the onset of the hot, dry winds of the summer south-west monsoon (Scholte & De Geest, 2010).

All cultivated exotic plants were introduced to Yemen between the 13$^{th}$ and 15$^{th}$ century AD (Varisco, 1991), and are therefore defined as "traditional". Apart from the widespread cultivation of date palms, small patches of finger millet, cotton and tobacco were grown, with a few kitchen-gardens in some of the better-watered permanent settlements of the northern plains. Brown (1966) reported that 'There is not, in fact, such a person as an arable farmer, in the sense of one who deliberately set out to grow more than he can eat so as to exchange his surplus for other goods and services, in the whole of Soqotra'.

The most widespread foods grown in the kitchen-gardens and on terraces were finger millet (*Eleusine coracana*), sweet potato (*Ipomea batatas*) and squash (*Cucurbita moschata*). Also cultivated were cowpea, (*Vigna sinensis*), hyacinth bean (*Lablab niger*) (with edible leaves, flowers, pods, seeds and roots), gourd or calabash (*Lagenaria siceraria*) (with edible shoots, tendrils and leaves), spring onions (*Allium cepa*), watermelon (*Citrullus lanatus*), various types of musk melon (*Cucumis melo*), chillis (*Capsicum frutescens*) and large white radish (*Raphanus sativus*). More recently tomato (*Solanum lycopersicum*) and cucumber (*Cucumis sativa*) were introduced (Miller & Morris, 2004). Nowadays many new fruits - such as banana, guava and papaya – as well as new vegetables, have been introduced. The cultivation of kitchen-gardens has spread these fruits and vegetables to many areas of the island where they were previously unknown. Some old cultivars were used in new ways, such as sweet potato which is now also cultivated as a green fodder for cattle, the cut foliage readily re-growing. It is fed to the most precious animals during a drought, or to sick livestock (Morris, 2002).

The vertical structure of kitchen-gardens on Soqotra is made up of three or four levels: sweet potatoes, water melons, aubergine and onions (lowest level); tomatoes, chilli peppers and legumes (intermediate level); and bananas, papaya or tamarind in the upper level (Ceccolini, 2002).

Traditionally, fertilisers were well-aged livestock manure (cattle, sheep and goat) and bat guano collected from the many caves of Soqotra. Garden soil was also improved by mixing in black earth dug from underneath and around certain shrubs or trees (as *Euclea*, *Dovyalis*, *Ficus* species, *Citrus*, *Acridocarpus*, *Rhus*, *Tamarindus*, *Hypericum scopularum* and large *Cissus* bushes), date palm foliage and earth removed from around the palms, riverbed silt, or dung-enriched earth collected from livestock folds, pens, milking yards and byres (Morris, 2002). When preparing a plot (new or old) for seed, the soil was made ready by placing small heaps of dried livestock dung (preferably cattle or sheep) across the plot and then laying dry, dead wood (of plants such as *Jatropha*, *Euphorbia arbuscula*, *Commiphora ornifolia* or one of the large-leaved *Boswellia*) alongside before setting fire to it. As the wood and dung burned it was tended by the gardener to ensure that it did not spread, and all of that material was reduced to ash. The ash was then spread in as even layer as possible across the entire plot and, once cooled, it was mixed into the soil thoroughly. Then the whole plot was smoothed over and trodden down. For date-gardens, in the coastal villages where fish were plentiful and constituted the main ingredient of the local diet, small fish and fish debris were dug into the ground around the base of the palms. Now some cultivators are soaking such material in a drum of water for three or more days, and then using the liquid to water their plants (Morris, 2002).

Water was obtained from nearby wells, or carried from a nearby spring or pool. In the Haggeher Mountains where water was more plentiful, channels were dug to divert the flowing water of streams to the cultivated plot. In the cultivated areas around the palace of the last Sultan, at Ilehe, a system of lined channels was constructed to lead water from a central cistern to the various plots. This is said by the islanders to have been a new idea introduced from the Hadramaut (Caton-Thompson & Gardner, 1939; Serjeant, 1964). Watering was carried out differently for different plants: for example climbing beans (*Lablab niger* and *Vigna sinensis*) need to be watered every two or three days, while melon and watermelon have to be watered daily. The newly planted-out shoots of sweet potato have to be watered every second day, after that they manage with watering every four days (Morris, 2002).

**Characteristics and tolerance of the cultivated plants**

The most water-hungry exotic plants grown in the kitchen-gardens of Soqotra Island are banana (*Musa* spp.) (2500 mm), papaya (*Carica papaya* L.), guava (*Psidium guajava*) (1500 mm), sweet potato (*Ipomoea batatas* (L.) Lam) (750 – 1250 mm) and other vegetables such as onion (*Allium cepa* L.), tomato (*Solanum lycopersicum*) and aubergine (*Solanum melongena* L.) (water demand after Rehm & Espig, 1991). The salt tolerance of all these vegetables is generally low, the lowest being the long white radish (*Raphanus sativus*) (Landon, 1993). PH values between 6 and 8 are the best for these plants, but most cultivars accept higher pH values. Vegetables prefer well-aerated soils with a sandy or sandy-loamy texture and low slightly soluble salt content. Sandy texture is provided by coastal substrates, but salts have to be removed by fresh-water irrigation. In contrast to vegetables and fruits (except melon), coconut palms accept up to 1% slightly soluble salt (Rehm & Espig, 1991), date palms – traditionally the plants most widely cultivated on the island – are able to cope with 1.5% slightly soluble salt, in marine environments mainly NaCl and MgCl. Date palms, typically for dry regions with high summer temperatures, use mainly ground water to a depth of 6 m, and brackish water is no problem (Rehm & Espig, 1991; Landon, 1993). Watermelons (*Citrullus lanatus* (Thunb.) are grown on the island in dunes and other sandy plains, and they have a high salt tolerance. Chilli peppers are widespread and most tolerant when irrigated.

## MATERIALS AND METHODS

In 1998 Mubarak Eesa Walid started to cultivate fruits and vegetables for his family's use in a garden about 300 m inland. Over a period of more than 8 years he expanded the garden 240 m towards the shoreline. The garden has two wells and a channel-irrigation system which distributes the surplus water. To determine the land development in Mubarak's Garden, the irrigation system and cultivated plants were mapped (cf. Fig. 2). Soil samples were taken from four sections of the garden (EIR01 to EIR08) of different time periods of cultivation. For this first insight into garden soils on Soqotra, sampling was carried out in the topsoil (5-10 cm) and the subsoil (20-30 cm). To compare these soils with natural materials, original beach sand (EIR00), dried and partially-burned fish material and sheep dung (EIR-F, EIR-S) were sampled, and data from a previously investigated Sodic Cambisol were added for comparison (WD13; Pietsch, 2006). Soil evaluation was based on Landon (1993). Bulk samples were air dried and sieved < 2 mm. Fine earth < 2 mm was used for (i) grain size analysis using a combined sieve and pipette method (KÖHN) after removal of organic material by $H_2O_2$, (ii) for gasvolumetric determination of $CaCO_3$, (iii) for the detection of exchangeable cations (Blume et al., 2000) and (iv) for $pH_{[H20]}$ and EC measurements with a glass electrode (Sentix 81, WTW) using a soil to solution ratio 1 : 2.5 (Rayment & Lyons, 2011). Slightly soluble salt contents (NaCl equivalent) were calculated according to the FAO (2006): salt % = EC $mS/cm^{-1}$*0.067*2.5, and evaluated according to Landon (1993). A portion of each sample < 2 mm was ground with a ball mill and used to determine total carbon content ($C_t$), which was measured after heat combustion (1150°C) with an element analyser (Elementar Vario EL III). Organic carbon was determined by the formula $C_{org} = C_t - C_{CaCO3}$. Plant-available phosphate ($P_{av}$) was determined with an IC (Dionex DX 120) and then evaluated according to Landon (1993). For soil physical and chemical data and analyses refer to Table 1. Soil classification was according to the WRB (IUSS Working group WRB 2007). Plant ecological specifications such as salt tolerance were applied from Rehm, Espig (1991).

## RESULTS AND DISCUSSION

### Size, irrigation and fertilisation of the garden

Mubarak's Garden has meanwhile extended nearly to the shoreline (Fig. 2). Other beds with tomatoes have been established next to his earlier garden, and some parts of this new area have been planted with young date palms. Undeveloped areas of land (dotted line) are grazed by goats. The garden area, 70 m wide and 240 m long, is subdivided into three smaller areas and a single large central area. All have different plant compositions and have been cultivated for different periods of time, with a minimum of one year and a maximum of more than eight years, the time of the current investigation. .

**Fig. 2: Mubarak Eesa Walid's kitchen-garden on the northern coast of Soqotra Island**

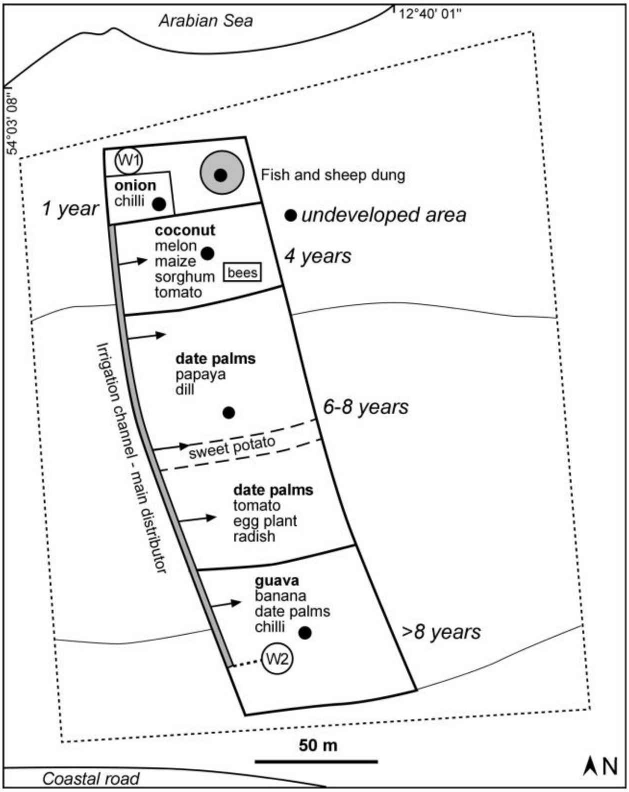



**Fig. 3: Land improvement in 'Eyrho**:
a. irrigation by the help of water channels – view direction south, b. burnt fish and sheep dung, c. papaya fruits and well (W2), in the background (EIR08), d. bed of sweet potatoes beneath date palms (EIR06), e. coconut palms surrounded by sorghum and tomatoes (EIR04), f. new beds with onion and chilli, near to the shoreline (EIR01).

When cultivating exotic plants in an arid hypersaline environment, high amounts of fresh water are necessary. This is provided by two wells: one little-used of brackish water (W1) and one heavily used, of fresh water (W2). Both wells are recharged from the groundwater of the Wadi Hajarah catchment area, the most eastern wadi of the Hadiboh coastal plain, but well W1 is strongly affected by sea-water input. As in the Hadramaut, water is pumped to the surface and led via channels to the garden beds. The main distributor (Fig. 3a), constructed from stone, leads the water from the well to the fields via adjacent channels.

The direction and flow of water is controlled by simple valves. The frequency of water supply is related to the type of plant being grown. The bed with sweet potatoes in the centre of the garden is bounded by two narrow stony channels (cf. Fig. 2, interrupted line). For watering single fruit trees, tube irrigation is applied. Pollination of plants has recently been supported by bees; a beehive has been set up in the second section of the garden, inland.

In some sections the soil has been enriched with fish material and sheep dung, stockpiled at the top of the garden (Fig. 3b). Fish dung holds 19% organic carbon and 6,590 $mg \cdot kg^{-1}$ $P_{av}$, and sheep dung 25% organic carbon and 13,250 $mg \cdot kg^{-1}$ $P_{av}$ (Tab. 1). Mubarak Eesa Walid also experimented with different natural fertilisers: some beds were enriched with dried and/or burned sheep dung, some with dried and burned fish material.

**Structure, plants and bed cultivation in Mubarak's garden**

The four sections of the garden grow many different kinds of fruits, vegetables and palms. The range of plants cultivated is unusually extensive, not only exotic plants, some of which might have been introduced to Yemen some 800 years ago (Varisco, 1991), but also because of the experimental approach of Mubarak Eesa Walid. Date palm (*Phoenix dactylifera* L.), long white radish (*Raphanus sativus*), different taxa of sorghum, fruit trees such as banana, and vegetables such as aubergine (*Solanum melongena* L.), onion (*Allium cepa)* and the herb, dill (*Anethum graveolens*) are all growing in the garden, and coconut (*Cocos nucifera*) and citrus trees such as lime (*Citrus aurantifolia*) and lemon (various *Citrus* sps.) as part of the upper vertical level, have been introduced by him to the coastline itself.

This great range of plants in the different sections and levels of the garden has resulted in a high plant diversity when compared to other kitchen-gardens on Soqotra (Cecollini, 2002). By introducing an irrigation system from Hadramaut based mainly on fresh water from a well (W2), water is permanently available, and salt-intolerant plants can be cultivated, such as banana, papaya, coconut, sweet potato, onion, tomato and aubergines. All vegetables normally have a low slightly soluble salt tolerance, and grow best with a pH of 6, but due to the fresh water irrigation and low, salt content, higher pH values are tolerated (Rehm & Espig, 1991). Date palms, typical for dry regions with high summer temperatures, can live with a shallow and a deep ground-water level of brackish water (down to 6 m); and can tolerate soil pH of 8 and slightly soluble salt content up to 1.5%.

Guava, banana, and some date palms and chilli peppers have been cultivated in the oldest and furthest-inland beds since 1998. This section (EIR08) has a well (W2) with fresh water (Fig. 3c), but this becomes slightly saline in dry years. Today this well provides nearly all the water for the whole garden, since the water of the well (W1) in section one – in use since 2007 – is brackish. The water of W1 is used to irrigate onion, chilli pepper and water melon. The third inland section (EIR06) has been in use for six to eight years, and was mainly planted with date palms, with some papaya (cf. Fig. 3c), tomatoes, aubergine and long white radish, as well as dill (the latter is not a typical herb on Soqotra). A bed of sweet potatoes is located in the centre of this section (Fig. 3d). The most recent attempt to grow citrus trees in the oldest and furthest inland section of the garden (profile EIR08) has failed:

one reason is the lack of sunlight available beneath the palm trees, the other is a moderate slightly soluble salt content of 1.4 % in the soil (Tab. 1).

Section two inland (EIR04) has been in use for about four years. It is the most unique part of the garden, because it is the only garden on Soqotra to be planted with coconut palms (Fig. 3e). Neighbouring Soqotrans did not believe that coconut could be successfully cultivated, because it is not a plant which has ever been grown on Soqotra. However, after four years the first coconut was successfully harvested. The salt tolerance of coconut trees is about 1% (Rehm & Espig, 2001). Section one at the shoreline (EIR01) was cultivated with onions and chilli in the first year (Fig. 3f). Only irrigation with fresh water from well W2 enables the growth of these cultivars.

**Modified sediment and soil properties**

Land improvement does not only mean a higher plant diversity, but also soil melioration. When interpreting changing soil properties as a result of agricultural land-use on a hypersaline dry tropical coast, three dimensions should be taken into consideration: (a) horizontal (shoreline-inland), (b) vertical (topsoil-subsoil), such as the depth function of clay contents and chemical properties, and (c) the time of cultivation in relation to the reference soil profiles EIR00 (beach sand) and WD13 (uncultivated Cambisol formed in red loam).

Texture

Along the north-south gradient of the garden, clay and fine silt content is increasing, while inland sand content is decreasing. In sections EIR06 and EIR08 clay content reaches 11 to 18.5%, two or three times higher than the soils closer to the shoreline with only 3 to 10% clay (EIR01 to EIR04, Fig. 4). The clay content in WD13 also demonstrates how this rises with increasing distance from the Haggeher Mountains (Pietsch, 2006). Cultivated soils formed in a mixture of red loam from weathered limestone, basalt and granite, and marine sands contain only 60 to 70% sand. The sand content of beach profiles at the shoreline in the north of the garden is 90 to 95% sand (EIR00, Fig. 4).

Depth functions of clay content of 1:2 from the topsoil to the subsoil (5% topsoil, 10% subsoil in EIR01-04) may be a result of a “silting up” process, due to the tides and related sedimentation (Birse et al., 1997; Leroy et al., 2004; Cheung & DeVantier, 2006). Clay content in the topsoil and subsoil in the older cultivated beds further inland do not vary significantly with depth: 11% (EIR06) and 14 to 18% (EIR08). This lack of difference could be explained by clay illuviation due to irrigation, whereas the different clay content in profile WD13 (9.5% topsoil, 21.5% subsoil) are due to different soil substrates (AB: sand above 2Bw: loamy sand; Pietsch, 2006).

SOM, $C_{org}$ and $P_{av}$

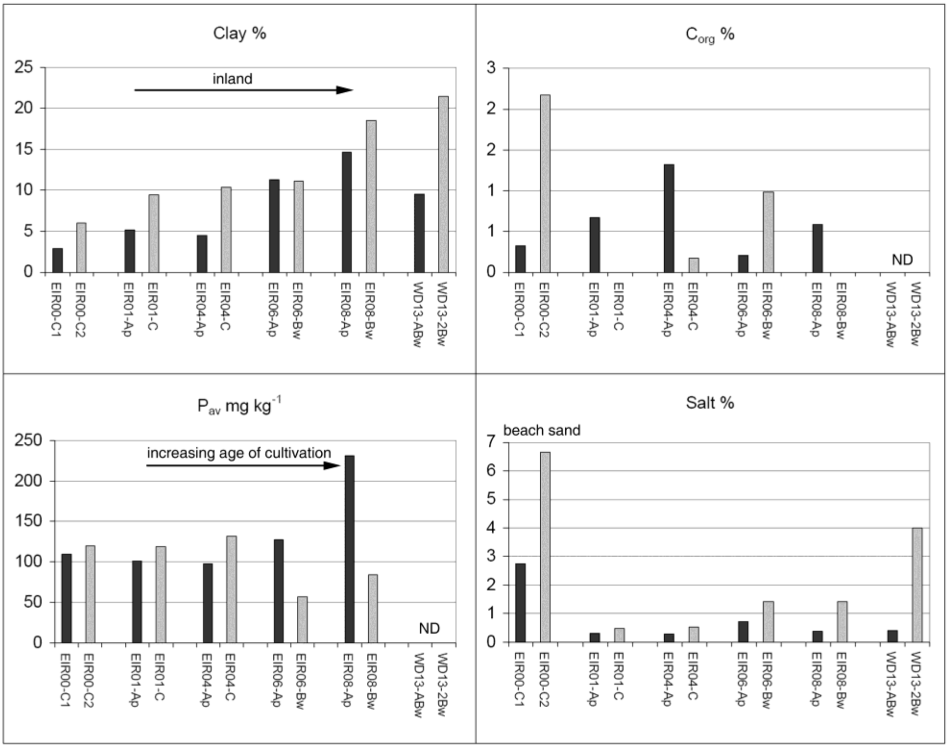
As expected, soil organic matter content is generally low, ranging from 0.6 to 1.1%. Nevertheless a trend can be seen: after 8 years of cultivation SOM contents increased slightly from 0.6 to 1.1% (cf. Tab. 1). Organic carbon is mainly the result of fertilisation with fish and sheep dung. In the topsoil it rises rapidly: even after one year it rose from 0 to 0.7% (EIR00-EIR01 Ap horizon), and after four years, to 1.3% (EIR01 Ap horizon, Fig. 4). The $P_{av}$ content in cultivated beds rose from approximately 100 $mg \cdot kg^{-1}$ to 230 $mg \cdot kg^{-1}$ after 8 years (EIR00-EIR08), because fish and sheep dung with high concentrations of $P_{av}$ was mixed with the soil (fish 6500, sheep 13.000 $mg \cdot kg^{-1}$ $P_{av}$, Tab. 1). 21 $mg \cdot kg^{-1}$ $P_{av}$ may already be enough for plants such as sweet potatoes, onion, sorghum and maize (Landon, 1993).

**Table 1: Substrates, cultivation, and soil physical and chemical data (- not determined)**

| Profile Horizon | Depth | Substrates | Cultivation | 2000–630 μm[a] | 630–200 μm[a] | 200–125 μm[a] | 125–63 μm[a] | 63–20 μm[a] | 20–6.3 μm[a] | 6.3–2 μm[a] | <2 μm[a] | SOM[b] | Salt[c] | $C_{org}$[d] | $CaCO_3$ | Ca[e] | Mg[e] | Na[e] | K[e] | Ca:Mg[f] | $P_{av}$ | pH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [cm] | | (years duration) | | | | | | | | [%] | | | | | | | | | | mg·kg$^{-1}$ | | μS/cm$^{-1}$ |
| **EIR01** | | | | | | | | | | | | | | | | | | | | | | | |
| Ap | 5–10 | Marine sand | Vegetables (1) | 12.5 | 47.0 | 27.0 | 5.3 | 1.4 | 1.3 | 0.3 | 5.2 | 0.8 | 0.3 | 0.7 | 50.1 | 71.0 | 23.5 | 5.6 | 0.0 | 3.0 : 1 | 100.7 | 8.3 | 180 |
| C | 20–30 | Marine sand | | 12.6 | 39.9 | 25.6 | 5.9 | 1.9 | 2.6 | 2.0 | 9.5 | 0.9 | 0.5 | 0.0 | 57.3 | 73.6 | 23.2 | 3.1 | 0.1 | 3.2 : 1 | 118.6 | 8.4 | 290 |
| **EIR04** | | | | | | | | | | | | | | | | | | | | | | | |
| Ap | 5–10 | Marine sand | Coconut, grain, | 17.0 | 49.0 | 22.9 | 4.6 | 0.3 | 1.1 | 0.5 | 4.6 | 0.7 | 0.3 | 1.3 | 40.8 | 50.7 | 35.8 | 13.5 | 0.0 | 1.4 : 1 | 98.1 | 8.2 | 170 |
| C | 20–30 | Marine sand | vegetables (4) | 17.7 | 44.5 | 15.4 | 4.3 | 1.7 | 1.7 | 4.4 | 10.3 | 0.9 | 0.5 | 0.2 | 48.7 | 49.7 | 37.9 | 11.5 | 0.9 | 1.3 : 1 | 132.1 | 8.3 | 320 |
| **EIR06** | | | | | | | | | | | | | | | | | | | | | | | |
| Ap | 5–10 | Marine sand, red loam | Date palms, vegetables, | 20.9 | 39.5 | 9.3 | 7.5 | 2.8 | 2.5 | 6.2 | 11.3 | 0.7 | 0.7 | 0.2 | 39.3 | 50.6 | 35.5 | 12.4 | 1.5 | 1.4 : 1 | 127.7 | 8.2 | 420 |
| Bw | 20–30 | Marine sand, red loam | fruits (6-8) | 13.6 | 38.0 | 6.8 | 4.6 | 2.5 | 3.6 | 19.8 | 11.1 | 0.7 | 1.4 | 1.0 | 36.9 | 57.9 | 26.3 | 13.5 | 2.2 | 2.2 : 1 | 56.7 | 8.2 | 840 |
| **EIR08** | | | | | | | | | | | | | | | | | | | | | | | |
| Ap | 5–10 | Marine sand, red loam | Date palms, fruits (>8) | 20.9 | 32.3 | 7.9 | 8.9 | 4.2 | 3.8 | 7.4 | 14.6 | 1.1 | 0.4 | 0.6 | 36.7 | 47.1 | 29.4 | 22.3 | 1.1 | 1.6 : 1 | 230.9 | 8.0 | 220 |
| Bw | 20–30 | Marine sand, red loam | | 27.3 | 29.7 | 3.8 | 3.0 | 3.5 | 3.3 | 10.9 | 18.5 | 0.6 | 1.4 | 0.0 | 52.7 | 29.6 | 50.1 | 18.7 | 1.6 | 0.6 : 1 | 84.0 | 8.1 | 850 |
| **EIR00** | | | | | | | | | | | | | | | | | | | | | | | |
| C1 | 5–10 | Marine sand | None | 16.8 | 49.1 | 24.6 | 4.7 | 1.0 | 0.7 | 0.2 | 2.9 | 0.6 | 2.8 | 0.3 | 51.7 | 52.8 | 26.0 | 19.1 | 2.1 | 2.0 : 1 | 109.5 | 8.4 | 1650 |
| C2 | 20–30 | Marine sand | | 14.4 | 51.3 | 21.0 | 3.9 | 0.8 | 1.6 | 1.0 | 6.0 | 0.6 | 6.7 | 2.2 | 36.1 | 42.7 | 23.1 | 24.0 | 1.2 | 1.3 : 1 | 119.5 | 8.1 | 3980 |
| **EIR-F** | 0 | Dried fish | Dung | - | - | - | - | - | - | - | - | - | - | 19.3 | - | - | - | - | - | - | 6.590.0 | - | - |
| **EIR-S** | 0 | Dried sheep | Dung | - | - | - | - | - | - | - | - | - | - | 25.1 | - | - | - | - | - | - | 13.250.0 | - | - |
| **WD13** | | | | | | | | | | | | | | | | | | | | | | | |
| ABw | 0–5 | Marine sand, red loam | None | 23.4 | 42.6 | 11.4 | 5.3 | 3.6 | 0.9 | 3.2 | 9.5 | 1.1 | 0.4 | - | 29.1 | 56.4 | 18.1 | 15.3 | 10.2 | 3.1 : 1 | - | 8.6 | 300 |
| 2Bw | 5–30 | Marine sand, red loam | | 22.2 | 32.9 | 8.1 | 4.1 | 2.8 | 2.5 | 5.9 | 21.5 | 1.5 | 4.0 | - | 35.7 | 73.5 | 10.2 | 15.1 | 1.2 | 7.3 : 1 | - | 7.9 | 230 |
| 2C | 30–55+ | Marine sand, red loam, reef | | 24.5 | 29.9 | 5.6 | 2.6 | 1.8 | 3.5 | 7.7 | 24.5 | 0.4 | 6.5 | - | 49.6 | 74.4 | 7.7 | 15.9 | 2.0 | 9.6 : 1 | - | 8.1 | 390 |

a Particle size classes (coarse, middle, fine, finest sand; coarse, middle, fine silt; clay)
b SOM Soil organic matter
c Slightly soluble salts (NaCl equivalent; deduced from $EC_{2.5}$ (FAO, 2006)
d $C_{org}$ organic carbon
e Exchangable cations in %
f Ratio of exchangable cations Calcium and Magnesium (Landon, 1993)

**Fig. 4: Distribution of clay, organic carbon ($C_{org}$), plant available phosphorous ($P_{av}$) and slightly soluble salts in topsoil (5-10 cm depth) and subsoil (20-30 cm depth)**




<u>$CaCO_3$ and slightly soluble salt contents</u>

The sources of calcium carbonate in sediments and soils are primarily mollusc shells embedded in marine quartz sand. Secondary calcification might play a role (Pietsch & Kühn, 2009): $CaCO_3$ contents of 36 to 57% are common in the garden beds; no significant distribution is visible, either along an inland gradient or vertically from the top- to the subsoil.

According to the WRB, soils are hyposodic with > 15% exchangeable Na, sodic with > 15% exchangeable Na-Mg and salic with > 1 to 2.5% slightly soluble salt contents. Beach sand EIR00 is in 20-30 cm depth with 6.7% slightly soluble salt hypersalic. The irrigation of beach sands leads to the leaching of slightly soluble salt and a de-salinisation down to 0.3% (cf. Fig. 4). EIR06 and EIR08 became slightly saline in the subsoil (1.4% slightly soluble salt) probably the result of permanent irrigation over > 6 or 8 years. This salt content, however, can be tolerated by most plants, and compared to the original salt content of beach sands and high salt content of the uncultivated Cambisol WD13 (subsoil 4% slightly soluble salt), the land has clearly improved in terms of de-salinisation.

<u>PH, exchangeable cations and Ca:Mg ratio</u>

PH values in the garden soils vary from 8 to 8.4 (cf. Tab. 1). Mg and Ca might be increasingly unavailable at these high pH values. Using calculated Ca:Mg ratios of < 3:1, $P_{av}$ uptake may be reduced (Landon, 1993), except in the recently cultivated bed EIR01, with an optimal ratio for plants of 3:1. Because the salinity along the Soqotran coasts is extremely fluctuating (Cheung & DeVantier, 2006), and the chemical parameters already discussed are very sensitive, a regional interpretation of any vertical or horizontal gradient seems to be unsatisfactory at this stage of research.

## CONCLUSION

In contrast to many results from research into land degradation caused by agricultural use in the dry tropics, the present study demonstrates positive effects on the land from agricultural use, i.e. in the form of (1) an increase in plant diversity and (2) a decrease in slightly soluble salt content. Certainly, (3) no appropriate increase/decrease in exchangeable cations and the Ca:Mg ratio are apparent, because both chemical parameters are very sensitive, due to the fluctuating salinity along the Soqotran coasts: the interpretation of any vertical or horizontal gradient seems unsatisfactory.

The study also demonstrates that an investigation of three dimensions is necessary when investigating and evaluating land improvement: (a) the horizontal (shoreline-inland), (b) the vertical (topsoil-subsoil) and (c) the period of cultivation in relation to unused sediments and soils. Selected plant ecophysiological parameters such as texture, salt tolerance, $CaCO_3$, $P_{av}$ and pH clearly indicate soil melioration, and increased soil quality over the years. $P_{av}$ contents reflect the intensity of fertilisation with dried and burned fish and sheep dung over 6 to >8 years, while $P_{av}$ contents in briefly exploited and undeveloped areas (beach sands) remain the same. Soil investigations also showed that even after only one year of cultivation the $C_{org}$ contents had strongly increased, and in topsoils a general decrease in slightly soluble salts was identifiable. This can be explained by differing periods of irrigation and the decrease of marine influence with distance from the shoreline. A vertical increase of clay content occurs in the soils which have been cultivated for the longest time; here not a result of a silting up process, but from long-term irrigation over more than 6 years.

The study documents that kitchen-gardening by Mubarak Eesa Walid along the shoreline in the North of Soqotra Island, under irrigation with fresh water and soil melioration by fertilisation, leads to enormous land improvement as well as an increase in subsistence food production.

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