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# Mangrove, *Avicennia marina*, Establishment and Growth under the Arid Climate of Kuwait

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*The State of Kuwait is making concerted efforts to enhance greenery along its coastline. This study was conducted during 1999–2002 for identifying key soil factors associated with successful establishment and rapid growth in Avicennia marina. Based on the review of available data, repeated visits to potential sites, on-site assessment and laboratory characterization of soils, five sites (Shuwaikh, Sulaibikhat I, Sulaibikhat II, Doha, and Sabiya) were selected for establishing pilot plantations. Acclimatized seedlings were used to establish these plantations. Periodic data indicated wide variations both in seedling survival and growth both among sites and at different locations within each site. The highest seedling survival (71.0 to 81.2%) was observed in the Doha site and ranged from 16.1 to 78.0% in other sites. In general, seedlings planted along the tidal line showed the survivability and produced greater number of branches than those planted farther away from the tidal line. Postplanting on-site and laboratory analyses of soil samples showed that the highest seedling survival was associated with the presence of silty loam or fine-textured sand fractions in the upper 5 cm layer, medium to coarse textured sand material between 5 and 30 cm and an anaerobic silty loam or clayey layer below 30 cm depth. In contrast, greater proportion of gravel or clay fractions in the upper 30 cm layers increased seedling mortality and affected plant growth. Other factors such as low soil moisture, poor drainage conditions, high soil salinity and high sodicity also increased seedling mortality in some areas.*

**Keywords** site selection, mangal, marine ecosystem, intertidal mudflats, coastal greening

Historically, marine ecosystems have been an important renewable resource for Kuwait. However, in recent years, increased developmental activities and misuse of native vegetation have greatly degraded the coastal environment and marine eco-systems. Harsh weather conditions have also accelerated the disappearance of vegetation cover in coastal and inland areas. Hence, the State of Kuwait has initiated a comprehensive national greenery program to both beautify and enrich the living environment. The 290 km long coastline, of which approximately 57% is the inter-tidal zone, offers a good potential for greenery development (Abu El-Nil et al., 2001). Afforestation of intertidal zones with *Avicennia marina* (Forssk.) Vierh. (mangrove) plants is considered a sound strategy to improve coastal environment and enrich marine biodiversity. Mangrove plants also protect the coastline from strong currents and support the accumulation of sediments and organic matter in the intertidal zone. These changes could improve the quality of mudflats and promote the survival and growth of marine fauna (Embabi, 1993; Ogino, 1993; Subandar et al., 2001). Due to their moderating influence on the climate, mangrove plants would enhance the aesthetic and recreational value of the coastline. In view of these benefits, studies were conducted during 1999–2002 to locate suitable sites along Kuwait's coastline and identify site characteristics that would support maximum seedling establishment and growth.

## Materials and Methods

### Climate and Geomorphology of Coastal Environment

Geographically, Kuwait occupies approximately 17,800 km$^2$ of the northwestern part of the Arabian Gulf, between 28°30′ and 30°05′N, and 46°33′ and 48°30′E. Kuwait's climate is characterized by harsh summers and mild winters. Temperature extremes are high, with means during the warmest and coolest months ranging between 46.2°C and 6.9°C (Kuwait Ministry of Planning, 1998). Winter brings occasional frost. Rainfall is minimal, not exceeding 115 mm a$^{-1}$, but evaporation is very high, averaging 14.1 mm d$^{-1}$. The relative humidity is low, and strong, dry, and hot, northwesterly winds prevail during summer, particularly in June and July. Kuwait's soils are sandy in texture, alkaline, high in calcareous materials (CaCO$_3$) and low in organic matter and plant nutrients. Underground water resources are limited and brackish in nature with total dissolved solids (TDS) concentrations ranging from 3.0 to 10.0 g L$^{-1}$.

The geomorphology of the Kuwait marine environment is characterized by a shallow shelf of depth less than 30 m, and the depth tends to increase towards the southeasterly direction (Subandar et al., 2001). One of the important features of this ecosystem is the Kuwait Bay, an elliptical engulfment protruding westward from the main Gulf water, with depths mostly between 0–10 m. Another important char-acteristic of this environment is its hyper saline condition created by high eva-poration and very little fresh water discharges from the Shatt Al-Arab and runoff (Al-Ghadban & Al-Ajmi, 1993)

The important parameters affecting Kuwait's coast are temperature, salinity, tides, currents, and waves. Water temperature ranges between 13.2°C to 31.5°C, and salinity fluctuates between 38.6 and 42.4% (Subandar et al., 2001). The tides in the northern part, including Kuwait Bay, are semidiurnal, ranging from 0.5 m (neap tides) to 4.2 m (spring tides) and run parallel to the coastline. In the Kuwait Bay, the maximum current velocity recorded during neap and spring tides never exceeded 50 cm/s (Abou-Seida & Al-Sarawi, 1990). The geomorphology of marine environ-ment in Kuwait encourages the formation of a highly sedimentary environment. Soft-substrate habitats (mudflats), which account for 57% of the Kuwait's coastline, are spread around the Bubiyan Island to Kuwait Bay and offer good potential for expanding fisheries industry.

## Site Selection

Preliminary selection of potential sites was made by reviewing aerial photographs and available information from different sources (Al-Sarawi et al., 1985). On visiting a number of sites, it was observed that the coastline in the southeast around Al-Khairan and near Kuwait city was affected by increased construction and urbanization activities and, as such, was covered by coarse sandy materials. In contrast, the mudflats around the Kuwait Bay contained mostly silty loam to fine sandy materials. Hence, the intertidal zones between Shuwaikh port and the Bubyan bridge in Sabiya were surveyed extensively to locate potential sites. Based on past experience and literature review, a set of nine criteria (accessibility; grazing pressure; texture of mudflats; topography; tidal coverage; presence of household wastes, construction materials and rubbles; contamination by fresh oil spills; discharge of drainage effluents; and accumulation of salt crystals on the soil surface) was developed (Table 1). Fourteen potential sites were thoroughly assessed using these criteria. On-site assessments were further supported by photographic records and on-site notes on existing physical features. Soil samples were collected from five highly potential sites. These samples were processed by air drying and sieving to separate gravel/rock fragments (>2 mm dia.) and fine fractions (<2 mm dia.). The weight of each fraction was recorded separately and the gravel/rock fragments were discarded. The fine soil fractions were analyzed for important physical and chemical properties using recommended procedures (Page et al., 1982; USDA, 1988, 1995, 1996). Soil texture was determined by the modified hydrometer method supplemented with wet sieving (Shahid 1992). The USDA textural class (Soil Survey Division Staff, 1993) was used to define soil texture class. Soil color was determined using the Munsell Soil Color Chart (Munsell, 1998).

On-site assessment of 14 potential sites and detailed physical and chemical characterization of five sites finally selected for establishing mangrove plantation are presented in Tables 1 and 2.

**TABLE 1** Criteria used for Selection of Potential Sites

| Site # | A | B | C | D | E | F | G | H | I | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☒ | √ | ☒ | ☒ | ☒ | ☒ | √ | √ | ☒ | |
| 2 | √ | √ | ☒ | ☒ | ☒ | √ | √ | √ | ☒ | |
| 3 | √ | √ | √ | √ | √ | ☒ | √ | √ | √ | |
| 4 | √ | √ | √ | √ | √ | √ | √ | √ | √ | Selected |
| 5 | √ | √ | √ | √ | √ | ☒ | ☒ | ☒ | √ | |
| 6 | √ | √ | √ | √ | √ | ☒ | ☒ | ☒ | √ | |
| 7 | √ | √ | √ | √ | √ | √ | √ | √ | √ | Selected |
| 8 | √ | √ | √ | √ | √ | ☒ | √ | ☒ | √ | |
| 9 | √ | √ | √ | √ | √ | √ | √ | √ | √ | Selected |
| 10 | ☒ | √ | √ | ☒ | ☒ | ☒ | √ | ☒ | ☒ | |
| 11 | √ | √ | √ | √ | √ | √ | √ | √ | √ | Selected |
| 12 | ☒ | ☒ | √ | ☒ | ☒ | √ | √ | √ | ☒ | |
| 13 | √ | √ | √ | ☒ | ☒ | √ | √ | √ | √ | |
| 14 | √ | √ | √ | √ | √ | √ | √ | √ | √ | Selected |

√ = Fulfills the criterion;
☒ = do not fulfill the criterion;
A - Easy accessibility; B - No grazing; C - Silty/clayey mudflats; D - Suitable topography; E - Regular tidal coverage; F - Noncontaminated from household refuse, construction materials and rubbles; G - Noncontamination by oil spills; H - Noncontamination by drainage effluents; I - Nonsaline and nonshelly.

TABLE 2 Physical and Chemical Characteristics of a Typical Soil Pedon Selected for Mangrove Plantation

| Site | Horizon | Layer (cm from surface) | PHs | ECe dS m$^{-1}$ | SAR (mmole L$^{-1}$)$^{0.5}$ | CaCO$_3$ % eq. | Sand (%) | Silt (%) | Clay (%) | Texture class |
|---|---|---|---|---|---|---|---|---|---|---|
| Shuwaikh | Akzg | 0–3 | 8.02 | 74 | 104 | 31.4 | 26 | 39 | 35 | CL |
|  | Bkzg | 3–30+ | 7.75 | 32 | 66 | 21.1 | 41 | 25 | 34 | CL |
| Sulaibikhat | Akzg | 0–5 | 8.11 | 64 | 93 | 40.0 | 30 | 34 | 36 | CL |
|  | Bkzg | 5–30 | 8.13 | 43 | 111 | 34.2 | 14 | 47 | 39 | SiCL |
| Sulaibikhat II | Akzg | 0–5 | 8.43 | 60 | 86 | 28 | 48 | 29 | 23 | L |
|  | Bkzg | 5–30 | 8.40 | 47 | 92 | 30.1 | 42 | 19 | 39 | CL |
| Doha | Akzg | 0–10 | 8.19 | 124 | 190 | 35.1 | 44 | 31 | 25 | L |
|  | Bkzg | 10–30+ | 8.23 | 115 | 135 | 34.1 | 34 | 31 | 35 | CL |
| Sabiya | Akzg | 0–10 | 8.01 | 51 | 186 | 15.3 | 72 | 16 | 12 | SL |
|  | Bkzg | 10–30+ | 8.08 | 28 | 170 | 19.8 | 69 | 18 | 13 | SL |

Akzg and Bkzg are horizons and textural definitions are as per USDA soil classification; A = surface horizon, B = subsurface horizon; k = presence of >15 % CaCO$_3$; g = presence of gleying or mottling; z = accumulation of salts more soluble than gypsum; pHs = pH of saturated paste; ECe = Electrolytic conductivity; SAR = sodium adsorption ratio; clay – < 0.002 mm; silt –0.002–0.05 mm; sand–0.05–2.0 mm; SL = sandy loam; L = Loam; CL = clay loam; SiCL = silty clay.

### Raising of Seedlings

Seeds (referred to as "propagules" in some mangrove species) of *Avicennia marina* used for raising seedlings were procured from United Arab Emirates. Freshly harvested seeds were packed in corrugated fiber board (CFB) cartons and hand carried on the following day. Immediately upon arrival, seeds were unpacked and graded into large (with an average weight of 5.0 g) and small size (average weight of 2.4–2.5 g) before placing them in fresh water (total dissolved salts around 500 mg $L^{-1}$). Holding water was changed daily and the separated peels were removed to prevent the accumulation of phenolic compounds in the holding water. Out of the various soaking duration treatments (0, 24, 48, or 72 h) tested, 24-h soaking treatment resulted in the most rapid and greater germination than other treatments. Hence, this treatment was used in subsequent studies. Presoaked seeds were germinated in specially designed galvanized iron (GI) trays or polyethylene-lined benches in an evaporatively cooled greenhouse. For improving survival and growth in the field, seedlings were acclimatized to prevailing salinity levels by gradually raising the salinity levels of the holding water to around 50 g $L^{-1}$ (50,000 ppm). The seedlings were maintained at this salinity level until they are transferred to the field.

### Field Planting

Acclimatized seedlings with an average height of 20–25 cm were planted in five selected sites for nine months. Thirty-cm planting holes were prepared in three or more rows (tidal line and one or more lines on either side of the tidal line) at $1 \times 1$ m spacing. Seedlings were handled to prevent any damage to the root system. The taproot with its root ball intact was inserted into the planting holes and back-filled with native soil. Approximately 1,500 to 2,000 seedlings were planted at each site.

### Postplanting Monitoring

Survival and growth of seedlings at different locations within each site were recorded at three-month intervals. Plant performance data were supported by on-site assessment and soil analysis. Following on-site assessment, soil samples were collected from different locations that contained maximum number of established and dead seedlings in each of the five sites. Soil samples were analyzed using procedures described above and compared with plant growth data to identify site characteristics that led to successful establishment and growth of seedlings.

### Statistical Analysis

The growth data were statistically analyzed using the analysis of variance (ANOVA) procedures and significant treatment means were identified by using the Duncan multiple range test at $p = 0.05$ (Little and Hills, 1978).

## Results

### Seedling Survival and Vegetative Growth

A considerable variation in the establishment and growth of *Avicennia marina* seedlings was observed both among sites and within each site (Table 3). Seedling survival was the highest (71.0 to 81.2%) in the Doha site and ranged from 16.1 to 86.0% in Sulaibikhat I, 21.4 to 65.8% in Sulaibikhat II, 40 to 78.0% in Shuwaikh, and from 40 to 63.8 % in Sabiya. In general, seedlings planted along or near to the tidal line showed the maximum survivability and height increases (Table 3).

TABLE 3 Average Survival, Height, and Number of Branches in *Avicennia marina* Seedlings in Five Selected Sites

| Site | Location of the seedlings | Final survival (%) | Average height (cm) day | | Average branches/Plant day | |
|---|---|---|---|---|---|---|
| | | | 90 | 270 | 90 | 270 |
| Shuwaikh | TL | 78.6a | 46.7a | 41.8a | 1.00a | 4.85a |
| | 3 m Below TL | 40.0b | 46.0a | 38.3a | 1.00a | 3.20a |
| | 2 m above TL | 70.9a | 20.5a | 30.5a | 1.30a | 4.50a |
| Sulaibikhat I | TL | 86.0a | 20.1a | 28.3a | 1.36a | 3.38a |
| | 1–2 m below TL | 68.8a | 18.8a | 27.8a | 1.45a | 3.30a |
| | 3–4 m below TL | 72.5a | 21.6a | 26.5a | 1.20a | 3.90a |
| | 6 m below TL | 16.1b | 20.5a | 26.1a | 1.24a | 3.20a |
| | 2 m above TL | 33.3b | 25.1a | 27.9a | 1.30a | 3.10a |
| Sulaibikhat II | TL | 65.8a | 27.3a | 31.3a | 1.36a | 3.92a |
| | 2 m below TL | 44.4ab | 24.3a | 37.8a | 1.45a | 3.47a |
| | 3 m below TL | 21.4b | 24.8a | 29.5a | 1.05a | 2.49a |
| Doha | TL | 81.2a | 18.6a | 21.7a | 1.93a | 7.20a |
| | 1 m below TL | 71.0a | 18.5a | 18.3a | 1.81a | 3.62b |
| | 3 m above TL | 63.8a | 22.6a | 31.9a | 1.00a | 2.83a |
| Sabiya | TL | 50.0a | 24.6a | 34.3a | 1.56a | 2.98a |
| | 3 m below TL | 40.0a | 22.6a | 31.7a | 1.56a | 3.28a |

TL = Tidal line; Average height measured from soil surface to the tip of the uppermost leaf. All plants died above TL in Shuwaikh site. The figures within each site followed by the same letter are not significantly different at $p = 0.05$.

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The average height of seedlings and the number of branches per plant also varied from site to site and at different locations within the same site (Table 3). Seedlings in the Shuwaikh site with an average height of 38.3 to 41.8 cm in 270 days after planting were the tallest as compared to those in other sites. The number of branches per plant was highest (3.62 to 7.2) in the Doha site as compared to that in the Shuwaikh (3.21 to 4.85), Sulaibikhat I (3.2 to 4.5), Sulaibikhat II (2.4 to 3.92), and Sabiya site (2.83 to 3.28). Again, plants along or near the tidal line produced the most number of branches.

### Postplanting Site Assessment

*Shuwaikh Site.* For postplanting site assessment, the Shuwaikh site was divided into three zones: the upper sloping sandy zone (above the tidal line where all seedlings died), the middle sandy-gravelly-muddy zone (showing successful establishment of seedlings), and the lower muddy zone (where a majority of seedlings died). The data presented in Tables 4 and 5 are based on the assessment of five profiles from each zone. The upper sandy zone contained mainly gravels (>2 mm in dia) and sand fractions up to 30 cm depth. Among various fractions that were <2 mm in dia, the medium and coarse sand fractions accounted for more than 90% (Table 4). The soil in this zone had low ECe, SAR, $CaCO_3$ content and saturation percentage (Table 5). In contrast, the lower muddy zone, which also resulted in maximum seedling mortality, was characterized as a deep muddy profile with very little sand or gravel fractions. The soil texture was either silty-clay (0–3 cm) or silty-clay to clay (3–60 cm). Salinity, sodicity and $CaCO_3$ levels in this zone were higher, but more uniformly distributed with depth than in the upper sandy zone. In contrast, the soil profile in the middle zone, which produced maximum number of healthy plants, was comprised of three distinct horizons: superficial (0–3 cm) clay layer, a sandy layer (3–30 cm) and a loamy-sand layer (30–60 cm). The surface layer had high salinity, SAR, and $CaCO_3$ levels. This layer also showed highest saturation percentage. The salinity, SAR, $CaCO_3$ level, and saturation percentage was lower in deeper layers (3–30 cm and 30–60 cm from the surface) compared to the surface layer. The presence of high proportion of sand fractions, low salinity, and low $CaCO_3$ levels in the 3–30 cm layer improved seedling establishment in this site.

*Doha Site.* Two locations were selected for postplanting assessment: zone 1 with successfully established seedlings and zone 2, which was devoid of plants. The data presented in Tables 4 and 5 are based on five profiles in each zone. On-site assessment showed the presence of sufficient moisture around the root system (upper 30 cm layer) even during low tide in the zone 1. In contrast, the corresponding layer in zone 2 was relatively dry with visible salt crystals. The soil profile in zone 1 comprised of an upper (0–5 cm) layer of wet sandy-loam mud followed by a sandy-loam layer (between 5 and 30 cm from the surface). The soil profile in zone 2 consisted of a 5 cm thick layer of dry clay loam and a dry sandy-loam to sandy-clay layer between 5 and 30 cm from the surface. The subsoil in zone 1 had considerably lower salinity (ECe = 32.4 dS m$^{-1}$) than that in zone 2 (ECe = 55.8 dS m$^{-1}$). The high tide persisted only for a short period and the tidal coverage was also not adequate to flush out salts from the soil matrix in zone 2. Other parameters such as pH, ESP, $CaCO_3$, and color did not indicate any clear cut variation between two areas. The textural differences and salinity status of the 5–30 cm layer appeared to have played a major role in the establishment of seedlings at this site.

*Sulaibhikhat - I.* Two locations (zone 1 with fully established seedlings and zone 2 with dead or dying plants) were selected for postplanting investigations. Five soil profiles were assessed in each zone and representative soil samples were collected for

TABLE 4 Particle Size Distribution in Soil Samples from Various Locations in Mangrove Plantations

| Site | Plant survival | Layer (cm from surface) | Total clay | Total silt | Total sand | Fine silt | Coarse silt | Very fine sand | Fine sand | Medium fine sand | Coarse sand | Very coarse sand | Textural class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shuwaikh | Live | 0–3 | 46.0 | 31.9 | 22.1 | 30.0 | 1.9 | 1.1 | 1.0 | 1.0 | 8.0 | 11.0 | Clay |
| | | 3–30 | 6.0 | 2.5 | 91.5 | 2.0 | 0.5 | 3.0 | 6.5 | 8.0 | 32.0 | 42.0 | Sand |
| | | 30–60 | 6.9 | 5.1 | 88.0 | 4.5 | 0.6 | 6.0 | 12.0 | 11.0 | 38.0 | 21.0 | Loamy-sand |
| | Dead | 0–3 | 2.0 | 2.5 | 95.5 | 1.9 | 0.6 | 0.4 | 1.1 | 42.0 | 48.0 | 4.0 | Sandy |
| | | 3–30 | 4.0 | 4.5 | 91.5 | 1.9 | 2.6 | 5.4 | 11.1 | 38.0 | 32.0 | 5.0 | Sandy |
| | Dead | 0.3 | 55.0 | 42.0 | 3.0 | 36.0 | 6.0 | 2.0 | 3.0 | 0.0 | 0.2 | 0.8 | Silty-clay |
| | | 3–60 | 52.0 | 40.0 | 8.0 | 39.0 | 1.0 | 2.0 | 3.0 | 0.0 | 1.7 | 0.1 | Silty-clay |
| Doha | Live | 0–5 | 13.4 | 11.8 | 74.8 | 9.7 | 2.1 | 9.5 | 20.3 | 30.0 | 12.0 | 3.0 | Sandy loam |
| | | 5–30 | 16.0 | 10.8 | 73.2 | 9.7 | 1.1 | 7.0 | 17.8 | 33.2 | 11.7 | 3.5 | Sandy loam |
| | Dead | 0–5 | 24.0 | 16.8 | 59.2 | 13.8 | 3.0 | 4.8 | 12.5 | 29.0 | 10.5 | 2.5 | Sandy-clay-loam |
| | | 5–30 | 23.8 | 13.2 | 63.0 | 11.2 | 2.0 | 3.5 | 13.0 | 34.0 | 10.2 | 2.3 | Sandy-clay-loam |
| Sulaibikhat I | Live | 0–5 | 15.0 | 16.5 | 68.5 | 14.5 | 2.0 | 3.5 | 31.0 | 22.0 | 4.0 | 1.0 | Sandy-loam |
| | | 5–20 | 18.5 | 7.5 | 74.0 | 6.5 | 1.0 | 10.5 | 22.0 | 19.5 | 10.5 | 7.0 | Sandy-loam |
| | | 20+ | 39.0 | 39.0 | 22.0 | 23.0 | 9.0 | 15.0 | 15.5 | 1.0 | 1.0 | 1.0 | Clay-loam |
| | Dead | 0–20 | 36.0 | 32.0 | 32.0 | 23.0 | 9.0 | 13.5 | 15.5 | 1.0 | 1.0 | 1.0 | Clay-loam |
| | | 20+ | 41.0 | 44.0 | 15.0 | 33.0 | 11.0 | 13.5 | 4.0 | 0.0 | 1.0 | 0.5 | Silty-clay |
| Sulaibikhat II | Live | 0–3 | 21.0 | 22.0 | 57.0 | 16.0 | 6.0 | 9.0 | 25.5 | 9.5 | 1.5 | 1.0 | Sandy-clay-loam |
| | | 3–20 | 35.0 | 32.0 | 33.0 | 24.0 | 8.0 | 18.5 | 12.5 | 6.0 | 2.5 | 0.5 | Clay-loam |
| | | 20+ | 42.0 | 37.0 | 21.0 | 28.9 | 9.0 | 12.5 | 6.0 | 3.0 | 1.5 | 0.5 | Clay |
| | Dead | 0–3 | 27.0 | 24.5 | 48.5 | 18.0 | 6.5 | 10.0 | 20.0 | 4.0 | 1.5 | 0.5 | Loam |
| | | 3+ | 38.0 | 36.0 | 26.0 | 25.0 | 11.0 | 22.5 | 5.0 | 7.0 | 3.5 | 3.5 | Clay-loam |
| Sabiya | Live | 0–10 | 7.0 | 12.0 | 81.0 | 7.5 | 4.5 | 35.0 | 41.3 | 3.0 | 1.2 | 0.5 | Sandy-loam |
| | | 10–45 | 6.8 | 7.5 | 85.7 | 5.0 | 2.5 | 37.3 | 45.5 | 1.6 | 0.6 | 0.5 | Sandy-loam |
| | Dead | 0–10 | 8.5 | 12.3 | 79.2 | 8.3 | 4.0 | 33.3 | 43.3 | 1.7 | 0.7 | 0.2 | Loamy Sand |
| | | 10–20 | 9.0 | 9.0 | 82.0 | 6.8 | 2.2 | 39.0 | 41.0 | 1.0 | 0.7 | 0.3 | Sandy-loam |
| | | 20–40 | 8.0 | 8.5 | 83.5 | 6.5 | 2.0 | 32.5 | 47.8 | 2.2 | | 0.0 | Loamy-sand |

The terms "live" and "dead" denote either almost all seedlings survived or no seedlings survived beyond three months of transplanting. The clay, silt and sand fractions are in percentage of the total on w/w; particle sizes – clay: <0.002 mm; fine silt: 0.002–0.02 mm; coarse silt: 0.05–0.02 mm; very fine sand: 0.05–0.1 mm; fine sand: 0.1–0.25 mm; medium fine sand: 0.25–0.5 mm; coarse sand: 0.5–1.0 mm; very coarse sand: 1.0–2.0 mm.

**TABLE 5** Physical and Chemical Characteristics of Soil in the Postplanting Stage

| Sites | Seedling mortality | Depth (cm) | pHs | ECe dS m$^{-1}$ | SAR (mmoleL$^{-1}$)$^{0.5}$ | CaCO$_3$, % eq. | SP | Color of dry soil |
|---|---|---|---|---|---|---|---|---|
| Shuwaikh | Live | 0–3 | 7.6 | 115.0 | 193.0 | 25.1 | 75.0 | Grey 7/10Y |
| | | 3–30 | 7.8 | 56.0 | 126.0 | 10.8 | 23.0 | Grey 1 7/10Y |
| | | 30–60 | 7.8 | 65.0 | 26.0 | 14.8 | 22.0 | Grey 1 7/10Y |
| | Dead | 0–3 | 7.7 | 38.0 | 82.0 | 8.5 | 20.0 | 10 YR 8/2 |
| | | 3–30 | 8.0 | 37.0 | 84.0 | 12.0 | 23.0 | Grey 1 7/10Y |
| | Dead | 0–3 | 7.7 | 97.0 | 138 | 27.7 | 79 | Grey 1 8/10Y |
| | | 3–60 | 7.8 | 63.0 | 128 | 27.9 | 80 | Grey 1 7/10Y |
| Doha | Live | 0–5 | 8.0 | 94.8 | 72.2 | 46.3 | 30.2 | 5Y 7/1 |
| | | 5–30 | 8.4 | 32.4 | 56.2 | 45.2 | 30.2 | 5Y 7/1 |
| | Dead | 0–5 | 8.4 | 92.2 | 69.0 | 41.9 | 34.9 | 5Y 7/1 |
| | | 5–30 | 8.4 | 55.8 | 63.1 | 43.9 | 37.7 | 5Y 7/1 |
| Sulaibikhat I | Live | 0–5 | 7.5 | 66.4 | 65.4 | 20.6 | 60.8 | 5Y 7/1 |
| | | 5–20 | 7.7 | 46.6 | 59.2 | 14.3 | 36.7 | 5Y 7/1 |
| | | 20+ | 7.9 | 62.8 | 64.6 | 23.2 | 62.8 | 5Y 7/1 |
| | Dead | 0–20 | 8.5 | 100.0 | 71.5 | 28.2 | 64.8 | 5Y 7/1 |
| | | 20+ | 7.9 | 74.8 | 68.0 | 28.2 | 64.8 | 5Y 7/1 |
| Sulaibikhat II | Live | 0–3 | 8.3 | 84.4 | 69.2 | 21.8 | 46.7 | 5Y 7/1 |
| | | 3–20 | 8.2 | 63.0 | 64.9 | 31.4 | 60.8 | 5Y 7/1 |
| | | 20+ | 8.2 | 57.6 | 63.8 | 38.0 | 64.8 | 5Y 7/1 |
| | Dead | 0–3 | 8.0 | 136.2 | 75.1 | 24.5 | 44.7 | 5Y 7/1 |
| | | 3+ | 8.2 | 84.3 | 69.6 | 40.4 | 60.8 | 5Y 7/1 |
| Sabiya | Live | 0–10 | 7.9 | 57.3 | 62.9 | 13.9 | 30.2 | 10 YR 5/2 |
| | | 10–45 | 8.1 | 50.8 | 58.2 | 17.1 | 30.1 | 10 YR 5/2 |
| | Dead | 0–10 | 7.6 | 63.2 | 63.5 | 21.0 | 29.3 | 10 YR 7/2 |
| | | 10–20 | 7.9 | 47.2 | 59.6 | 25.2 | 30.0 | 10 YR 7/2 |
| | | 20–40 | 8.0 | 46.5 | 59.6 | 18.3 | 29.2 | 10 YR 7/2 |

pHs = pH of the saturated soil paste; ECe = electrolytic conductivity of the saturated extract; ESP = exchangeable sodium percentage; SP = saturation percentage.

laboratory characterization. The soil profile in zone 1 consisted of an upper 5 cm clay-loam textured muddy layer (clay 35%), a sandy loam layer (74% sand) between 5 and 20 cm and a silty-clay layer (22% sand) beyond 20 cm from the surface (Table 4). The 5–20 cm layer showed iron (red) mottling). The profile in zone 2 consisted of only two recognizable horizons: a 20 cm thick hypersaline clay-loam upper layer and a silty-clay layer beyond 20 cm from the surface (Table 4). The two zones varied considerably in salinity status, pH and $CaCO_3$ content. These results suggested that high salinity, greater proportions of clay and silt fractions, high $CaCO_3$ levels, and poor drainage conditions in the upper 20 cm layer were the major causes for plant failure at this site.

*Sulaibhikhat - II.* Following visual assessment of the site, five soil profiles were excavated in each of the two zones (zone 1 where plants established successfully and zone 2 where plants failed to establish). On-site investigations revealed that soil profiles in zone 1 contained three distinct layers; a 3 cm sandy-clay-loam layer at the top, a clay-loam layer between 3 and 20 cm from the surface and a clay/muddy layer below 20 cm from the surface (Table 4). The upper two layers (up to 20 cm from the surface) were relatively dry, well drained and more saline (ECe ranged between 63.0 and 84.4 dS m$^{-1}$) than the third layer (below 20 cm from the surface). In contrast, soil profiles in zone 2 comprised of two distinct layers; a superficial silty-loam layer followed by a deep hard clay-loam layer. The soil in both layers was more saline and poorly drained than the corresponding layers in zone 1 (Table 5).

The hypersaline nature, presence of high proportions of clay fractions and poor drainage conditions of the subsurface layer appeared to have contributed to high seedling mortality at this site.

*As-Sabiya Site.* Five locations were selected for postplanting assessment, two representing areas with good seedling establishment (zone 1) and three in areas containing greater numbers of dead or dying plants (zone 2). The soils in both zone were predominantly sandy with varying levels of silt fractions. The laboratory analysis of soil samples also did not show differences in major properties. It is interesting to note that this site had lower seedling survival compared to other sites.

## Discussion

The observed variations in seedling establishment, seedling growth, and site parameters among and within various sites reflect on the highly dynamic nature of the intertidal zones in Kuwait. Under Kuwait's coastal environment, *A. marina* grew at an average rate of 0.03 to 0.15 m a$^{-1}$, which is rather low compared to that in other countries in the Arabian Peninsula, for example, 0.1 cm d$^{-1}$ in Abu Dhabi, UAE (El-Shourbagy et al., 1995), 0.40 m a$^{-1}$ in Umm Al-Qaiwa, UAE, (Tamaei et al., 2002), 0.15 m a$^{-1}$ in seedling and 0.89 m a$^{-1}$ in direct seeded plantations in Zirku Island, UAE (Sarkal et al., 2002) and 0.5 m a$^{-1}$ in Oman (Cookson et al., 2002),. The prevalence harsh arid climate, short period of rapid growth (July to November) and complete stoppage of growth during December and February probably contributed to lower growth rates in Kuwait compared to that in other countries (Abu El-Nil et al., 2001).

In the present study, seedling survival and growth appeared to have been influenced mainly by textural composition of the soil in the upper 20–30 cm layer of the profile. This horizon represents the root zone in young plants. The soil texture, in turn, influenced other soil properties, such as aeration, drainage, saturation percentage, and amount of interstitial water and salinity status around root system.

Mangrove plants in general and *Avicennia marina* in particular, often grow in anaerobic soils. However, soil profiles in healthy mangrove plantations have an aerobic surface horizon, which changes at varying depths to strongly anaerobic horizon. The depth at which this change occurs is usually related to the landform on which the soil is located. According to Cookson & Lepiece (1997), fine loamy textured soils (Typic Fluvaquents) produced tall healthy plants with dense growth, whereas sandy and coarse loamy soils (Typic Torripsamments and Typic Torrifluents) were devoid of plants. Other factors such as the covering of young plants with green sea algae and rubbish left behind by receding tidal water, low soil fertility, degree of soil aeration, and oil spills have also been associated with high seedling mortality and slow growth in *A. marina* in the Arabian Peninsula (Cookson et al., 2002; Kogo, 1986; Saenger et al., 2002; Tamaei et al., 2002). Higher mortality and poor growth of seedlings in the Shuwaikh site compared to that in others was due to the dumping of green algae during the winter of 2001. This site is also vulnerable to petroleum oil spills due to its close proximity to the Shuwaikh port.

Soil texture and amount of interstitial water play an important role in maintaining salinity levels around the root system near to seawater salinity. Higher proportions of fine fractions (clay) reduce the drainage capacity of the soil and consequently increase the saturation percentage. Under arid climatic conditions, the interstitial water evaporates rapidly leaving behind the salt in the surface layers. Hypersaline conditions in the surface and subsurface layers adversely affect long-term establishment and development of pneumatophores that are essential for supplying oxygen to the roots. Embabi (1993) showed that *Avicennia marina* plants do not survive in soils that have developed high salinity or surface salt crusts. In contrast, higher levels of medium to coarse sand fractions in subsurface layers reduce salinity levels, promote pneumatophores development, and improve oxygen supply to root systems. Ogino (1993) also emphasized the fact that a mangrove ecosystem is an interaction between soils, seawater, and plants and opined that soil related factors may be more important in determining mangrove growth. Clough (1993) also reported that mangroves in Australia grow in soils of a wide range of texture with salinity levels near to that of tidal water. Other researchers have also stressed the importance of soil factors and their interactions with aerial environment and seawater parameters in the successful establishment, abundance and growth of newly planted mangrove seedlings (Hutchings & Saenger 1987; Ogino, 1993; Saenger, 1993).

These results confirm that soil related factors play a key role in the establishment and growth of *Avicennia marina* seedlings in early stages. Therefore, these parameters can be used in conjunction with other site characteristics listed Table 1 to identify suitable sites for establishing new mangrove plantations along Kuwait's coastline.

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