

Response of selected indigenous dryland agroforestry tree species to salinity and implications for soil fertility management

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Abstract Salt-tolerant plants are known to remove excess soluble salts from the soil and thus may be used in land reclamation. We studied the responses of the trees, *Balanites aegyptiaca* L. (Zygophyllaceae), as well as the Fabaceae, *Acacia tortilis* (Forssk) Hayne, and *Tamarindus indica* L. to salinity. Three experiments were conducted on germination, in the laboratory; seedling performance in a lath house; and the impact of the tree species on soil productivity in the field in Afar regional state along the Awash river, eastern Ethiopia. Mixtures of salts, composed of chlorides and sulfates, were tested at different concentrations in both germination and lath house experiments in randomized complete block designs. Seedling root collar diameter and height were measured every 2 weeks. Soil samples were collected from randomly selected pots to examine the effect of salinity on soil properties. The effects of trees on

in situ soil productivity were studied by collecting 72 soil samples at different distances from the tree and different soil depths. The soil productivity index was calculated by summing the products of sufficiency of available water capacity, aeration, bulk density, pH, electrical conductivity, and the weighting factor for each layer. The study revealed that germination percentage and rate decreased significantly with increasing salt concentrations. The effects of the three tree species on soil properties were significantly different at 12.2 dS m⁻¹ salinity level compared to the control. *A. tortilis* was the least salt sensitive. Balancing the key requirements of adequate germination and growth and the ability to reduce the salt concentration of the soil solution, *B. aegyptiaca* is the species with the most potential. Therefore, the study suggests to use *B. aegyptiaca* as agroforestry trees in the form of parkland in arid and semi-arid areas where salinity problems are prominent.

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Introduction

Economic growth and high population pressure are driving irrigation development in the arid and semi-arid regions, mainly to improve farmers' income and boost agricultural productivity (Fernández-Cirelli

et al. 2009). The lowlands of Ethiopia are among the areas where irrigation practices are expanding quickly. The arid and semi-arid lowlands of Ethiopia constitute about 63 % of the country's land mass and are characterized by erratic rainfall, extreme drought, and flash floods (MoA 1997). For these reasons, irrigation is an important means of improving food security (Girma and Fentaw 1996).

However, the increasing use of irrigation in the lowlands of Ethiopia, particularly in the middle and lower Awash basin, has resulted in the removal of native trees and their replacement with shallow-rooted agricultural crops (Girma and Fentaw 1996). Removal of deep-rooted perennial trees and shrubs reduces interception of water and results in increased nutrient leachiness (Cuff et al. 1993). In the middle Awash, improper irrigation practices have resulted in high soil salinity levels and this, coupled with poor drainage regimes, has prompted land abandonment (Girma and Awulachew 2007). For example, more than 2000 ha of the Melka Sedi-Amibara State Banana Farm (1971–1986) and other private cotton farms (1982–1992) have been abandoned because of high salinity. Furthermore, the prevalent high temperatures (i.e., >34 °C) and consequent high evaporation rates aggravate the salinity hazard (Girma and Awulachew 2007).

Salinization of soil creates extremely unfavorable conditions resulting in a delay in germination and stunted seedling growth (Kang and Saltveit 2002). According to Kader and Jutzi (2004), rate and percentage of germination and seed vigor index of sorghum were reduced due to high salinity. Excess salt increases the osmotic potential of the soil solution, which, in turn, affects water movement in the soil and availability to the plants. Salinity thus leads to a reduction of nutrient uptake and utilization by plants because of this high osmotic pressure (Grattan and Grieve 1999).

Establishing trees successfully in such areas requires screening and selection of salt-tolerant species (Ramezani et al. 2010). Trees often improve microclimate, can sequester carbon, provide nutrients through litter fall and decomposition, improve nitrogen (N) balances if they are N-fixers, release important proteins and organic acids to the soil (which may facilitate the decomposition process and nutrient cycling), improve water infiltration and soil aeration, and reduce erosion (Qureshi et al. 1993). Planting trees and shrubs also can increase the interception of surface water, increasing ground water recharge, which, in

turn, reduce salinity (Thorburn and George 1999). Trees introduced to irrigated lands may also serve as windbreaks and maintain higher soil humidity and lower soil temperatures, thus reducing evaporation, further reducing salinity (Dechasa 2010). Planting salt-tolerant trees, therefore, can improve soil health and crop productivity (Qureshi et al. 1993). However, several studies have shown that different tree species respond differently to salinity. For example, *Acacia tortilis* and *A. nilotica* have significantly improved the fertility of different soil types in middle Awash, compared to the adjacent bare lands (Abebe et al. 2006). A study was therefore conducted on the effects of salinity on germination and seedling performance of *A. tortilis*, *Balanites aegyptiaca*, and *Tamarindus indica*, and their effects on soil productivity.

Materials and methods

Study site

The experiment was conducted at Werer Agricultural Research Center located at 09°13'59"N, 40°10'47"E in Amibara district, North Eastern Rift valley in Afar Regional State, Ethiopia. The mean annual rainfall is 560 mm with a mean daily maximum and minimum temperature of 34 and 18 °C, respectively. The dominant soil type of the study site is Eutric Fluvisol (FAO 1997). The dominant crops grown in the area are cotton, maize, wheat, sorghum, and groundnut (Shiferaw et al. 2004). Most people in the district are pastoralists. The major land uses at the study site are agriculture (31 %), grazing land (12 %), *Acacia sp.* dominated woodland (16 %), shrub land (16 %), forest (11 %), invasive *Prosopis juliflora* (7 %), and human settlement (7 %) (Abdurahman 2002).

Pre-planting soil and water properties

Before installing any treatments, soil samples were collected to 30 cm depth. The soil samples were air-dried, sieved to 2 mm, and labeled. Soil texture was determined by the hydrometer method (Gee and Bauder 1986), and organic carbon was determined using the wet combustion method (Walkley and Black 1934). The pH of the soil was determined using a pH Meter (Jackson 1958). The EC of the soil was determined using an Electrical Conductivity Meter. Cation exchange capacity of the soil was measured

Table 1 Physical and chemical properties of the soil

Properties	Measured values
pH (H ₂ O)	8.1
Sand content (%)	32
Silt (%)	28
Clay (%)	40
EC _e (dS m ⁻¹)	4.06
SAR	6.36
Organic Carbon (%)	1.02
CEC (cmol + kg ⁻¹)	43
Exchangeable Ca ²⁺ + Mg ²⁺ (cmol + kg ⁻¹)	17.25
Exchangeable K ⁺ (cmol + kg ⁻¹)	1.92
Exchangeable Na ⁺ (cmol + kg ⁻¹)	5.11

after extraction with ammonium acetate solution (Okalebo et al. 1993). Exchangeable bases (Na⁺, K⁺, Mg²⁺, and Ca²⁺) were extracted with 1 N ammonium acetate after adjusting pH to 7 (Okalebo et al. 1993). Na⁺ and K⁺ were measured separately using a flame photometer. The sodium adsorption ratio (SAR) was calculated based on the ratio of the concentration of exchangeable Na⁺ to the concentration of the square root of the sum of Ca²⁺ and Mg²⁺ (Younger and Casey 2003). The pre-planting properties of the soil, which is saline in nature, with low organic carbon content, are presented in Table 1.

The main water source in the study site was from Awash river (MoA 1997). The pH (H₂O) of the river was alkaline, ranging from 8.4 to 8.6. EC_w of the river ranged from 0.23 to 0.78 dS m⁻¹, which is safe to use for irrigation and drinking (Girma and Fentaw 1996).

Seed germination test

For the controlled germination test, seeds of *B. aegyptiaca*, *A. tortilis*, and *T. indica* were purchased from the Forestry Research Center, Addis Ababa, Ethiopia. The seed germination test was carried out under controlled laboratory conditions for twenty days. A liter of salt solution was prepared using soluble salt mixture of NaCl, KCl, CaCl₂, MgCl₂, Na₂SO₄, K₂SO₄, CaSO₄, and MgSO₄, with the proportion of 3:3:1:1:1:1:1:1, respectively, after dissolving them in tap water. Finally, six salt levels were prepared with EC values of 4.1, 6.1, 8.1, 10.1, 12.2,

and 14 dS m⁻¹. Distilled water was used as a control (Ramoliya and Pandey 2002). The amount of salt in tap water is presented in Table 2.

Before the germination test, seeds were pre-treated following the technique described by Bekele (2007). Accordingly, seeds of *B. aegyptiaca* and *A. tortilis* were soaked in boiled water for 10 min and 24 h, respectively. Seeds of *T. indica* were soaked in cold water for 12 h. Five treated seeds of each species were placed on 9-cm-diameter plastic petri dishes lined with Whatman No.1 filter papers. The filter papers were moistened with either 10 ml tap water or 10 ml salt solution. Subsequently, the petri dishes were kept at room temperature in the laboratory. Sixty-three petri dishes were used, including the six treatments of the saline solutions and the control. They were arranged in three replications in a complete randomized design.

Germination was observed daily for 15 days. Germination start day was determined by counting the number of days after sowing. Final germination percentage was calculated for each treatment. The germination rate (GR) was calculated using Eq. 1 given by El-Keblawy and Al-Rawai (2005):

$$GR = \sum \frac{n_i}{t_i}, \quad (1)$$

where n_i represents the number of germinates and t_i the days at 2, 4, 6, 8, 10, 12, and 14.

Soil sampling, preparation, and seedling performance test

Surface soil samples were collected from a depth of 0–20 cm randomly from experimental fields at Werer Agricultural Research Center (WARC). The samples were air-dried, ground, and sieved (2 mm sieve). Concurrently, four levels of salt solution were prepared from salt mixtures of NaCl, KCl, CaCl, MgCl, Na₂SO₄, K₂SO₄, CaSO₄, and MgSO₄ at the ratio of 3:3:1:1:1:1:1:1, respectively. The ECs of the four salt treatments were 6.2, 8.2, 10.1, and 12.2 dS m⁻¹ and control (EC = 4.1; soil with its natural content) (Table 3). Different naturally dominant chlorides and sulfates were added to the soil to avoid antagonistic and promoting effects of some ions on the uptake of other ions. Afterwards, the soil samples for each salt level were treated separately with the prepared salt solutions except for the control (Ramoliya and Pandey 2002). For each treatment level, five

Table 2 Quantities of salts used for salt solution preparation for controlled germination test

Electrical conductivity (dS m ⁻¹)	NaCl (g l ⁻¹)	KCl (g l ⁻¹)	CaCl ₂ (g l ⁻¹)	MgCl ₂ (g l ⁻¹)	Na ₂ SO ₄ (g l ⁻¹)	K ₂ SO ₄ (g l ⁻¹)	Ca ₂ SO ₄ (g l ⁻¹)	Mg ₂ SO ₄ (g l ⁻¹)	Total salt (g l ⁻¹)
Distilled water (control)	–	–	–	–	–	–	–	–	–
4.1	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	1.4
6.1	0.8	0.8	0.2	0.2	0.2	0.2	0.2	0.2	2.8
8.1	1.2	1.2	0.3	0.3	0.3	0.3	0.3	0.3	4.2
10.1	1.6	1.6	0.4	0.4	0.4	0.4	0.4	0.4	5.6
12.2	2.0	2.0	0.5	0.5	0.5	0.5	0.5	0.5	7.0
14.0	2.4	2.4	0.6	0.6	0.6	0.6	0.6	0.6	8.4

plastic pots (filled with 2 kg of soil) were used. Tap water was added to the soil and allowed to dry up for 7 days. Finally, pots were kept inside a lath house using a randomized complete block design with 5 replications. Seedlings (from 3 species *B. aegyptiaca*, *A. tortilis*, and *T. indica*) were planted and pots were kept on petri plates to collect the leachates. Seedling height and root collar diameter were measured every 2 weeks for 3 months (30 April–30 July, 2012). Maximum seedling root length, shoot dry weight (stem + leaves), and root dry weight were determined on 3 randomly harvested seedlings per salt level per species. Seedling root length was measured from root base to tip of the taproot. Dry weight was determined after thoroughly washing the sampled seedlings and drying them at 70 °C for 48 h. Shoot dry weight refers to the aboveground parts. Root dry weight included all fine lateral roots in addition to the taproot.

Effect of soil salinity on post-soil physical and chemical properties

The effects of salinity on soil physical and chemical properties were measured at the end of the experiment

following the methods described above in soil media section. Three pots were randomly selected per tree species and salinity level.

Relationships between tree presence and in situ soil productivity index

The soil productivity index (PI), sensu Driessen and Konijn (1992), was determined by collecting soil samples from four randomly selected trees per species (*A. tortilis*, *B. aegyptiaca*, and *T. indica*) which naturally grow and are maintained as parkland agroforestry in the area. The selected trees were on similar slope positions, in similar natural woodland, and had similar height and diameter. Soil samples were collected at 0–25 and 25–50 cm depths at three different radii (at the tree base, under the crown, and 2 m away from the tree canopy). Seventy-two soil samples were collected. Soil texture, bulk density, pH, EC_e, field capacity (FC), and permanent wilting point (PWP) were measured and parameter values converted into a sufficiency value (after Andrews 1992 and Neill 1979). PI was computed using a standard equation (Neill 1979). Based on the calculated productivity

Table 3 Quantities of salt used to prepare soil media with different EC levels for seedling growth performance test in lath house

Electrical conductivity (dS m ⁻¹)	NaCl (g/100 kg)	KCl (g/100 kg)	CaCl ₂ (g/100 kg)	MgCl ₂ (g/100 kg)	Na ₂ SO ₄ (g/100 kg)	K ₂ SO ₄ (g/100 kg)	Ca ₂ SO ₄ (g/100 kg)	Mg ₂ SO ₄ (g/100 kg)	Total salt (g/100 kg)
Control	–	–	–	–	–	–	–	–	–
6.2	60	60	20	20	20	20	20	20	240
8.1	120	120	40	40	40	40	40	40	480
10.2	180	180	60	60	60	60	60	60	720
12.2	240	240	80	80	80	80	80	80	960

The control soil had an EC value of 4.1

index, the species' potential to improve soil productivity was classified into different ranks as per Eq. II described by Fernando (2003):

$$PI_{\text{soil}} = \sum_{i=1}^n (A_i \times B_i \times C_i \times D_i \times E_i \times WFi), \quad (\text{II})$$

where PI_{soil} represents the productivity index, A_i the sufficiency of available water capacity, B_i the sufficiency of aeration, C_i the sufficiency of the bulk density, D_i the sufficiency of the pH, E_i the sufficiency of electrical conductivity, WFi the weighting factor for each layer; n the number of layers considered in calculation, and i the serial number, i.e., 1, 2, ..., n .

$$WFi = \frac{(RD_m - D_1)^2 - (RD_m - D_2)^2}{RD_m^2},$$

where RD_m represents the maximum depth of root system (cm) (determined from secondary data and 100 cm was used as a maximum (Seid et al. unpublished)), D_1 the depth of the upper boundary layer (cm), and D_2 the depth of the lower boundary layer (cm).

Statistical analysis

The data were subjected to analysis of variance using SAS 9.0 to test for any difference among the tree species, salinity levels, and interactions between species and salt levels. The significant differences between treatment means were separated using LSD test ($P < 0.05$).

Results and discussion

Salinity effect on seed germination

High soil salinity significantly reduced ($P < 0.05$) germination of all three tree species compared to the control. The three tree species showed varied responses to salinity levels. Salinity levels between 4.1 and 10.2 dS m⁻¹ had no significant effect on germination rate of the studied species' seeds. Germination delay was observed at the two highest salinity levels (12.2 and 14 dS m⁻¹) and was significant ($P < 0.05$). Germination started on the third day of the experiment for both *T. indica* and *A.*

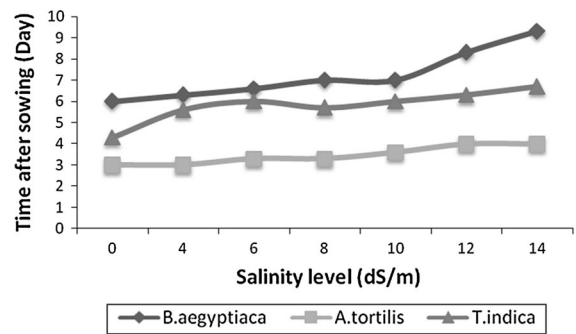


Fig. 1 Salinity effect on the start of seed germination

tortilis and on the sixth day for *B. aegyptiaca* at a salinity level of 4.1 dS m⁻¹ (Fig. 1). The hardy seed coat of *B. aegyptiaca* may impede imbibition of water and cause embryo germination delay.

There were significant differences in final germination percentage among the three species and also interactions between species and salinity level ($P < 0.05$). *Acacia tortilis* had a significantly higher germination percentage than both *B. aegyptiaca* and *T. indica* at salinity levels between 4.1 and 10.2 dS m⁻¹ ($P < 0.05$). Germination percentage for *A. tortilis* ranged from 93 % at 4.1 dS m⁻¹ to 33 % at 12.2 dS m⁻¹ salinity level and such a progressive reduction with increased salt level concentration was similar for the other two species (Fig. 2). These results agree with those of Corney et al. (2003) and Jamil et al. (2006) that state salt stress reduces final germination percentage and delays seed germination commencement. The decrease in seed germination percentage may be attributed to osmotic retention of water or toxicity inside the embryo (Zekri 1993).

Salinity level, tree species, and the interaction showed significant differences in seed germination rates (all $P < 0.05$) with germination rates particularly low at salinity levels of 12.2 dS m⁻¹ and higher (Fig. 3). The effect of salinity on seed germination rate varied from species to species. For example, *B. aegyptiaca* had significantly delayed germination ($P < 0.05$) compared to the other two species. *Acacia tortilis* seeds appeared to be tolerant to salinity and *B. aegyptiaca* and *T. indica* were moderately tolerant although only at the lower salinity level (4.1–10.2 dS m⁻¹). This could be due to the low capacity of the seeds to use the limited available soil water, hindering germination (Khalil and Siam 2003). These results

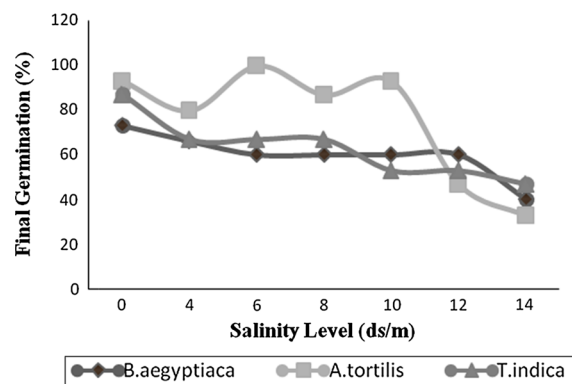


Fig. 2 Salinity effect on seed germination percent

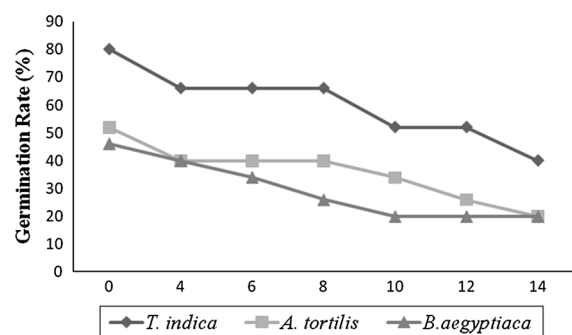


Fig. 3 Salinity effect on seed germination rates

agree with those of Ozdener and Kutbay (2008) which reported that the rate and percentage of seed germination were significantly reduced by increased salinity levels.

Salinity effects on seedling growth

Except for *B. aegyptiaca*, salinity significantly decreased seedling height ($P < 0.05$). Seedling height for *A. tortilis* and *T. indica* were maintained at salinity levels up to 8.1 dS m⁻¹. However, growth was stunted when salinity level was increased to 10.2 dS m⁻¹ and beyond (Fig. 4). In contrast, *B. aegyptiaca* showed little or no response in maximum seedling height, at the higher levels of salinity (36 cm height at 12.2 dS m⁻¹ compared to 42 cm height at 4.1 dS m⁻¹). *Acacia tortilis* seedlings showed low tolerance to salinity (10 cm at 12.2 dS m⁻¹ compared to 26 cm at 4.1 dS m⁻¹ (control)) relative to the responses of *B. aegyptiaca* and *T. indica* seedlings (Fig. 4). Massai et al. (2004) reported that salinity may reduce plant seedling

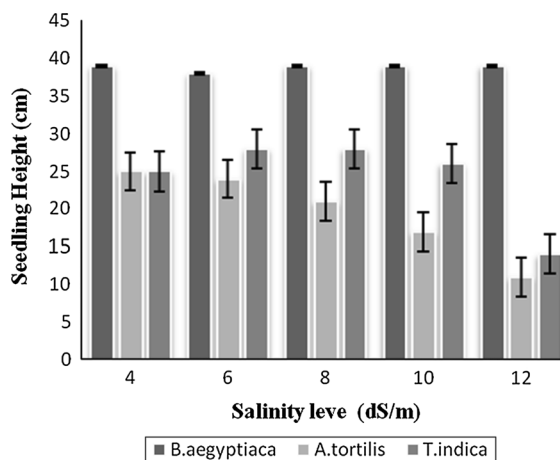


Fig. 4 Salinity effect on seedling height (cm)

growth by influencing photosynthesis through stomatal closure and reduced water uptake. It may also dry the root zone of the plant and prevent the roots from performing their normal osmotic activity (Massai et al. 2004). High salt levels in the soil affect soil nutrient movement and uptake by the plant roots. This would cause stress and reduce the overall plant growth (Massai et al. 2004).

Salinity had no effect on root collar diameter (RCD) of *B. aegyptiaca*. For the other species, RCD was reduced significantly only in the 12.2 dS m⁻¹ treatment (Table 4). Seedling root length was significantly affected by salt level ($P < 0.05$) with *A. tortilis* having the most significant reduction in length, even at the lowest added salinity level. Neither *T. indica* nor *B. aegyptiaca* showed significant differences between salt levels and the control (Table 4). Reduction in seedling root length of *A. tortilis* could be due to the increased energy needed to use the available soil water held in the soil (Ali 1987; Singh et al. 1991). *Tamarindus indica* showed a significant reduction in shoot dry weight, with significant reductions at 8.1 dS m⁻¹ and higher concentrations, but no reduction in root dry weight. Other species did not show significant differences in SDW with changing salinity. The reduction in SDW could be due to lack of extra energy needed by the plant to invest on its physiological growth (Ashraf and Khan 1993). No significant differences were evident for root dry weight; however, salinity did significantly affect seedling shoot-to-root ratio ($P < 0.05$), with effects evident at the lowest salt addition for *B. aegyptiaca* and *A. tortilis*, and a decreasing shoot:root ratio as salinity levels increased.

Table 4 Seedling growth at different EC levels for the three species

Seedling growth parameters						
EC Level (dS m ⁻¹)	RCD (mm) Mean ± SD	H (cm) Mean ± SD	RL(cm) Mean ± SD	SDW (g) Mean ± SD	RDW(g) Mean ± SD	S:R Mean ± SD
<i>Balanites aegyptiaca</i>						
4	3.3 ± 0.3	39.0 ± 3	10.3 ± 1	2.1 ± 0.35 ^b	1.46 ± 0.14	1.4 ± 0.11 ^a
6	3.4 ± 0.3	38.0 ± 2	9.1 ± 0.7	1.1 ± 0.25 ^{ab}	1.55 ± 0.18	1.2 ± 0.15 ^{bc}
8	3.3 ± 0.3	39.0 ± 2	9 ± 0.6	2.1 ± 0.46 ^{ab}	1.58 ± 0.43	1.3 ± 0.06 ^{ab}
10	3.4 ± 0.2	39.0 ± 3	8.5 ± 0.5	1.5 ± 0.21 ^b	1.43 ± 0.06	1.1 ± 0.14 ^c
12	3.3 ± 0.3	39.0 ± 3	8.5 ± 1	2.5 ± 0.5 ^a	2.12 ± 0.24	1.1 ± 0.14 ^c
<i>P</i>	0.9200	0.9230	0.1690	0.2731	0.1315	0.0440*
<i>Acacia tortilis</i>						
4	2.7 ± 0.3 ^a	24.6 ± 3 ^a	7.8 ± 0.3 ^a	1.23 ± 0.45	0.57 ± 0.20	2.2 ± 0.15 ^a
6	2.6 ± 0.2 ^a	24.2 ± 1 ^a	5.8 ± 0.6 ^b	0.67 ± 0.15	0.47 ± 0.07	1.6 ± 0.15 ^b
8	2.5 ± 0.3 ^a	21.2 ± 2 ^b	5.8 ± 0.3 ^b	0.60 ± 0.20	0.40 ± 0.10	1.5 ± 0.15 ^{bc}
10	2.4 ± 0.2 ^a	17 ± 2 ^c	5 ± 0.5 ^c	0.63 ± 0.06	0.51 ± 0.02	1.3 ± 0.07 ^{cd}
12	2.0 ± 0 ^b	10.6 ± 2 ^d	4.2 ± 0.3 ^d	0.30 ± 0.10	0.29 ± 0.11	1.0 ± 0.06 ^d
<i>P</i>	0.0023*	< .0001*	< .0001*	0.5683	0.7603	< .0001*
<i>Tamarindus indica</i>						
4	3.6 ± 0.4 ^a	24.8 ± 1 ^a	6.3 ± 0.5	2.3 ± 0.30 ^a	0.37 ± 0.06	6.3 ± 0.5
6	3.6 ± 0.2 ^a	28.2 ± 2 ^a	5.9 ± 1.5	1.96 ± 0.51 ^a	0.30 ± 0.10	6.6 ± 0.6
8	3.6 ± 0.4 ^a	28 ± 4 ^a	6.1 ± 0.3	1.46 ± 0.21 ^b	0.23 ± 0.06	6.4 ± 0.6
10	3.7 ± 0.3 ^a	26.4 ± 2 ^a	5.8 ± 0.3	1.36 ± 0.06 ^{bc}	0.20 ± 0.0	6.8 ± 0.3
12	2.4 ± 1.3 ^b	14 ± 8 ^b	5 ± 0	0.90 ± 0.10 ^c	0.15 ± 0.02	5.8 ± 0.3
<i>P</i>	0.0307*	0.0002*	0.2958	0.0215	0.0840	0.3860

* Significant at $P < 0.05$. Mean values represent seedling root collar diameter (RCD), height (H) and root length (RL), shoot dry weight (SDW), root dry weight (RDW), and shoot-to-root ratio (SRR). Whenever a factor is significant, means with different letters are significantly different at $P < 0.05$ according to least square means difference (LSD)

For *T. indica*, there were no significant differences between treatments (Table 4). Seedling shoot-to-root mass ratio value of seedlings grown in control soil media was significantly higher than those grown in soil media with high salinity.

Effects of salinity on soil physical and chemical properties in the lath house experiment

Balanites aegyptiaca and *A. tortilis* significantly reduced salinity by 64 and 69 %, respectively (Table 5). Salinity had a significant effect on soil pH, EC_e, OC, and CEC ($P < 0.05$) in the lath house experiment (Table 6), and there was a significant interaction between salinity level and species. *Balanites aegyptiaca* and *T. indica* significantly increased the soil pH more than *A. tortilis* (Table 6). There was a decrease in soil EC (between 40 and 70 %) for each

salinity level compared to the initial soil EC value. The result also indicates that as salinity level increased, soil organic carbon (OC) decreased (Table 6). This might be due to the increase in salt mineralization and reduction of microbial activities in the soil. For all tree species, the values of CEC in salinized soil was significantly lower (20 %) than the control soil (Table 6). The lowered CEC and OC values indicate a lowering of soil fertility status, which would be likely to reduce crop yields. The recorded post-SAR value had 25 % reduction compared to the initial SAR value. Except at 12.2 dS m⁻¹, the values of SAR among treatments tend to remain almost the same.

Soil productivity index

There was a significant difference ($P < 0.05$) in in situ soil productivity potential among the three tree species

Table 5 Initial salinity at the beginning of the experiment (ISL), estimated amount of salt remaining in the soil (SRS), and estimated amount taken up by the plants by the end of the experiment (SUPS)

ISL (dS m ⁻¹)	<i>B. aegyptiaca</i>		<i>A. tortilis</i>		<i>T. indica</i>	
	SRS (dS m ⁻¹)	SUPS (dS m ⁻¹)	SRS (dS m ⁻¹)	SUPS (dS m ⁻¹)	SRS (dS m ⁻¹)	SUPS (dS m ⁻¹)
4.1 (control)	2.2	1.9	2.3	1.8	3.4	0.7
6.2	3.2	3.0	3.6	2.6	3.8	2.4
8.1	3.6	4.5	3.7	4.4	4.2	3.9
10.2	3.7	6.4	3.7	6.5	4.6	5.6
12.2	4.4	7.8	3.8	8.4	5.2	7.0

Table 6 Effect of salinity on post-soil properties after planting tree seedlings

EC Level (dS m ⁻¹)	pH Mean ± SD	EC _e (dS m ⁻¹) Mean ± SD	OC (%) Mean ± SD	CEC (cmol (+) kg ⁻¹) Mean ± SD	SAR Mean ± SD
<i>Balanites aegyptiaca</i>					
Before	8.05	4.06	1.02	43	6.36
Control	8.25 ± 0.1 ^b	2.2 ± 0.1 ^d	0.82 ± 0.01 ^a	40 ± 0.5 ^a	5.86 ± 0.2
6	8.32 ± 0.1 ^{ab}	3.2 ± 0.3 ^c	0.70 ± 0.01 ^b	38 ± 0 ^b	5.56 ± 0.1
8	8.44 ± 0.1 ^a	3.6 ± 0.1 ^b	0.80 ± 0.01 ^a	37 ± 1 ^b	5.53 ± 0.08
10	8.41 ± 0.1 ^a	3.7 ± 0.01 ^b	0.71 ± 0.02 ^b	37 ± 0.5 ^b	5.46 ± 0.4
12	8.39 ± 0.1 ^a	4.4 ± 0.6 ^a	0.57 ± 0.03 ^c	37 ± 1 ^b	5.43 ± 0.57
<i>P</i>	0.0413*	0.0001*	< .0001*	0.0011*	0.5383
<i>Acacia tortilis</i>					
Control	8.18 ± 0.1 ^b	2.3 ± 0.15 ^b	0.62 ± 0.02 ^b	38 ± 1.2 ^{ab}	5.50 ± 0.06
6	8.28 ± 0.04 ^a	3.6 ± 0.09 ^a	0.76 ± 0.04 ^a	38 ± 2.6 ^a	5.12 ± 0.3
8	8.29 ± 0.01 ^a	3.7 ± 0.01 ^a	0.68 ± 0.01 ^{ab}	38 ± 3 ^{ab}	5.03 ± 0.6
10	8.34 ± 0.01 ^a	3.7 ± 0.13 ^a	0.75 ± 0.03 ^a	37 ± 2 ^{ab}	5.01 ± 0.02
12	8.36 ± 0.01 ^a	3.8 ± 0.12 ^a	0.60 ± 0.04 ^{ab}	34 ± 0.5 ^b	4.97 ± 0.2
<i>P</i>	0.0310*	0.0035*	0.0040*	0.0240*	0.2252
<i>Tamarindus indica</i>					
Control	8.23 ± 0.02 ^c	3.4 ± 0.46 ^d	0.79 ± 0.04 ^a	36 ± 2.5 ^a	5.31 ± 0.2
6	8.37 ± 0.01 ^a	3.8 ± 0.7 ^{cd}	0.83 ± 0.05 ^a	37 ± 2.1 ^a	4.95 ± 0.3
8	8.38 ± 0.03 ^a	4.2 ± 0.04 ^{bc}	0.77 ± 0.04 ^a	38 ± 2.1 ^a	4.89 ± 0.4
10	8.42 ± 0.04 ^a	4.6 ± 0.09 ^{ab}	0.77 ± 0.03 ^{ab}	37 ± 1.3 ^a	4.90 ± 0.2
12	8.31 ± 0.02 ^b	5.2 ± 0.18 ^a	0.70 ± 0.02 ^b	32 ± 1.0 ^b	4.43 ± 0.3
<i>P</i>	<.0001*	0.0136*	0.0332*	0.0135*	0.0900

* Significant at $P < 0.05$; mean values represent soil pH, electrical conductivity (EC_e), organic carbon (OC), cation exchange capacity (CEC), and sodium adsorption ratio (SAR). Mean values with the same letter are not significantly different at $P < 0.05$ according to LSD

(*A. tortilis*, *B. aegyptiaca*, and *T. indica*). The productivity indices at the base and under the crown of the selected trees were significantly higher than away from the canopy of the tree (Table 7). While this may simply reflect better germination and long-term survival in historic soil hotspots with higher initial PI

and therefore might not be fully causative, our results in the manipulative lath house experiment do suggest a positive tree effect and this could be due to the reduced soil temperatures under the canopy of the trees that may increase the immobility of soluble salts in the soil.

Table 7 Effect of multipurpose tree species on soil productivity index (PI) at 0–50 cm depth

Species type			
Radii	<i>B. aegyptiaca</i>	<i>A. tortilis</i>	<i>T. indica</i>
Base	0.253 ± 0.058 ^a	0.325 ± 0.108 ^a	0.222 ± 0.044 ^a
Crown	0.191 ± 0.018 ^b	0.201 ± 0.020 ^b	0.055 ± 0.016 ^b
Outside	0.133 ± 0.038 ^c	0.064 ± 0.016 ^c	0.040 ± 0.002 ^b
Pr > F	<.0001*	<.0001*	<.0001*

* Significant at $P < 0.05$; mean values represent productivity index (PI) of four replicated soil samples for each tree species. Mean values with the same letter are not significantly different at $P < 0.05$ according to LSD

Conclusions

Higher salt concentration in soil has adverse effect on seed germination and subsequent seedling growth. The results show that tolerance to salinity is reduced when EC is above 10.2 dS m^{-1} . Based on germination characteristics alone, *A. tortilis* was found to be the most salt-tolerant followed by *B. aegyptiaca* and *T. indica*; however, root collar diameter, height, and root length of *A. tortilis* were severely impacted by salinity. For all the tree species, seedling height and shoot, as well as root dry weight, decreased when the salt level increased. Based on seedling growth parameters (e.g., collar diameter, height, root length, and density), *B. aegyptiaca* had tolerance to salinity even at high levels (12.2 dS m^{-1}). At the seedling stage, *B. aegyptiaca* and *T. indica* had the greatest ability to remove salt from the soil solution. Therefore, balancing the key requirements of adequate germination and growth and the ability to reduce the salt concentration of the soil solution, *B. aegyptiaca* is the species with the most potential. Therefore, the study suggests to use *B. aegyptiaca* as agroforestry trees in the form of parkland in arid and semi-arid areas where salinity problems are prominent.

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