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Effect of salinization of soil on emergence, growth and survival of seedlings of Acacia nilotica

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Abstract

RAMOLIYA, P. J. & PANDEY, A.N. 2002. Effect of salinization on emergence, growth and survival of seedlings of Acacia nilotica. *Bot. Complutensis* 26: 105-119.

Effects of salinization of soil on emergence, growth and physiological attributes of seedlings of *Acacia nilotica* (Linn.) Del. (Mimosaceae) were studied. A mixture of chlorides and sulphates of Na, K, Ca and Mg was added to the soil and salinity was maintained at 4.1, 6.2, 8.1, 9.9, 12.2 and 14.3 dS m^{-1}. A negative relationship between percent seed germination and salt concentration was obtained. Seedlings did not emerge when soil salinity exceeded 12.2 dS m^{-1}. Results suggested that this tree species is salt tolerant at seed germination stage. Seedlings survived and grew up to soil salinity 12.2 dS m^{-1} and eventually this species is salt tolerant at seedling stage too. Elongation of stem and root was retarded by increasing salt stress. However, this species has a tendency for rapid root extension and roots are able to extract water from very dry saline soil (6.8 % moisture). Among the tissues, young roots and stem were most tolerant to salt stress and were followed by old roots and leaf successively. Leaf tissue exhibited maximum reduction in dry mass production in response to increasing salt stress. However, production of young roots and death of old roots were found to be continuous and plants apparently use this process as an avoidance mechanism to remove excess ions and delay onset of ion accumulation in this tissue. This phenomenon, designated «fine root turnover» assumes an importance to the mechanisms of salt tolerance. The ability of this plant to thrive in dry regions is further conferred by the xeromorphic features of its leaves.

Key words: Salinization of soil, *Acacia nilotica*, Seedling emergence, Seedling growth, Salt tolerance, Adaptation.

Resumen

RAMOLIYA, P. J. & PANDEY, A.N. 2002. Efecto de la salinización en el brote, crecimiento y supervivencia de Acacia nilotica. *Bot. Complutensis* 26: 105-119.

Se estudiaron los efectos de la salinización del suelo sobre la emergencia, el crecimiento y los atributos fisiológicos de plántulas de *Acacia nilotica* (L.) Del. (Mimosaceae). Se añadió al suelo una mezcla de cloruros y sulfatos de Na, K, Ca y Mg, y se mantuvo la salinidad a 4.1, 6.2, 8.1, 9.9, 12.2 y 14.3 dSm^{-1}. La relación obtenida entre el porcentaje de germinación de semillas y la concentración de sal fue negativa. Las plántulas no emergieron cuando la salinidad excedió 12.2 dSm^{-1}. Los resultados sugieren que esta especie arbórea tolera la sal en la germinación. Las plántulas sobrevivieron y crecieron hasta con una salinidad de 12.2 dSm^{-1} y eventualmetne esta especie también tolera la sal en el estado de plántula. La elongación del tallo y de la raíz fue retrasada al incrementarse el estrés salino. Sin embargo, esta especie tiene una tendencia al crecimiento rápido de la raíz, y las raíces son capaces de extraer agua de suelos salinos muy secos (6,8% humedad). Las raíces y tallos jóvenes fueron los más tolerantes al estrés salino entre los tejidos, y después las raíces viejas y las hojas a continuación. La máxima reducción en producción de masa seca en respuesta al aumento de estrés salino la exhibió el tejido de la hoja. Sin embargo, se encontró que la producción de raíces jóvenes y la muerte de raíces viejas fue un proceso contínuo, y, aparentemente, las plantas usan este proceso como un mecanismo de evasión, para deshacerse del exceso de iones y retrasar los daños de la acumulación de iones en este tejido. Este fenómeno, denominado «renovación de raíces finas» resulta de importancia entre los mecanismos de tolerancia de sal. La capacidad de esta planta para prosperar en regiones secas es debida también a las características xeromórficas de sus hojas.

Palabras clave: salinización del suelo, *Acacia nilotica*, emergencia de plántulas, crecimiento de plántulas, tolerancia a la sal, adaptación.

INTRODUCTION

Salinization of soil is a world-wide problem, however, it is of common occurrence in arid and semi-arid regions. Soil salinity is a scourge for agriculture, forestry, pasture development and other similar practices. An understanding of responses of plants to salinity is of great practical significance. It has been reported that high concentrations of salts have detrimental effects on plant growth (Bernstein, 1961; Kramer 1983; Garg and Gupta, 1997; Mer *et al.,* 2000) and excessive concentrations kill growing plants (Donahue *et al*., 1983). Many investigators have reported retardation of germination and growth of seedlings at high salinity (Ayers and Hayward, 1948; Bernstein, 1962; Garg and Gupta, 1997). However, plant species differ in their sensitivity or tolerance to salts (Troech and Thompson, 1993; Brady and Weil, 1996). There are many different types of salts and almost an equally diverse set of mechanisms of avoidance or tolerance. In addition, organs, tissues and cells at different developmental stages of plants exhibit varying degrees of tolerance to environmental conditions (Munns, 1993; Ashraf, 1994). It is found that shoot growth is often suppressed more than the root growth by soil salinity (Ramoliya and Pandey, 2002; Maas and Hoffman, 1977). However, there have been comparatively few investigations on the effect of soil salinity on root growth (Garg and Gupta, 1997). The effect of high concentrations of salts in soil on the growth of plants is primarily through soil solution. Therefore, it is expected that dry soil may affect plant growth more than wet soil. Also, occurrence of frequent droughts is almost a regular phenomenon in saline deserts. Eventually, responses of roots and shoots of plants to soil salinity should be understood especially under wet and dry soil conditions. The knowledge acquired regarding the growth and survival of plants under natural conditions could be used as a tool for screening of plant species for the afforestation of saline deserts.

Acacia nilota (Linn.) Del. (Mimosaceae) is one of the dominant tree species in the vast area of Kutch (a northern saline desert) of Gujarat State in India. It also grows successfully in coastal area as well as in non-saline and marginal semi-arid central area of Saurashtra region which is located adjacent south to kutch. This tree species is of much importance to local people because it yields fuel, fodder, timber, tannin, gum, etc. Tejwani (1994) reported that it is extremely drought tolerant and one of the most important speices for soil conservation and agroforestry practices in arid and semi-arid areas of India and reproduces naturally by seed germination. However, the potential of this tree spices to grow and survive in saline desert of Kutch is not known. The present investigation was carried out to understand the adaptive features of *A. nilotica*, which allow it to grow and survive in saline and arid regions.

STUDY AREA

The present study was carried out at Naliya (23^0 28' N, 68^0 80' E) in Kutch. The soil is a non-calcareous sandy loam containing 70.1% sand, 13.7% silt and 16.2% clay. The available soil water between wilting coefficient and field capacity ranged from 7.6% to 22.4%, respectively. The total organic carbon content was 0.6% and pH was 8.1. The electrical conductivity of the soil ranged from 4.1 to 6.2. dS m^{-1}. Soil fertility was poor with respect to nitrogen (0.07%) and phosphorus (0.01%) contents. Details of soil properties are given by Ramoliya and Pandey (2002). The Kutch and Saurashtra regions are tropical monsoonic and can be eco-climatically classified as arid and semi-arid type, respectively. The entire area is markedly affected by south-western monsoon which causes the onset of wet season in mid-June, and its retreat by the end of September coincides with a lowering of temperature and gradual onset of winter. Total annual rainfall is about 395 mm at Naliya and about 554 mm in central area of Saurashtra which occurs totally during rainy season. The year is divisible into three seasons: summer (April-mid June), monsoon (mid June-September) and winter (November-February). The months of October and March are transition periods between rainy (monsoon) and winter and between winter and summer seasons, respectively. Winters are generally mild and the summers hot.

MATERIALS AND METHODS

Seedling emergence

Surface soil (0-10 cm depth) was collected from a nearby field, air-dried and passed through a 2-mm mesh screen. Six lots of soil, of 100 kg each, were separately spread, about 50 mm thick, over polyethylene sheets. A mixture of NaCl, KCl, $CaCl_2$, $MgCl_2$, Na_2SO_4, K_2SO_4, $CaSO_4$ and $MgSO_4$ in a proportion of 3:3:1:1:1:1:1:1, was then thoroughly mixed with soil to give electrical conductivity of 6.2, 8.1, 9.9, 12.2 and 14.3 dS m^{-1} in the five lots of soil, respectively. The soil of sixth lot served as control. The electrical conductivity of the control soil was 4.1 dS m^{-1}. For the measurement of electrical conductivity, soil suspension in distilled water was prepared in 1:2 ratio in terms of weight. Suspension was shaken and allowed to stand overnight. Thereafter, electrical conductivity of supernatant solution was determined by a conductivity meter. The quantities of salt added to the soil are given in Appendix I. Different naturally dominant chlorides and sulphates were added to soil so that antagonistic and promoting effects of some ions on the uptake of other ions may not be excluded. A high proportion of chlorides in the salt mixture was maintained as the study area is in proximity to the Arabian Sea and seawater enters and spreads at certain spatially separated locations at its most northern part. Five polyethylene bags for each level of soil salinity were each filled with 2 kg of soil. Tap water (drinking water) was added to the soils to field capacity and soils were then allowed to dry for 6 days. Soils were then raked using fingers and seeds were sown on 20 June 1999. Bags were kept inside a wire-net cage of 10 X 10 m area which had its top covered by a thick and transparent plastic sheet because it was the onset of rainy season. Ten seeds were sown in each bag at a depth of about 8-12 mm. Immediately after sowing, soils were watered and thereafter watering was carried out on alternate days. Emergence of seedlings was recorded every day over a period of forty days. Salt concentration at which seed germination was reduced to 50% (SG_{50}) was determined by developing regression equation between percent seed germination and salt concentration.

Appendix I
Salt quantities used to prepare soils of different electrical conductivities

Electrical conductivity (dS m^{-1})	*NaCl [g(100kg)$^{-1}$]*	*KCl [g(100kg)$^{-1}$]*	*$CaCl_2$ [g(100kg)$^{-1}$]*	*$MgCl_2$ [g(100kg)$^{-1}$]*	*Na_2SO_4 [g(100kg)$^{-1}$]*	*K_2SO_4 [g(100kg)$^{-1}$]*	*$CaSO_4$ [g(100kg)$^{-1}$]*	*$MgSO_4$ [g(100kg)$^{-1}$]*	*Total Salt [g(100kg)$^{-1}$]*
4.1	0	0	0	0	0	0	0	0	0
6.2	60	60	60	20	20	20	20	20	240
8.1	120	120	40	40	40	40	40	40	480
9.9	180	180	60	60	60	60	60	60	720
12.2	240	240	80	80	80	80	80	80	960
14.3	300	300	100	100	100	100	100	100	1200

Seedling growth

For growth studies, seedlings of *A. nilotica* were grown in petriplates from medium sized seeds collected at Naliya in Kutch. Soil of each concentration of salt was filled into forty open-bottomed cylinders (10 cm diameter X 10 cm depth, cut from PVC pipe) and bulk density of the dry soil was maintained at 1 g cm^{-3}. Thereafter, tap water was added to soils up to field capacity (sufficient water to initiate drainage). A higher mortality was expected with the increase of salinity so single seedlings (with root length varying from 0.5-1.5 cm) on 20 June 1999 were planted on the top of soils of (4.1 and 6.2 dS m^{-1}) two seedlings on soils of (8.1 and 9.9 dS m^{-1}) and three seedlings on soils of (12.2 and 14.3 dS m^{-1}) salinity in the filled cylinders. The bottom of each cylinder was affixed with a wire-net so that roots could easily pass through and penetrate the composition of soil filled in lower cylinder. Cylinders were kept in petriplates to enable collections of leachates caused by watering which were returned to the soils. Cylinders with seedlings were kept inside the cage for 16 days for establishment of the seedlings. During this period seedlings contained in plastic cylinders were watered on alternate days. The mean maximum temperature in the cage during seedling establishment phase was about 31.8 ± 0.1°C. About 95%, 90%, 73%, 62.5%, 41.7% and 25% seedlings survived at 4.1, 6.2, 8.1, 9.9, 12.2 and 14.3 dS m^{-1} conductivity, respectively. Emergence of the second leaf occurred after one week following transplantation of seedlings on soils with 4.1, 6.2, 8.1 and 9.9 dS m^{-1} salinity. However, on soils of 12.2 and 14.3 dS m^{-1} electrical conductivity, the second leaf emerged after 10 days. Further experiments were not conducted on seedlings grown on soil with 14.3 dS m^{-1} conductivity because seedlings were very weak and seeds did not germinate in soil where salinity exceeded 12.2 dS $m.^{-1}$ Seedlings were thinned such that only one was allowed to grow after full emergence of the second leaf. Other seedlings were uprooted. Soil was last watered on 5 July 1999 and thereafter seedlings were not irrigated.

Thirty two seedlings in each soil salinity treatment were further selected for two water treatments. Sixteen seedlings were grown in soil at field capacity (22.4% water: dry weight) and sixteen in soil at 10% water content. For maintaining soil at 10% water content, 20 kg of dry soil mixed with salt mixture for each level of salinity was spread on polyethylene sheets separately in the laboratory. Tap water was sprinkled on soils at a ratio of 200 ml water/kg soil. After two days, soil was thoroughly mixed by hands and spread for air drying under fan. Soil was consistently examined for moisture by rubbing between fingers and its moisture was determined gravimetrically. When soil moisture was between 10 to 11%, soil was stored in polyethylene containers to avoid evaporation. Wetting and drying of soil was repeated with modified ratio of water to soil if expected moisture content was not obtained. Soil moisture was finally determined on 5 July 1999 before soils were filled in cylinders and a round figure of 10% moisture was recorded for the soil of each concentration of salinity. On 6 July 1999 each cylinder was placed on top of an identical cylinder filled with soil at similar concentration of salt and maintained at either field capacity or at 10% water content. The junction of upper and lower cylinders was sealed with waterproof adhesive tape. The soil surface in the upper cylinder was covered with aluminum foil to prevent evaporation and both cylinders were wrapped with polyethylene sheet. Sixteen replicates for each of the two water treatments, factorialized with 5 grades of soil, (4.1, 6.2, 8.1, 9.9 and 12.2 dS m^{-1} salinity) were prepared. This gave a total of 160 cylinders, which were arranged in 16 randomized blocks.

Sixty eight days after the cessation of watering about 40-50% of seedlings growing at 12.2 dS m^{-1} conductivity and experiencing drier water treatment began to wilt and the experiment was terminated. Morphological characteristics of each seedling were recorded. Shoot height and root length (tap root) were measured. Leaf area was marked out on graph paper. Dry weights of leaves, stems and roots in upper and lower cylinders were determined together with residual water content of the soil. Data recorded for morphological characteristics and dry weight of different components of seedlings grown on soil with five levels of salinity and under moist and drier treatments were analysed by two-way ANOVA to assess the effect of water treatment and salinity on plant growth. Salt concentration at which dry weight of leaf, stem, upper root and lower root components of seedlings was reduced to 50% (DW_{50}) was determined by developing regression equation between dry weight of each component and salt concentration.

Physiological attributes

Additional seedlings grown on soils with 4.1 and 12.2 dS m^{-1} conductivity and under field capacity treatment were used to determine certain physiological attributes. Fifteen days before the termination of the experiment water lost via transpiration during 24 h was determined. For transpiration measurement, eight plants (four plants grown in soil with 4.1 dS m^{-1} and four in soil at 12.2 dS m^{-1} conductivity) were washed to obtain plants with intact root systems. A cotton plug was fitted to each plant around the stem, and the plant was then inserted into a conical flask filled with a measured volume of water so that the root system remained deeply immersed, and the mouth of the flask was sealed. The conical flasks containing plants were covered with black cloth and placed inside the cage. After 24 h, the volume of water in each flask was measured. The difference in volume between the two measurements was used to determine water loss through transpiration. Details of the method are given by Ramoliya and Pandey (2002). Relative water content of leaves was determined following the method described by Barrs and Weatherley (1962). The leaves were detached from the plants at about 10 a.m. Twenty leaflets of bipinnately compound leaves were taken and their fresh weight was taken accurately on an electrical balance. Weighed leaflets were then placed in water for 4 hours at 4°C., after which these leaflets were carefully blotted to remove the surface water and turgid weight of leaflets were taken to make calculation for water uptake. Dry weight of the leaflets was determined by drying the tissues at 80°C to constant weight. Fresh weight, water uptake (turgid weight) and dry weight data of leaflets were used for the determination of relative water content.

$$\text{Relative Water Content (RWC)} = \frac{\text{Fresh weight - Dry weight x 100}}{\text{Turgid weight - Dry weight}}$$

For the stomatal study, a collidion solution was applied to the upper and lower leaf surfaces at mid day and then the dry films were removed and the stomatal number and size of the stomatal aperture were determined under the microscope. Data for physiological characteristics were analysed by Student t-test.

RESULTS

Effect of salinization on emergence of seedlings

Seedlings emergence was noted on 10th day after sowing and 96% seed germination was achieved over a period of 23 days under control (4.1 dS m^{-1} salinity) conditions (Fig. 1). Seedling emergence was recorded on the 13th, 14th, 14th

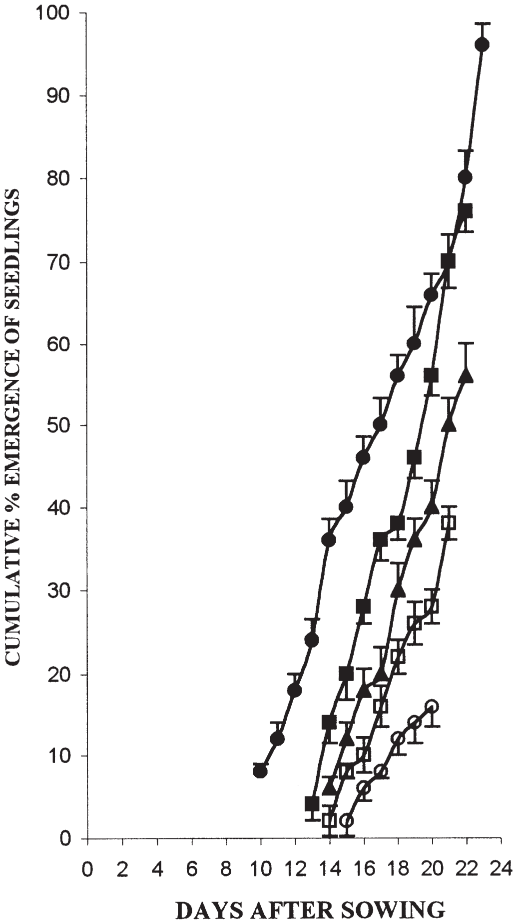

Figure 1.—Cumulative emergence of seedlings of *Acacia nilotica* in response to soil salinity, in experimental conditions, 4.1 dS m^{-1} (•), 6.2 dS m^{-1} (■), 8.1 dS m^{-1} (▲), 9.9 dS m^{-1} (❑), 12.2 dS m^{-1} (○).

and 15th days after sowing in soils with salinities of 6.2, 8.1, 9.9 and 12.2 dS m^{-1}, respectively. Emergence occupied a period of 22, 22, 21 and 20 days in soils with salinities of 6.2, 8.1, 9.9 and 12.2 dS m^{-1}, respectively. Percentage seed germination was respectively, 76%, 56%, 38% and 16%, in soils of above salinities. Seedlings did not emerge from soils with further increase in salinity. A high negative relationship ($r = -0.999$, $n = 249$, $p < 0.01$) between percentage seed germination and concentration of salt was obtained according to the following expression: $Y = 135.600 - 9.900X$ where, Y is percent seed germination and X is salt concentration.

Effect of water treatment and salinization on leaf expansion and stem and root elongation

The drier water treatment significantly reduced shoot height ($F = 20.127$, $p < 0.01$), leaf area ($F = 11.926$, $p < 0.01$) and root length ($F = 32.161$, $p < 0.01$) of seedlings (Fig. 2). Increasing concentration of salt in soil also retarded elongation of stem ($F = 21.877$, $p < 0.01$) and root ($F = 20.598$, $p < 0.01$) of seedlings. However, the effect of salt was more pronounced under drier treatment. There was a negative linear relationship ($r = -0.565$ and -0.645) between shoot height and increasing salt concentration under moist and drier water treatments, respectively. A negative linear relationship ($r = -0.565$ and -0.615) was also obtained for root length and salt concentration under moist and drier treatments, respectively. Nevertheless, roots penetrated the 10 cm thick column of dry and saline sub soils (soils contained in lower cylinders) to their full depth or to a considerable depth. Seedlings began to wilt when soil with 12.2 dS m^{-1} salinity in the upper cylinders above the dry subsoil dried to 6.8%, below the permanent wilting percentage (values for residual soil moisture are not shown). As a result, it appears that *A. nilotica* extracts water from very dry saline soil. Leaf emergence was delayed by increasing salt stress. Further, leaf expansion was significantly reduced ($F = 16.530$, $p < 0.01$) by increased concentration of salt under both moist and drier treatments, respectively but effects were more pronounced with drier soil. A negative relationship ($r = -0.573$ and -0.526) was obtained between leaf area and salt concentration under moist and drier treatments, respectively.

Effect of water treatment and salinization on dry weight

Dry weight significantly decreased for leaf ($F = 16.531$, $p < 0.01$), stem ($F = 5.844$, $p < 0.05$), shoot ($F = 22.780$, $p < 0.01$), upper root ($F = 3.904$, $p < 0.05$), lower root ($F = 6.094$, $p < 0.05$) and total root ($F = 4.969$, $p < 0.05$) under drier treatment (Fig. 3). There was also a significant decrease in the dry weight of leaf ($F = 22.678$, $p < 0.01$), stem ($F = 15.925$, $p < 0.01$), shoot ($F = 39.660$, $p < 0.01$), upper root ($F = 6.671$, $p < 0.01$), lower root ($F = 6.536$, $p < 0.01$) and total root (F =

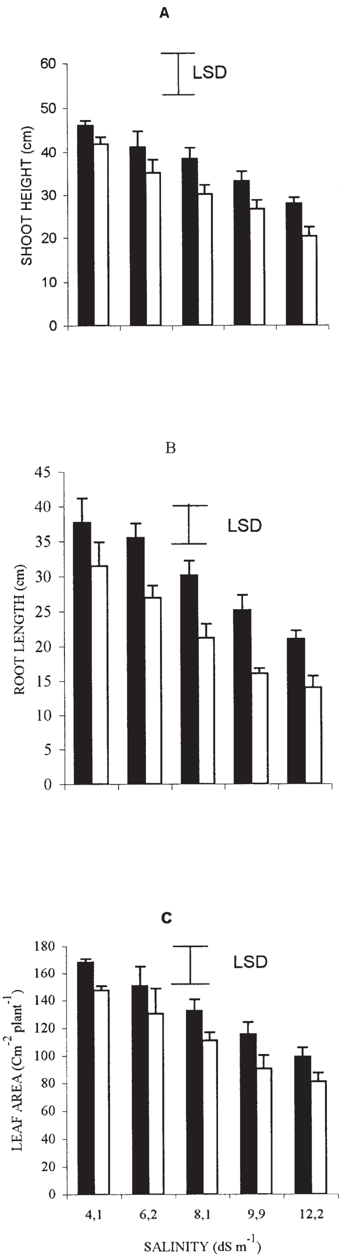

Figure 2.—Effect of salinization of soil under field capacity and drier (10%) soil moisture) water treatments on elongation of A, shoot and B, root and C, expansion of leaf of Acacia nilotica seedlings. Symbol I represents LSD.

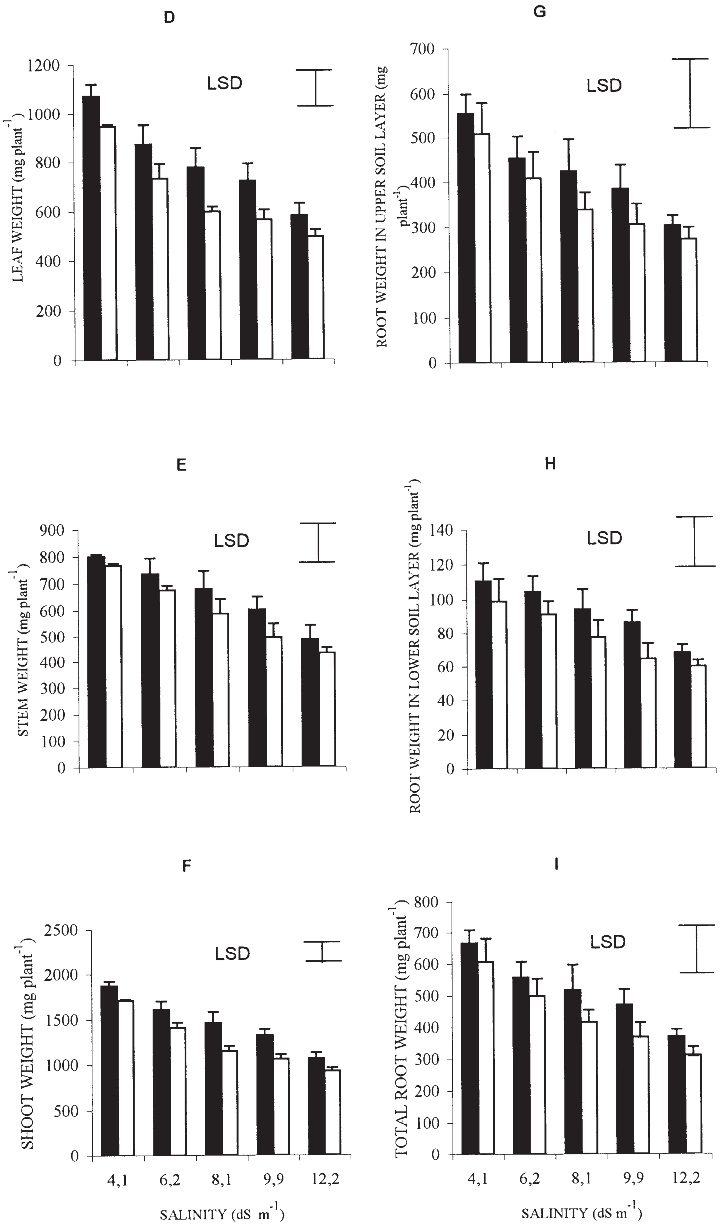

Figure 3.—Effect of salinization of soil under field capacity and drier (10% soil moisture) water treatments on dry weight (mg) of D, leaf; E, stem; F, shoot (leaf + stem);G, root weight in upper soil layer; H, root weight in lower soil layer and I, Total root weight of Acacia nilotica seedlings. Symbol I represents LSD.

9.036, $p < 0.01$) of seedlings in response to increasing concentration of salt. A negative relation was obtained between dry weight of different tissues and salt concentration (r = –0.526, –0.472, –0.632, –0.385, –0.385 and 0.433 for leaf, stem, shoot, upper root, lower root and total root, respectively) under moist treatment and (r = –0.722, –0.639, –0.822, –0.379, –0.381 and –0.439 for leaf, stem, shoot, upper root, lower root and total root, respectively) under drier soil.

Percentage relative weights of tissues of salinized plants compared to those of control plants were computed as salinized tissue dry weight/control dry weight X 100. Dry weight values of tissues shown in Fig. 3 were used for the calculation of percentage relative weight of tissues. Values for percentage relative weight varied from 94.3 to 61.4 for young (lower) roots, from 91.1 to 60.7 for stem, from 81.7 to 54.4 for old (upper) roots and from 81.2 to 54.1 for leaf under moist treatment, in respect to increasing soil salinity from 4.1 to 12.2 dS m^{-1}. Almost similar variations in values of percentage relative weight for different components of seedlings were obtained under drier treatment also. The salt concentrations in moist soil at which dry weights will be reduced to 50% of those of control plants (DW_{50}) were 12.6, 14.8, 13.1, and 15.2 dS m^{-1} for leaf, stem, old (upper) root and young (lower) root tissues, respectively.

Effect of salinization on physiological attributes

Pot-grown plants on soils with 4.1 and 12.2 dS m^{-1} salinity and at field capacity moisture exhibited significant decrease ($p < 0.05$) in specific leaf area in response to increased salinity when t-test was applied (Table 1). Stomatal number, size of stomatal aperture, transpirational loss of water and relative water content of leaves did not differ in response to increased salinity. However, size of stomatal aperture was small, transpirational loss of water was remarkably low and relative water content of leaves was high.

Table 1
Effect of salinization of soil under field capacity moisture on specific leaf area, number of stomata at upper and lower surfaces of leaves, length and width of stomatal aperture, water loss per unif leaf area and relative water content of leaf of seedlings of *Acacia nilotica* (±1 SE) in kuth, India

Salinity (dS m^{-1})	*Specific leaf area* ($mm^2\ mg^{-1}$)*	*Number of stomata at upper surface of leaf (number mm^{-2})*	*Number of stomata at lower surface of leaf (number mm^{-2})*	*Length of stomatal aperture (µm)*	*Width of stomatal aperture (µm)*	*Water loss per unif area ($gDM^{-2}day^{-1}$)*	*Relative water content of leaf (%)*
4.1	17.3 ± 1.0	158.6 ± 3.2	217.8 ± 5.1	1.4 ± 0.0	0.75 ± 0.0	21.2 ± 1.0	72.2 ± 2.0
12.2	13.1 ± 1.3	149.0 ± 3.3	201.2 ± 5.8	1.4 ± 0.0	0.75 ± 0.0	19.4 ± 0.8	71.4 ± 2.1

* Specific leaf area of the seedlings differ at $p < 0.05$ when they are grown at 4.1 and 12.2 dS m^{-1} salinity under moist treatment as compared by t-test.

DISCUSSION

Our earlier work (Mer *et al*., 2000) indicated that seed germination of salt tolerant barley (*Hordeum vulgare*) was reduced to 50% (SG_{50}) in soil with salinity at 4.1 dS m^{-1}, but for *A. nilotica* SG_{50} was in soil with salinity at 8.6 dS m^{-1}. Under field conditions near Naliya and also in a large area of the saline desert of kutch, maximum soil salinity is found during dry period and minimum during rainy season (wet period) in the year. In general, salinity for 0–10 cm layer of soil varies from 4 to 6 dS m^{-1}. As a result, seeds of *A. nilotica* can germinate during rainy season and grow without adverse effect of salinity during post-monsoon period. It is a considerably high salinity level. As a result, this plant species is salt tolerant at the seed germination phase of plant growth. However, salt concentrations exceeding 12.2 dS m^{-1} were detrimental to seed germination and it can be attributed to decreasing osmotic potential of the soil solution with increasing concentration of salt. It was observed that seeds began to shrink after a week and later became inviable in the soil with high concentration of salt. Although the effects of high salt content on metabolic processes are yet to be fully elucidated, it is reported that salinity reduces protein hydration (Kramer, 1983) and induces changes in the activities of many enzymes (Dubey and Rani, 1990; Garg *et al*., 1993) in germinating seeds.

Reduction in growth of shoot components of *A. nilotica* under control conditions and drier treatment can be attributed to water stress. Kramer (1983) reported that plants subjected to water stress show a general reduction in size and dry matter production. In the present study, tap roots, penetrated the subsoil (soil in lower cylinders) to full depth of to the considerable depth and secondly, root/shoot dry weight ratio (0.36) was equal in soils with increasing salt concentration under both moist and drier treatments. These results suggest that this species has a tendency for rapid root extension and also to produce a large quantity of roots. In addition, greater decrease of moisture in soils contained in upper cylinders under drier treatment than that under moist treatment suggests that root extension into the dry subsoil depended on the moisture content in the upper cylinders (values for soil moisture are not shown). Rapid root extension ensures the existence of plants in dry habitats (Sydes and Grime, 1984; Etherington, 1987; Pandey and Thakarar, 1997) and is an adaptation to survive in dry habitats. Results for rapid root elongation and utilization of moisture from soils filled into upper cylinders for root growth suggest that in dry regions the available rainfall can wet the surface soil and *A. nilotica* seedling can use the available moisture for the extension and proliferation of roots into the deep layer of soil and achieve establishment over the rainy season. Our results are in accordance with the findings of Pandey *et al*. (1994) for rapid elongation and proliferation of roots of *Prosopis chilensis* seedlings in dry habitats. Root growth (upper and lower cylinders' root weight) was related with the growth of shoot and consequently root/shoot dry weight ratio was similar under the two water treatments. Root/shoot dry weight ratio for *A. nilotica* (0.36) was similar to that for aridity and salt tolerant seedlings of *Prosopis chilensis* (0.40) when grown on dry soil (Pandey *et al*., 1994).

Reduction in the growth of seedlings was also recorded in response to increasing salt stress. In general, salinity can reduce the plant growth or damage the plants through: (i) osmotic effects (causing water deficit), (ii) toxic effects of ions and (iii) imbalance of the uptake of essential nutrients (Garg and Gupta, 1997). These modes of action may operate on the cellular as well as on higher organizational levels and influence all aspects of plant metabolism (Kramer, 1983; Garg and Gupta, 1997). Our results for reduction of shoot growth and leaf area development of *A. nilotica* with increasing salt concentration are in conformity with the finding of Curtis and Lauchli (1986), who reported that growth of Kenaf (*Hibiscus cannabinus*) under moderate salt stress was affected primarily through a reduction in elongation of stem and leaf area development. Garg and Gupta (1997) reported that salinity causes reduction in leaf area as well as in rate of photosynthesis which together result in reduced crop growth and yield. Also, high concentration of salt tends to slow down or stop root elongation (Kramer, 1983) and causes reduction in root production (Garg and Gupta, 1997). As a result, water stress and salt stress both reduce the plant growth and their effects are additive.

Results for relative weight of tissues suggest that young (lower) roots exhibited least decline in dry weight and were more resistant to increasing salt stress under moist and drier treatments. Young roots were successively followed by stem, old (upper) roots and leaf in an order of salt resistance as: young root > stem > old root and > leaf. Values of DW_{50} for leaf, stem, old (upper) root and young (lower) root also indicate that leaf tissue constituting a major proportion of shoot weight is more sensitive to salinity in regard to dry mass accumulation than stem tissue. Old roots are more sensitive to salt stress than new roots. Consequently, quantum of dry weight reduction was maximum for leaf and upper root tissues, whereas there was least reduction in dry weight of young root tissues. Results also indicate that production of young roots continued, though exhibiting reduction, while leaf production was highly reduced or stopped by increasing salt stress. Root/shoot dry weight ratio remained constant because of concurrent and differential reduction of dry weight of leaf, stem, old (upper) root and young (lower) root tissues. Constant root/shoot dry weight ratio, reduction of dry weight of old roots and tendency to produce a large quantity of young roots in response to increasing salinity under moist and drier treatments suggest that *A. nilotica* plants have a mechanism of old root turnover (loss of old roots followed by subsequent production of new ones) to delay onset of salt stress by indirectly eliminating excess ions through the death of ion saturated old roots. Tozlu *et al.* (2000) obtained death of fine roots of *Poncirus trifoliata* in response to increasing concentration of NaCl and designated this mechanism as «fine root turnover». Moreover, since young roots and stem tissues are salt-resistant, the plants of *A. nilotica* could sequester the salts, that they absorb, in the roots and stems, thus minimizing the exposure of leaf cells and, hence, the photosynthetic apparatus, to salt. This is a vital aspect of salt tolerance in the «Integration in the whole plant» for glycophytes (Garg and Gupta, 1997).

Lower specific leaf area of plants at the salinity of 12.2 dS m^{-1} compared to that of plants at control (4.1 dS m^{-1}, salinity) conditions indicates increase in leaf thickness in response to salt stress. Increase in leaf thickness is considered a mechanism of plants for salt tolerance (Garg and Gupta, 1997). Low transpiration rate was related to small size of stomatal aperture. These characteristics confer xeromorphic features to this plant species. High relative water content of leaf is considered an adaptation to xeric conditions. Davidson and Reid (1989) studied the response of three *Eucalyptus* species to severe drought in summer of 1982/83 at Snug Plains, South-eastern, Tasmania, Australia and reported that *E. pulchella* maintained higher relative water content of leaf and is a relatively drought resistant species. Pandey *et al.* (1994) found that *Prosopis chilensis* maintains high relative water content in leaves and grows successfully in dry regions of Western India. Our results suggest that *A. nilotica* growing in dry habitats has experienced selection favouring water-conservative or drought-surviving adaptations. It is observed that under natural conditions plants of this species, either they are seedlings, saplings or mature trees, shed their leaves during dry period, especially during summer season. Leaf shedding is a characteristic feature of plants to avoid loss of water through transpiration.

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