Effect of salinisation of soil on growth and macro- and micro-nutrient accumulation in seedlings of *Butea monosperma* (Fabaceae)

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Abstract

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Effects of salinisation of soil on emergence, seedling growth and mineral accumulation of *Butea monosperma* Taub. (Fabaceae) were studied. Sodium chloride (NaCl) was added to the soil and salinity was maintained at 0.3, 1.9, 3.9, 6.2, 8.2, 10.2, 12.2 and 13.8 dSm^{-1}. Salinity caused reduction in water content of all tissues (leaves, stems, tap roots and lateral roots) that resulted in internal water deficit to plants. Increasing salt stress impaired succulent feature of tap roots. Succulence is an adaptation of this tree species to salt stress because it temporarily puts off the setting of severe water deficit induced by salt stress. Sodium content significantly increased in leaves and stems and there was no effective mechanism to block Na transfer to shoot tissues. Potassium content also significantly increased in tissues, however, Na was transferred to the tissues in greater proportion than K. Nitrogen and phosphorus contents significantly decreased in all tissues in response to salinisation of soil. Changes in tissues and whole plant accumulation patterns of the other elements tested, as well as possible mechanisms for avoidance of Na toxicity in this tree species during salinisation, are discussed.

Key words: Salinisation of soil, *Butea monosperma*, Seedling emergence, Seedling growth, Salt tolerance, Adaptation, Accumulation, Macro– and micro–nutrients.

Introduction

Plants are not incompatible to salts, but most of the plants do not grow in saline soils. Globally, soil salinity is more common in arid and semi-arid regions than in humid regions. An understanding of responses of plants to salinity is of great practical significance. High concentrations of salts have detrimental effects on plant growth (Garg & 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 (Bernstein 1962, Garg & Gupta 1997, Ramoliya et al. 2004). However, plant species differ in their sensitivity or tolerance to salts (Brady & 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). It is reported that soil salinity suppresses shoot growth more than the root growth (Maas & Hoffman 1977, Ramoliya et al. 2004). However, fewer studies on the effect of soil salinity on root growth have been conducted (Garg & Gupta 1997). The high salt content lowers osmotic potential of soil water and consequently the availability of soil water to plants. In saline soil, salt induced water deficit is one of the major constraints for plant growth. In addition, many nutrient interactions in salt–stressed plants can occur which may have important consequences for growth. Internal concentrations of major nutrients and their uptake have been frequently studied (e.g. Maas &

Grieve 1987, Cramer et al. 1989), but the relationship between micro-nutrient concentrations and soil salinity is rather complex and remains poorly understood (Tozlu et al. 2000). The knowledge acquired regarding the growth and survival of plants under natural habitat conditions could be useful for (i) screening of plant species for the afforestation of saline deserts and also (ii) for understanding the mechanisms which plants have evolved for the avoidance and/or tolerance of salt stress.

Butea monosperma, (Lam.) Taub. (Fabaceae), a tree species, grows in Kutch (north-west saline desert) of Gujarat State in India. It also grows successfully in the non-saline and marginal semi-arid area of the Saurashtra region, which is located adjacent and to the south of kutch. *Butea monosperma* is a forest tree species in Gujarat as well as in several other states in India. This tree species is of multiple use to the local people. When in fully flower this tree is a conspicuous and handsome object in the forests. A gum called "Begal Kino" is obtained from the bark and flowers furnish a brilliant but fleeting dye. Leaves are useful for packing materials and making plates. The wood is used mainly for fuel. However, the potential of this tree species to grow and survive in saline desert of Kutch is not known. The present investigation was carried out (i) to understand the adaptive features of *B. monosperma* which allow it to grow and survive in saline and arid regions, and (ii) to assess the pattern of macro- and micro-nutrient accumulation within the tissues of this tree species in response to salt stress.

Materials and methods

Study area

The present study was conducted in a greenhouse of the botanical garden of Saurashtra University at Rajkot (22^0 17′ N Lat, 70^0 49′ E Long) in Gujarat. For the emergence and growth of seedlings, the top 10 cm black-cotton soil, which is predominant in Saurashtra region of Gujarat, was collected from an agricultural field. This soil is a clayey loam containing 19.6% sand, 20.3% silt and 60.1% clay. The available soil water between wilting coefficient and field capacity ranged from 18.3% to 35.0%, respectively. The total organic carbon content was 1.3% and pH was 7.2. The electrical conductivity of soil was 0.3dSm^{-1}. Nitrogen, phosphorus, potassium, calcium and sodium contents were 0.15%, 0.05%, 0.03%, 0.05% and 0.002%, respectively. This soil is fertile and fit for intensive agriculture. The details of the physical and chemical properties of soil are given by Pandya et al. (2004). The ecoclimate of this locality

is semi-arid (Pandey et al. 1999). The 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 lowering of temperature and gradual onset of winter. Total annual rainfall is about 554mm and occurs entirely almost during June-September. The year is divisible in to 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 mild and the summers hot.

Seedling emergence

Surface soil was collected, air-dried and passed through a 2-mm mesh screen. Eight lots of soil, of 100 kg each, were separately spread, about 50mm thick, over polyethylene sheets. Sodium chloride (NaCl) amounting to 170, 390, 640, 820, 1070, 1275 and 1550g was then thoroughly mixed with soil of seven lots, respectively to give electrical conductivities of 1.9, 3.9, 6.2, 8.2, 10.2, 12.2 and 13.8 dSm^{-1}. There was no addition of NaCl to eighth lot of soil that served as control. The electrical conductivity of control soil was 0.3 dSm^{-1} and this value was approximately equal to 3 mM salinity. For the measurement of electrical conductivity a soil suspension was prepared in distilled water at a ratio of 1:2 in terms of weight. The suspension was shaken and allowed to stand overnight. Thereafter, electrical conductivity of the supernatant solution was determined with a conductivity meter. Twenty polyethylene bags for each level of soil salinity were each filled with 2 kg of soil. Tap water was added to each bag to bring the soils to field capacity and soils were allowed to dry for six days. Soils were then raked using fingers and seeds were sown on 8 September 2003. Seeds of *B. monosperma* were collected from the saline desert of Kutch. Bags were kept in a greenhouse because it was the rainy season. Ten seeds were sown in each bag at a depth of 8-12 mm. Immediately after sowing, soils were watered and thereafter watering was carried out on alternate days. Emergence of seedlings was recorded daily over a period of thirty days. A linear model was fitted to cumulative proportion of seed germination and increasing soil salinity using the expression:

$$\text{Sin}^{-1}\sqrt{P} = \beta_0 + \beta_1 X$$

where, $\text{Sin}^{-1}\sqrt{P}$ is cumulative proportion of seed germination, X is soil salinity and β_0 and β_1 are

constants. Salt concentration at which seed germination was reduced to 50% (SG_{50}) was estimated using the model.

Seedling growth

For the growth studies, two seedlings that emerged first were left in each of 20 bags at each level of salinity and others were uprooted. Seedlings grown in soils at 0.3, 1.9, 3.9 and 6.2 dSm^{-1} salinity exhibited emergence of the second leaf after thirty days. Emergence of the second leaf confirmed the establishment of the seedlings. Moreover, seedlings emerged in soil at 8.2 dSm^{-1} salinity, but were remarkably weak and died in one month. Therefore, further experiments were not possible on those seedlings. Seedlings did not emerge in soils where salinity exceeded 8.2 dSm^{-1}. Following emergence of the second leaf, one seedling having better vigor was allowed to grow in each bag and another seedling was further uprooted. Seedlings were watered (to raise the soil moisture to field capacity) at alternate days. Leaf necrosis began on seedlings grown in soil at 3.9 and 6.2 dSm^{-1} salinity after about thirty eight days. However, it was more severe on leaves of seedlings grown in soil at 6.2 dSm^{-1} salinity than on leaves of seedlings grown in soil at 3.9 dSm^{-1} salinity. Two lower leaves of about 75% seedlings grown in soil at 6.2 dSm^{-1} salinity were completely affected by necrosis over the next fortnight period and shoot tips of those seedlings began to dry. Eventually, experiment was terminated after 60 days. Seedlings were washed to remove soil particles adhered with roots. Morphological characteristics of each seedling were recorded. Shoot height and root length (tap root) were measured. A characteristic feature of seedlings was that their tap roots were succulent and markedly thick. Therefore, maximum thickness (circumference) of tap roots was measured. A thin wire was twisted round the tap root at the thickest part and the length of the wire was measured. Leaf area was marked out on graph paper. Fresh and dry weights of leaves, stems, tap roots and lateral roots were determined. Percent water content in plant tissues (leaves, stems, tap roots and lateral roots) was calculated using fresh and dry weight values.

$$\text{Percent water content} = \frac{\text{Fresh weight - Dry weight}}{\text{Fresh weight}} \times 100$$

Data recorded for morphological characteristics, dry weight and water content of different components were analyzed by one way ANOVA to assess the effect of salinity on plant growth. Salt concentration at which dry weight of leaves, stems, tap roots and lateral roots of seedlings was reduced by 50% (DW_{50}) was determined by fitting a straight line relationship between the response and salt concentration.

Mineral analyses of plant materials

Mineral analyses were performed on leaves, stems, tap roots and lateral root tissues. Plant parts of the seedlings grown in soil at same level of salinity were pooled separately. Plant samples were ground using mortar and pestle. Three subsamples of plant tissues were analyzed. Total nitrogen was determined by Kjeldahl method (Piper 1944) and phosphorus content estimated by the chlorostannous molybdophosphoric blue colour method in sulfuric acid (Piper 1944). Concentrations of Ca, Mg, Na, K, Zn, Fe, Mn and Cu were determined by atomic absorption spectroscopy after triacid (HNO_3: $H2SO_4$: $HClO_4$ in the ratio of 10:1:4) digestion. Mineral data were analysed by one way ANOVA. Correlations and linear regression equations between mineral content and salt concentrations were determined.

Results

Effect of salinisation on seedling emergence

Seedlings began to emerge 2 days after sowing and 90 % seed germination was obtained over a period of 16 days under control (0.3 dSm^{-1} salinity) conditions (Fig. 1). Seedling emergence in the saline soils was recorded on 4, 5, 5, and 6 days after sowing. Emergence occupied a period of 13, 15, 16 and 15 days in soils with salinities of 1.9, 3.9, 6.2 and 8.2 dSm^{-1}, respectively and percentage seed germination was 67%, 53%, 47% and 28%, respectively. Seedlings did not emerge from soils with further increase in salinity. There was a significant reduction in germination of seeds ($p < 0.01$) with increasing salt stress. A negative relationship between percentage seed germination and concentration of salt was obtained according to the following expression: $Y = 69.5 - 4.6X$, ($R^2 = 0.911$, $p < 0.01$)., where, Y is $Sin^{-1}\sqrt{P}$ of proportion of cumulative seed germination and X is salt concentration.

Effect of salinisation on leaf expansion, stem and root elongation, and tap root thickness

Increasing concentration of salt in soil significantly retarded ($p < 0.01$) elongation of stems and roots
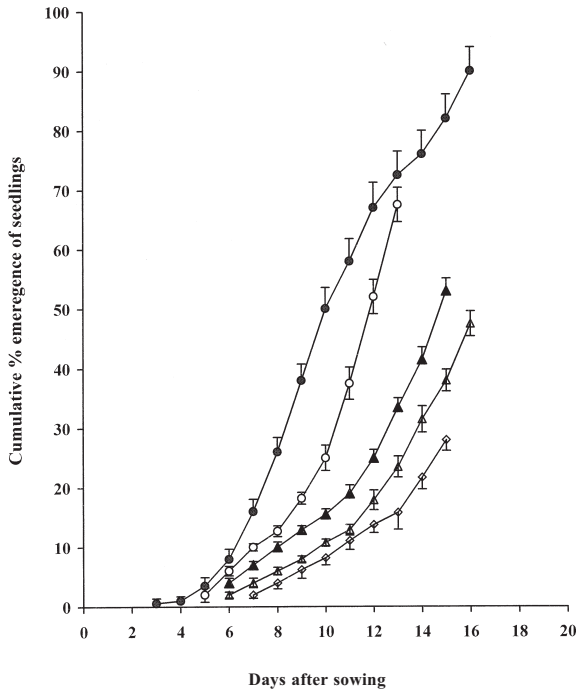
Figure1. Cumulative emergence of seedlings of *Butea monosperma* in response to soil salinity. 0.3 dSm⁻¹ (●), 1.9 dSm⁻¹ (○), 3.9 dSm⁻¹ (▲), 6.2 dSm⁻¹ (△), 8.2 dSm⁻¹ (◇). Error bars represent SE.

(Fig. 2). Nevertheless, root length was equal to shoot height for seedlings grown in soil under control conditions. There was a negative linear relationship between shoot height and increasing salt concentration in soil ($r = - 0.636$, $p < 0.01$). A negative linear relationship was also obtained between root length and salt concentration ($r = - 0.734$, $p < 0.01$). In addition, leaf expansion was significantly reduced ($p < 0.01$) by increasing concentration of salt in soil. A negative relationship was obtained between leaf area and salt concentration ($r = - 0.776$, $p < 0.01$). Tap roots of seedlings grown in soil under control conditions contained milky juice and were 3-4 times thicker than the stems. However, thickness of tap roots significantly decreased ($p < 0.01$) with increasing concentration of salt in soil. There was a significant negative relationship ($r = - 0.937$, $p < 0.01$) between thickness of tap roots and salt concentration.

Effect of salinisation on dry weight

Dry weight significantly decreased ($p < 0.01$) for leaves, stems, shoots (leaves + stems), tap roots and lateral roots of seedlings in response to increasing
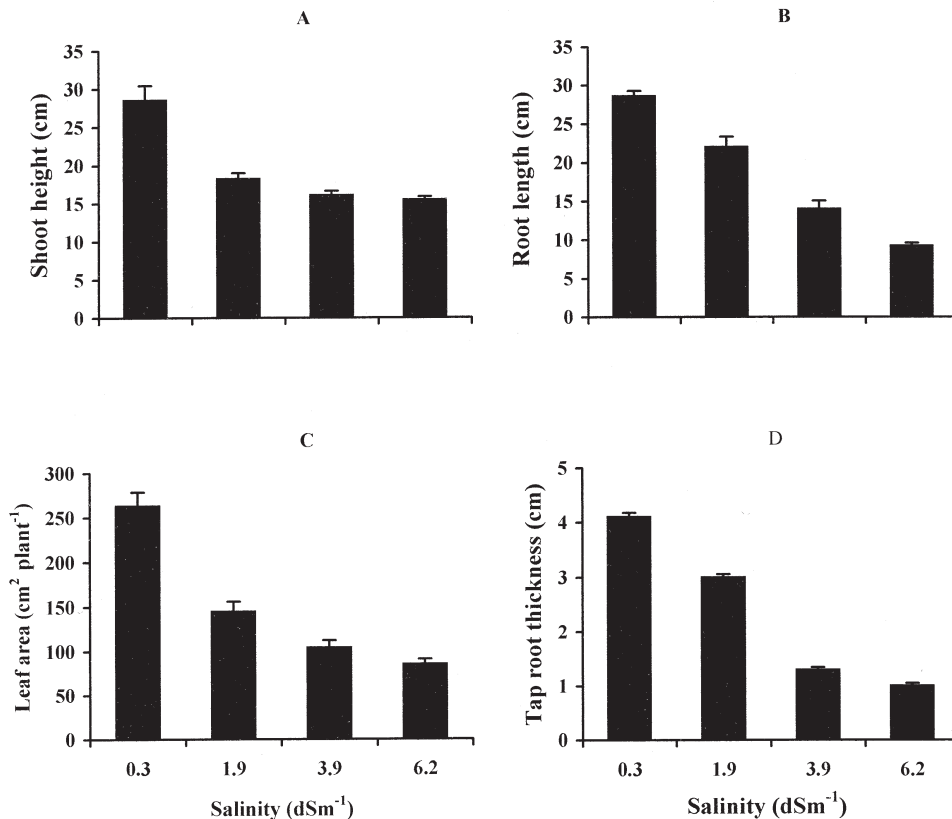

Figure 2. Effect of salinisation of soil on elogation of A. shoots and B. roots; C. expansion of leaves and D, thickness of succulent tap roots of *Butea monosperma* seedlings. In this and Figs. 3 and 4, line bars on histogram bars represent the SE.
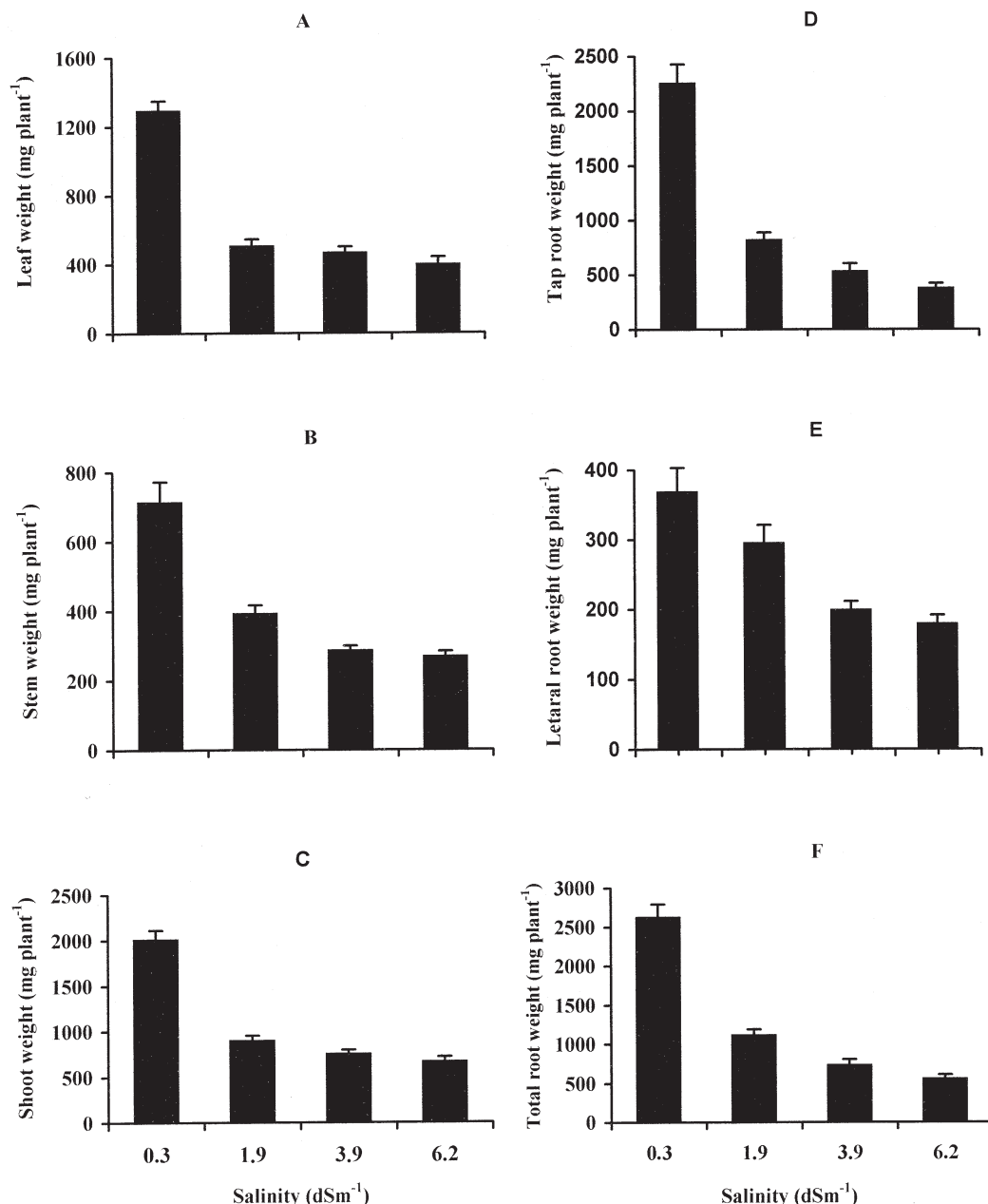
Figure 3. Effect of salinisation of soil on dry weight (mg) of A. leaves; B. stems; C. shoots (leaves + stems); D. tap roots; E. lateral roots and F, total roots of *Butea monosperma* seedlings.

concentration of salt (Fig. 3). A negative relationship was obtained between dry weight of different tissues and salt concentration (r = - 0.703, - 0.637, - 0.709, - 0.744, - 0.575 and - 0.762, p < 0.01, for leaves, stems, shoots, tap roots, lateral roots and total roots, respectively).

Percentage relative weight of tissues of salinized plants compared to those of control plants were computed as (salinized tissue dry weight/control dry weight) × 100. Dry weight values of tissues given in Fig. 3 were used for the calculation of percentage

relative weight of tissues. Values of percentage relative weight varied from 80.1 to 48.6 % for lateral roots, from 54.9 to 37.5% for stems, from 39.1 to 30.7% for leaves and from 35.7 to 16.3 % for tap roots in response to increasing soil salinity from 1.9 to 6.2 dSm^{-1}. As has been estimated using regression equations given in results, the salt concentration at which dry weight will be reduced to 50% of control plants (DW_{50}) were around 3.2, 3.8, 2.2, and 5.4 for leaves, stems, tap roots and lateral root tissues, respectively. Root/shoot dry weight ratio was 1.4
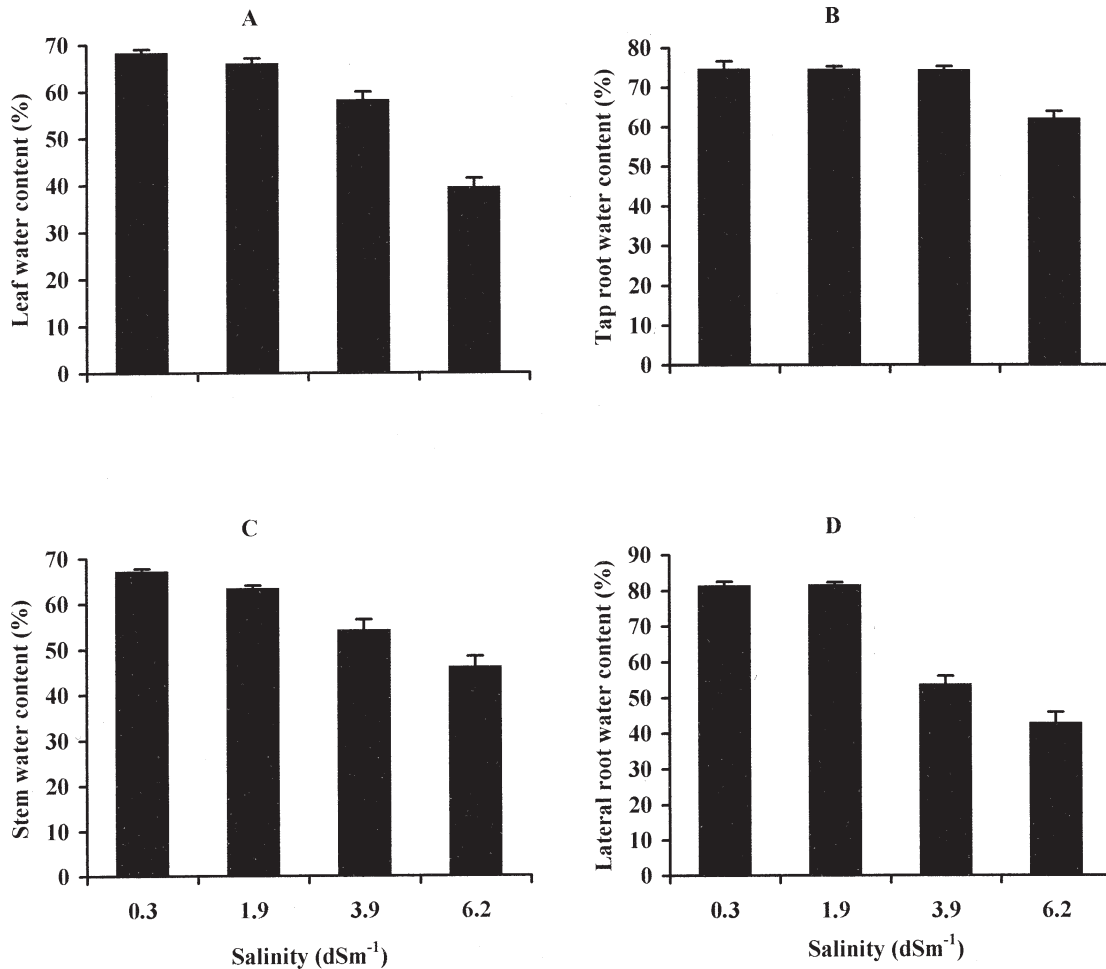
Figure 4. Effect of salinisation of soil on water content (%) of A. leaves; B. stems; C. tap roots and D, lateral roots of *Butea monosperma* seedlings.

under control conditions, while it was obtained 1.3, 1.0 and 0.9 for seedlings grown in soils at 1.9, 3.9 and 6.2 dSm^{-1} salinity, respectively.

Effect of salinisation on water content of tissues

Water content in leaves, stems, tap roots and lateral roots significantly decreased ($p < 0.01$) with increasing concentration of salt in soil (Fig. 4). There was maximum water content in lateral roots and minimum in stems. Tissues, according to their water content, can be arranged in the following decreasing order: lateral roots > tap roots > leaves > stems. There was a negative relationship between water content in different tissues and salt concentration ($r = - 0.644, - 0.515, - 0.323$ and $- 0.723$, $p < 0.01$, for leaves, stems, tap roots and lateral roots, respectively).

Effect of salinisation on mineral accumulation

Potassium and sodium content and K/Na ratio

Potassium content (as mg g^{-1} dry weight) exhibited a significant increase in leaves, stems and lateral roots ($p < 0.01$) with the increase of salt concentration in soil (Fig. 5). In tap root tissues K content gradually increased in response to increasing salt concentration in soil. There was relationship between increase in k content in leaves, stems and lateral roots and increase in salt concentration in soil ($r = 0.946, 0.926$ and 0.852, $p < 0.01$, respectively). Sodium content also significantly increased ($p < 0.01$) in leaves and stem tissues, while it gradually increased in tap roots and lateral root tissues with increasing soil salinity. A positive relationship was obtained between Na
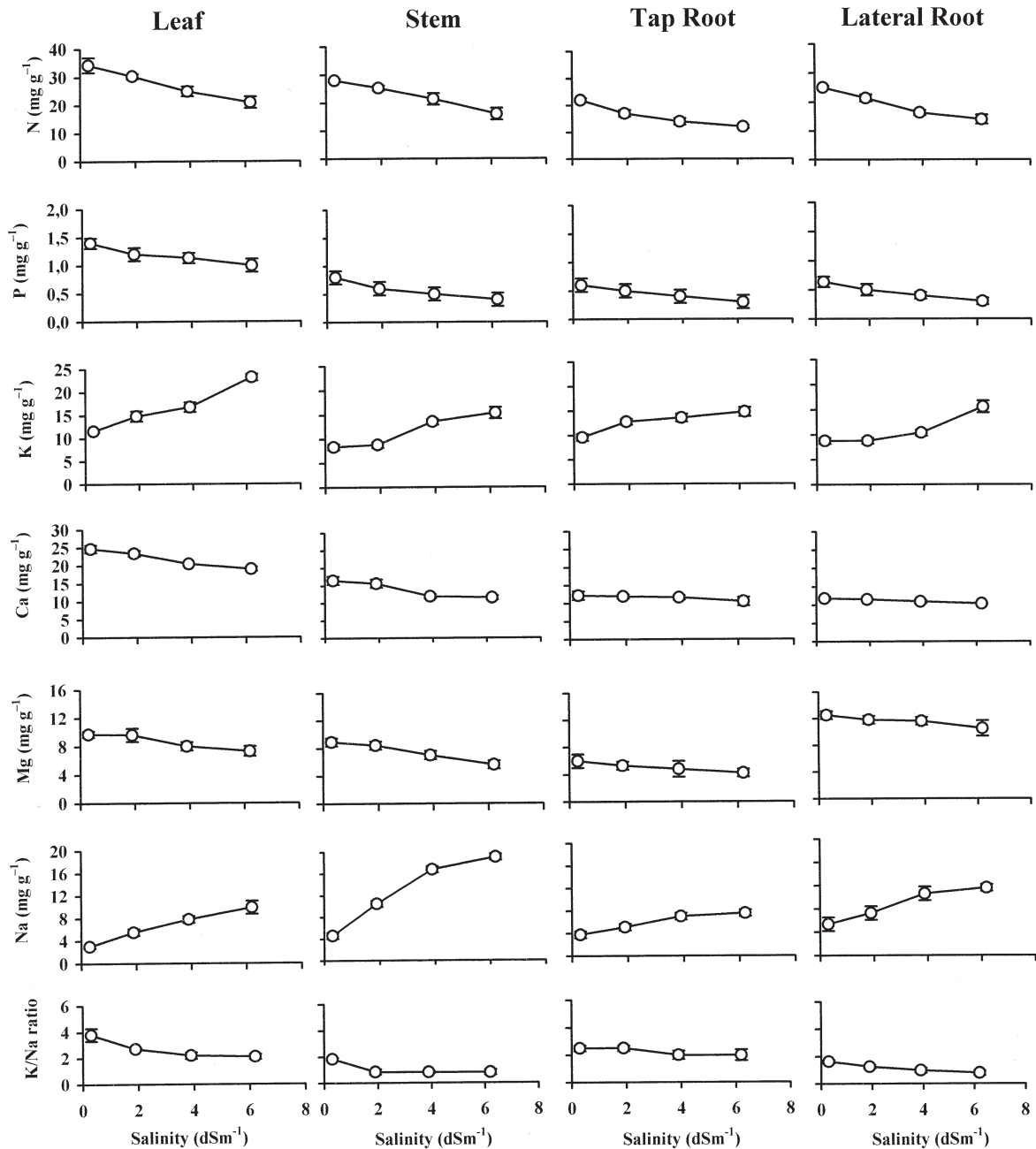
Figure 5. Effect of salinisation of soil on the accumulation of nitrogen, phosphorus, potassium, calcium, magnesium, sodium and K/Na ratio in leaves, stems, tap roots and lateral root tissues of *Butea monosperma* seedlings. In this and Fig. 6 bars on symbols represent the SE.

content in leaves and stem tissues and increase in salt stress ($r = 0.918$ and 0.838, $p < 0.01$, respectively). The K/Na ratio significantly decreased ($p < 0.01$) in leaves, stems and tap root tissues, while it gradually decreased in lateral roots with salinisation of soil. There was a significant relationship between reduction of K/Na ratio in tissues and increase in salt stress ($r = -0.689$, $p < 0.01$ for leaves, $r = -0.637$, $p < 0.05$, for stems and $r = -0.794$, $p < 0.01$, for tap roots).

Nitrogen, phosphorus, calcium and magnesium

The concentration of N, K and Ca was, in general, greater than that of P, Mg and Na in all tissues under control and salt-stress conditions. However, N content significantly decreased in leaves ($p < 0.05$), stems ($p < 0.01$), tap roots ($p < 0.01$) and lateral roots ($p < 0.01$) in response to increasing salt concentration in soil (Fig. 5). A negative relationship was obtained between N content in different tissues and salt

concentration (r = - 0.748, p < 0.01, for leaves, r = - 0.739, p < 0.01, for stems, r = - 0.679, p < 0.01, for tap roots and r = - 0.634, p < 0.05, for lateral roots). Phosphorus content significantly decreased (p < 0.05) in leaves, stems, tap roots and lateral roots in response to salinity. There was a negative relationship between P content in tissues and salt concentration (r = - 0.718, p < 0.01, for leaves, r = - 0.654, p < 0.05, for stems, r = - 0.579, p < 0.05, for tap roots and r = - 0.604, p < 0.05, for lateral roots). Concentration of calcium significantly decreased in leaves and stems (p < 0.01), while it gradually decreased in tap roots and lateral root tissues in response to increase in soil salinity. There was a significant negative relationship between Ca content in leaves and stems and increasing concentration of salt in soil (r = - 0.903 and - 0.814, p < 0.01, respectively). Magnesium content exhibited a significant decrease in leaves (p < 0.05), stems (p < 0.01), tap roots (p < 0.01) and lateral roots (p < 0.01) in response to increase in salt stress. There was a significant negative relationship between Mg

content in tissues and salt concentration in soil (r = - 0.696, - 0.918, 0.857 and - 0.840, p < 0.01, for leaves, stems, tap roots and lateral roots, respectively).

Micro–elements

There was a significant increase in the concentration of Zn in leaves, stems, tap roots and lateral roots (p < 0.01), of Cu in stems and tap roots (p < 0.05), and of Mn in stems, tap roots and lateral roots (p < 0.01) in response to increase in salt-stress (Fig. 6). The changes for Cu in leaves and lateral roots, and of Mn in leaves were gradual with increasing salt concentration. However, concentration of Fe significantly decreased in leaves, stems, tap roots and lateral roots (p < 0.01) with increase in soil salinity. A significant relationship was obtained between soil salinity and concentration for Zn in tissues (r = 0.924, 0.945, 0.942 and 0.765, p < 0.01, for leaves, stems, tap roots and lateral roots,
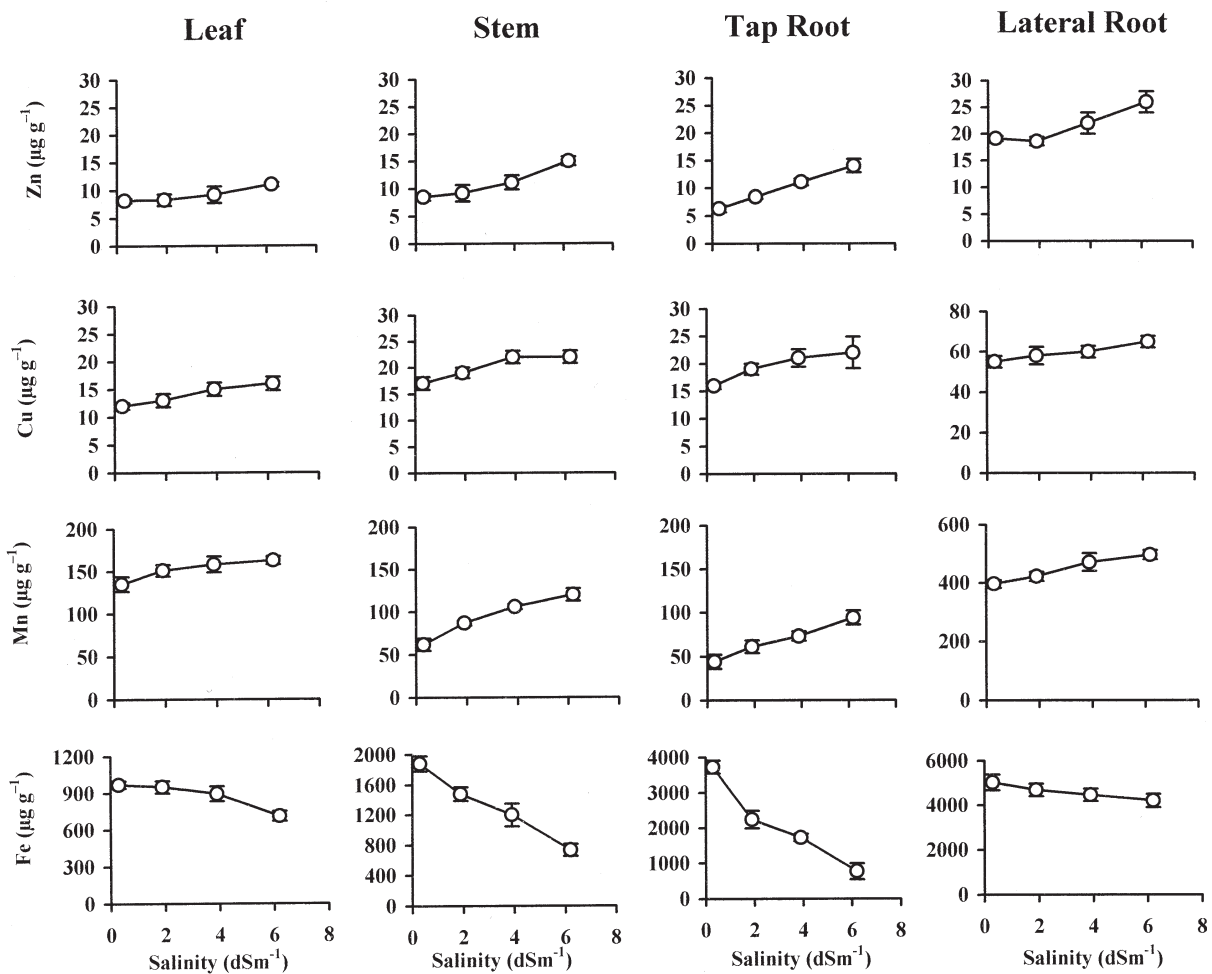

Figure 6. Effect of salinisation of soil on the accumulation of zinc, copper, manganese and iron in leaves, stems, tap roots and lateral root tissues of *Butea monosperma* seedlings.

respectively). Also, there was a significant relationship between salt concentration and concentration for Cu in stems (r = 0.744, p < 0.01) and tap roots (r = 0.795, p < 0.01). Further, a significant relationship was recorded between salt concentration and concentration for Mn in stems, tap roots and lateral roots (r = 0.948, 0.977 and 0.974, p < 0.01, respectively). On the contrast, a significant negative relationship was obtained between salt concentration and concentration for Fe in tissues (r = - 0.935, - 0.994, - 0.974 and – 0.898, p < 0.01, for leaves, stems, tap roots and lateral roots, respectively).

Discussion

Our earlier work (Mer et al. 2000) indicated that germination of salt tolerant barley (*Hordeum vulgare*) seeds was reduced to 50% (SG_{50}) in soil with salinity at 4.1 dSm^{-1}. SG_{50} for *B. monosperma* was in soil with salinity at 5.2 dSm^{-1}, a considerably higher salinity level. As a result, this plant species is salt tolerant at seed germination phase of plant growth. Under field conditions in a large area of the saline desert of Kutch, maximum soil salinity is found during the dry period and minimum during the rainy season (wet period) in the year. In general, salinity for the top 0 – 10 cm layer of soil varies from 4.0 to 6.0 dSm^{-1}. Eventually, seeds of *B. monosperma* can germinate and seedlings achieve establishment during the rainy season. However, salt concentration exceeding 8.2 dSm^{-1} salinity was 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 within a few days in the soil with high salt concentration and later became nonviable. 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 & Rani 1990, Garg et al. 1993) in germinating seeds.

Reduction in water content of leaves, stems, tap roots and lateral roots of seedlings grown in saline soils might have resulted internal water deficit to plants, which in turn, reduced the growth of shoots and roots. Kramer (1983) reported that plants subjected to water stress show a general reduction in size and dry matter production. Moreover, tap root elongation averaged at 28 cm for seedlings grown in soil under control conditions. Result suggests that this species has a tendency for rapid root extension. It is suggested that rapid root extension ensures existence of plants in dry habitats (Etherington 1987, Pandey & Thakarar 1997) and is an adaptation to survive in dry habitats. However, rapid decrease in thickness of succulent tap roots and their milky juice content (for milky juice only visual observation was made by cutting tap roots) with increasing soil salinity suggests that salinity impaired succulence of tap roots. The critical salt concentration for tolerance of seedlings and persistence of succulence of tap roots was 6.2 dSm^{-1} because seedlings died in soils with further increase in salinity. Though succulence is primarily an adaptation to water stress, it provides salt resistance to plants because it temporarily puts off the setting of severe water-deficit induced by salt stress. Root/shoot dry weight ratios of seedlings grown in control and saline soils indicate that root growth was much greater than shoot growth. This type of root growth is an adaptation for plants that grow in arid and moderate saline soils. Root/shoot dry weight ratio for *B. monosperma* under control conditions was 1.4 compared to that for aridity and salt tolerant seedlings of *Prosopis chilensis* (0.40) growing abundantly in the saline desert of kutch (Pandey et al. 1994).

In general, salinity can reduce plant growth or damage the plants through: (i) osmotic effect (causing water deficit), (ii) toxic effects of ions and (iii) imbalance of the uptake of essential nutrients. These modes of action may operate on the cellular as well as on higher organizational levels and influence all the aspects of plant metabolism (Kramer 1983, Garg & Gupta 1997). Results for reduction of shoot growth and leaf area development of *B. monosperma* with increasing salt concentration are in conformity with finding of Curtis & Lauchli (1986), who reported that growth in Kenaf (*Hibiscus cannabinus*) under moderate salt stress was affected primarily through a reduction in elongation of stem and leaf area development. Garg & 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 & Gupta 1997).

Results for dry weight and relative dry weight of tissues in response to increasing salinity suggest that there was lowest reduction in dry weight of lateral roots, while reduction was maximum for tap roots. Consequently, lateral roots were most resistant, and tap roots were highly sensitive to increasing soil salinity. Tissues can be arranged in decreasing order of salt resistance as: lateral roots > stems > leaves > tap roots. Moreover, there was concurrent and differential reduction in dry weight of tissues. The rapid dry weight reduction in tap roots, which contributed a major share to total root mass, caused

reduction in root/shoot dry weight ratio with increasing salt stress. In principle, salt tolerance can be achieved by salt exclusion or salt inclusion. The salt excluders exhibit water deficit which reduces the plant growth. Adaptation by exclusion requires mechanisms for avoidance of an internal water deficit. Adaptation by salt inclusion requires either high tissue tolerance to Na^+ and Cl^- or avoidance of high tissue concentration. The includers utilize inorganic salts in metabolic processes. Consequently, growth of these plants does not decline under natural conditions and plants are salt tolerant. However, low tolerance for salinity (6.2 dSm^{-1}) and reduction in growth of leaves, stems and root tissues of *B. monosperma* with increasing salt stress suggest that this tree species can be grouped among salt excluders. Greenway and Munns (1980) reported that in glycophytes salt exclusion is predominant salt avoidance mechanism. The salt tolerant lateral roots may restrict the salt transport to the shoots of this tree species. Considering selectivity of ions by root cells, it is still unclear which cell types control the selectivity of ions from the soil solution.

The cation K is essential for cell expansion, osmoregulation and cellular and whole–plant homeostasis (Schachtman et al. 1997). High stomatal K requirement is reported for photosynthesis (Chow et al. 1990). The role of K in response to salt stress is also well documented, where Na and K exchange during salt uptake (Fox & Guerinot 1998). In the present study, significant increase of K content in all tissues of seedlings with increasing soil salinity suggests that Na increased K uptake. The exchange of K^+ for Na^+ by the cells in the stele of the roots or in the vascular bundles in stems is considered as one type of control to the transport of salt to leaves or growing tissues.

Moreover, the significant increase of Na in leaves and stem tissues of *B. monosperma* suggests that this mechanism to block Na transfer to growing tissues was not effective at high salt concentration. Also, lateral roots which were most resistant to salt stress do not have ability to accumulate high concentration of Na. Further, complete necrosis in two lower leaves for about 75 % seedlings grown in soil at 6.2 dSm^{-1} salinity testifies a high mortality of seedlings of this species that is found in the saline desert of Kutch. High mortality of seedlings may be a major reason for low abundance of *B. monosperma* in saline habitats. Further, a significant decrease in K/Na ratio in leaves, stems and tap roots also indicates that Na was transferred to these tissues in greater proportion than K. The pattern of accumulation of K and Na in *B. monosperma* conforms to group C and /or group

D plants in Marschner's (1995) classification of the ability of plants to substitute Na with K. In this classification Marschner divided plants into four groups, A, B, C and D depending upon whether K is mostly exchangeable with Na. Sodium has a positive effect on growth in A and B plants (mostly salt-tolerant plants). Group C plants contain very little K that can be substituted with Na without a negative effect on growth, and group D plants exhibit no K/Na substitution (salt-sensitive plants).

It is reported that uptake mechanisms of both K and Na are similar (Watad et al. 1991, Schroeder et al. 1994). Plants utilize two systems for K acquision, low–and high–affinity uptake mechanisms. Low affinity K uptake is not inhibited by Na but the high–affinity process is (Watad et al. 1991, Schroeder et al. 1994). Similarly, Na toxicity in plants is correlated with two proposed Na uptake pathways (Maathuis & Sanders 1994, Niu et al. 1995). The K and Na profiles of *B. monosperma* under salinisation suggest that similar mechanism might operate in this species.

In general, salinity reduces N accumulation in plants (Feigin 1985, Garg et al. 1993). This is due to the fact that an increase in chloride uptake and accumulation is mostly accompanied by a decrease in shoot nitrate concentration (Torres & Bingham 1973, Garg & Gupta 1997). The interaction between salinity and P is very complex and there is no clear cut mechanistic explanation for decreased, increased or unchanged P uptake in response to salinisation in different species (Grattan & Grieve 1992). However, it is known that P concentration is related to the rate of photosynthesis, but it decreases the conversion of fixed carbon into starch (Overlach et al. 1993) and therefore decrease of P in leaves will reduce shoot growth. A decreased P concentration in root tissues, on the other hand, strongly stimulates the formation of root hairs and lateral roots in leguminous trees, rape, spinach, tomato and white lupin (Racette et al. 1990).

Calcium is important during salt stress, e.g., in preserving membrane integrity (Rengel 1992), signalling in osmoregulation (Mansfield et al. 1990) and influencing K/Na selectivity (Cramer et al. 1987). In the present study there was a significantly decrease of Ca content in leaves and stems, while decrease was gradual in tap roots and lateral roots. As a result, Na induced Ca deficiency in tissues. It is reported that uptake of Ca^{2+} from the soil solution may decrease because of ion interactions, precipitation and increases in ionic strength that reduce the activity of Ca^{2+} (Janzen & Chang 1987, Garg & Gupta 1997). Under field conditions, it is observed that *B. monosperma* grows abundantly in Ca-rich soil. As a result, Ca

fertilizers in adequate amount may mitigate Na toxicity (especially leaf necrosis and reduction in succulence of tap roots) to the seedlings of this species. Besides the role of Mg in chlorophyll structure and as an enzyme cofactor, another important role of Mg in plants is in the export of photosynthates, which when impaired leads to enhanced degradation of chlorophyll in Mg deficient source leaves, resulting in increased oxygenase activity of RuBP carboxylase (Marschner & Cakmak 1989).

Mechanistic explanations for the influence of salinity on micro-element concentration are difficult due to (i) the relatively small differences between control and salinised tissues and (ii) the non linear relationship between some of the micro-element content in tissues and salt concentration. It appears that salinity > 1.9 dSm^{-1} increased Zn and decreased Fe accumulation at the whole plant level. Whole plant levels of the other microelements remained almost unchanged, but some nutrients were transferred from one tissue to another in response to increasing soil salinity.

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References

Bernstein L. 1962. Salt affected soils and plants. In: Proceedings of the Paris Symposium, UNESCO (May 1960). Arid Zone Research 18: 139-174.

Brady NC & Weil RR. 1996. The Nature and Properties of Soils. Englewood Cliffs, New Jersey: Prentice-Hall.

Chow WS, Ball MC & Anderson JM. 1990. Growth and photosynthetic responses of spinach to salinity: implications of K nutrition for salt tolerance. Australian Journal of Plant Physiology 17: 563-578.

Cramer GR, Epstein E & Lauchli A. 1989. Na-Ca interactions in barley seedlings: relationship to ion transport and growth. Plant Cell and Environment 12: 551-558.

Cramer GR, Lynch J, Lauchli A & Polito VS. 1987. Influx of Na, K$^+$ and Ca into roots of salt-stressed cotton seedlings. Effects of supplemental Ca. Plant Physiology 83: 510-516.

Curtis PS & Lauchli A. 1986. The role of leaf area development and photosynthetic capacity in

determining growth of Kenaf under moderate salt stress. Australian Journal of Plant Physiology 13: 553-565.

Donahue RL, Miller RW & Shickluna JC. 1983. Soils: An Introduction to Soils and Plant Growth. Englewood Cliffs, New Jersey: Prentice-Hall.

Dubey RS & Rani M. 1990. Influence of NaCl salinity on the behaviour of protease, aminopeptidase and carboxyl-peptidase in rice seedlings in relation to salt tolerance. Australian Journal of Plant Physiology 17: 215-224.

Etherington JR. 1987. Penetration of dry soil by roots of Dactylis glomerata L. clones derived from well drained and poorly drained soils. Functional Ecology 1: 19- 23.

Feigin A. 1985. Fertilization management of crops irrigated with saline water. Plant Soil 89: 285-299.

Fox TC & Guerinot ML. 1998. Molecular biology of cation transport in plants. Annual Review of Plant Physiology and Plant Molecular Biology 49: 669-696.

Garg BK & Gupta IC. 1997. Saline Wastelands Environment and Plant Growth. Jodhpur: Scientific Publishers.

Garg BK, Vyas SP, Kathju S, Lahiri AN, Mali PC & Sharma PC. 1993. Salinity-fertility interaction on growth, mineral composition and nitrogen metabolism of Indian mustard. Journal of Plant Nutrition 16: 1637-1650.

Grattan SR & Grieve CM. 1992. Mineral element acquisition and growth response of plants grown in saline environments. Agriculture Ecosystems and Environment 38: 275-300.

Greenway H & Munns R. 1980. Mechanism of salt tolerance in nonhalophytes. Annual Review of Plant Physiology 31: 149-190.

Janzen HH & Chang C. 1987. Cation nutrition of barley as influenced by soil solution composition in a saline soil. Canadian Journal of Soil Science. 67: 619-629.

Kramer PJ. 1983. Water Relations of Plants. New York: Academic Press.

Maas EV & Grieve CM. 1987. Sodium induced calcium deficiency in salt-stressed corn. Plant Cell and Environment 10: 559-564.

Maas EV & Hoffman GJ. 1977. Crop salt tolerance-current assessment. Journal of Irrigation Drainage Division ASCE 103: 115-134.

Maathuis FJM & Sanders D. 1994. Mechanism of high-affinity potassium uptake in roots of Arabidopsis thaliana. Proceedings of the National Academy of Sciences USA 91: 9272-9276.

Mansfield TA, Hetherington AM & Atkinson CJ. 1990. Some aspects of stomatal physiology. Annual Review of Plant Physiology and Plant Molecular Biology 41: 55-75.

Marschner H & Cakmak I. 1989. High light intensity enchances chlorosis and necrosis in leaves of zinc,

potassium and magnesium deficient bean (Phaseolus vulgaris) plants. Journal of Plant Physiology 134: 308-315.

Marschner H. 1995. Mineral Nutrition of Higher Plants. London: Academic Press.

Mer RK, Prajith PK, Pandya DH & Pandey AN. 2000. Effect of salts on germination of seeds and growth of young plants of Hordeum vulgare, Triticum aestivum, Cicer arietinum and Brassica juncea. Journal of Agronomy and Crop Science 185: 209-217.

Munns R. 1993. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. Plant Cell and Environment 16: 15-24.

Niu X, Bressan RA, Hasegawa PM & Pardo JM. 1995. Ion homeostasis in NaCl stress environments. Plant Physiology 109: 735-742.

Overlach S, Diekmann W & Raschke K. 1993. Phosphate translocator of isolated guard-cell chloroplasts from Pisum sativum L. transport glucose-6-phosphate. Plant Physiology 101: 1201-1207.

Pandey AN, Rokad MV & Thakarar NK. 1994. Root penetration and survival of Prosopis chilensis and Dalbergia sissoo in dry regions. Proceedings of Indian National Science Academy 60: 137-142.

Pandey AN & Thakarar NK. 1997. Effect of chloride salinity on survival and growth of Prosopis chilensis seedlings. Tropical Ecology 38: 145-148.

Pandey AN, Parmar TD & Tanna SR. 1999. Desertification: a case study from Saurashtra region of Gujarat state of India. Tropical Ecology 40: 213–220.

Pandya DH, Mer RK, Prajith PK & Pandey AN. 2004. Effect of salt stress and manganese supply on growth of barley seedlings. Journal of Plant Nutrition 27: 1361-1379.

Piper CS. 1944. Soil and Plant Analysis. New York: Interscience.

Racette S, Louis I & Torrey JG. 1990. Cluster root formation by Gymnostoma papuanum (Casuarinaceae) in relation to aeration and mineral nutrient availability in water culture. Canadian Journal of Botany 68: 2564-2570.

Ramoliya PJ, Patel HM & Pandey AN. 2004. Effect of salinization of soil on growth and macro –and micro– nutrient accumulation in seedlings of Acacia catechu (Mimosaceae). Annals of Applied Biology 144: 321-332.

Rengel Z. 1992. The role of calcium in salt toxicity. Plant Cell and Environment 15: 625-632.

Schachtman DP, Kumar R, Schroeder JI & Marsh EL. 1997. Molecular and functional characterization of a novel low-affinity cation transporter (LCTI) in higher plants. Proceedings of the Natural Academy of Sciences USA 94: 11079-11084.

Schroeder JI, Ward JM & Gassmann W. 1994. Perspectives on the physiology and structure of inward-rectifying K channels in higher plants: biophysical implications for K uptake. Annual Review of Biophysics and Biomolecular Structure 23: 441-471.

Torres BC & Bingham FT. 1973. Salt tolerance of Mexican wheat. I. Effect of NO_3 and NaCl on mineral nutrition, growth and grain production of four wheats. Soil Science Society of America Proceedings 37: 711-715.

Tozlu I, Moore GA & Guy CL. 2000. Effect of increasing NaCl concentration on stem elongation, dry mass production, and macro- and micro-nutrient accumulation in Poncirus trifoliata. Australian Journal of Plant Physiology 27: 35-42.

Watad AA, Reuveni M, Bressan RA & Hasegawa PM. 1991. Enhanced net K uptake capacity of NaCl-adapted cells. Plant Physiology 95: 1265-1269.