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Some Aspects of Salinity, Plant Density, and Nutrient Effects on *Cressa cretica* L.

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ABSTRACT

The effects of salinity, density, and nutrient on the growth, reproduction, and ecophysiology of a perennial halophyte, *Cressa cretica* L., were studied. Lower salinity concentration (425 mM) promoted the growth, but the highest salinity (850 mM) did not have a significant effect. Plants grew faster and were healthier at low density treatment. Lack of nitrogen (N) in the medium substantially inhibited shoot growth. Higher rhizome length and increased dry weight were some of the symptoms of N-deficiency. Phosphorus (P)-free plants also showed higher dry weight and higher ratio of rhizomes to shoots. Reproductive capacity of *Cressa cretica* plants was not affected by the absence of P. Growth and reproduction of *Cressa cretica* plants were significantly inhibited by potassium (K) deficiency. Optimal plant growth was recorded in complete nutrient solution. Higher concentrations of oxalate were found in plants growing under low density conditions and in non-saline controls. Proline concentration increased with the increase in salinity of the medium. Chlorophyll a and b synthesis were inhibited by high salinity treatments whereas changes in density regimes did not have an effect.

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INTRODUCTION

Growth of halophytes in several genera, including *Salicornia, Suaeda*, and *Atriplex* is stimulated by some level of salinity (Flowers et al., 1986; Munns et al., 1983), however, most species of halophytes are inhibited by salt increments, with none making optimal growth at seawater concentrations (Ungar, 1991). Yeo and Flowers (1980) reported that dry biomass of *Suaeda maritima* increased to >150% of controls when salinity levels increased from 10 to 170 mM NaCl. Further increases in salinity from 170 to 680 mM caused a gradual decrease in biomass production to less than 50% of the control. Flowers (1972) showed that the dry mass production of the halophyte *Suaeda maritima* reached optimal level in treatments receiving between 170 and 340 mM NaCl (2.5 times greater than that of nutrient controls). Biomass yields in 680 mM NaCl were 1.5 times greater than the nutrient controls. Biomass production of *Salicornia herbacea* was stimulated at NaCl concentrations up to 200 mM (Baumeister and Schmidt, 1962).

Intraspecific competition may influence the survival, growth, and fecundity of populations in saline habitats (Ungar, 1991). Halophytes may be morphologically plastic in their response to increased plant density, but mortality was not directly correlated with density-dependent factors (Ellison, 1987; Jefferies et al., 1983; Riehl and Ungar, 1982, 1983, 1987). Mortality of halophytes growing in inland and coastal salt marshes was probably due to physical factors in the highly stressful salt marsh environment, such as flooding and high salinity, rather than competition (Jefferies et al., 1983; Ungar, 1987).

Nutrient deficiencies may be a factor controlling the growth of halophytes in salt marshes. Fertilization experiment with *Suaeda maritima* indicated that upper marsh untreated controls had yields one fifth that of lower marsh plants but N + P fertilization increased upper marsh yields to the levels of the lower marsh (Piggot, 1969). Similar increases in yields have been reported by that of N + P fertilization of *Salicornia europaea* plants (Jefferies and Perkins, 1977). Fertilization with complete fertilizer (NPK) significantly increased yield of *Atriplex litoralis* plants when compared with the treatments containing individual elements (Steen, 1984). He hypothesized that N may be a limiting factor in the biomass production of *A. litoralis* in a balanced nutrient solution in saline habitats. However, Steen (1984) concluded that shortages in other nutrients such as P and K could influence the effect of N by limiting biomass production. Usually beach sand lacks N, P, and K (Willis and Yemm, 1961) and mineral nutrition may increase the salinity resistance of plants.

A variety of mechanisms could contribute to the salt tolerance of halophytes (Gorham, 1995). Most of the highly salt-tolerant halophytes are salt 'includers' and are able to withstand high tissue salt concentrations. Compartmentation of ions in vacuoles and accumulation of compatible solutes in the cytoplasm, as well as the presence of genes for salt tolerance, may bestow salt resistance (Gorham, 1995). Increase in salinity in the growth medium of halophyte results in the rise of cellular concentration of proline (Chu et al., 1976; Joyce et al., 1992; Mohammed and Sen, 1987), and oxalate (Austenfeld, 1974; Karimi, 1984; Osmond, 1963).

Cressa cretica L. (Convolvulaceae) is one of the dominant halophytic perennial plants that are widely distributed in pure stands along the coastal salt marshes of Karachi, Pakistan. *Cressa cretica* regenerates every year and above ground part produces numerous seeds and then dies (Aziz, 1994). New aerial parts were produced a few months later from the newly generated node on the rhizomes. Recruitment through seeds is rare. In this study we present the effects of salinity, plant density and nutrient stresses on the ecophysiology, growth, and reproduction of *Cressa cretica.*

MATERIALS AND METHODS

Seeds of *Cressa cretica* were collected from a population at Sands pit beach, Karachi, Pakistan and stored at 4°C. Prior to germination, seeds were scarified with concentrated sulfuric acid for 3 to 5 minutes and then thoroughly washed with distilled water. Seeds were germinated in Petri plates lined with a double layer of Whatman # 1 filter paper moistened with distilled water. Seeds were germinated in light at room temperature. One week old, equal sized seedlings were transplanted in 36-cm-diameter plastic pots. Pots were filled with acid-washed beach sand. Plants were grown for 2 weeks in the greenhouse and irrigated with distilled water and then different nutrient and salinity treatments using half-strength Hoagland solution were applied through sub-irrigation. Plants were treated with three NaCl concentrations, (0, 425, and 850 mM) two plant densities (3 and 6 plants per pot), and four different nutrient solution regimes (N-free, P-free, K-free, and complete). Each treatment had three replicates. Twenty-four trays with three pots each were arranged in a completely randomized design. Distilled water was added at 24 h intervals to compensate for losses due to evapotranspiration. The solutions were changed weekly. Plants were grown for 17 weeks. Height of the above-ground parts were recorded weekly and are referred to as shoot growth in the text. Plants were harvested prior to dispersal of seeds. Plants were separated into above and below-ground parts and the length, number of ramets, and seeds and dry weights of all plant parts were measured. Leaf chlorophyll content was determined by the methods of Machlachlam and Zalik (1963), oxalate was analyzed by Moir's (1953) method as modified by Karimi (1984), and proline was analyzed by the methods of Bates et al. (1973). A Bounferroni test was used to determine if significant differences were present among means (SPSS, 1996).

RESULTS

Shoot growth (length of the above-ground part of plant) of *Cressa cretica* showed an increase at initial and later stages of the life cycle and very slow growth

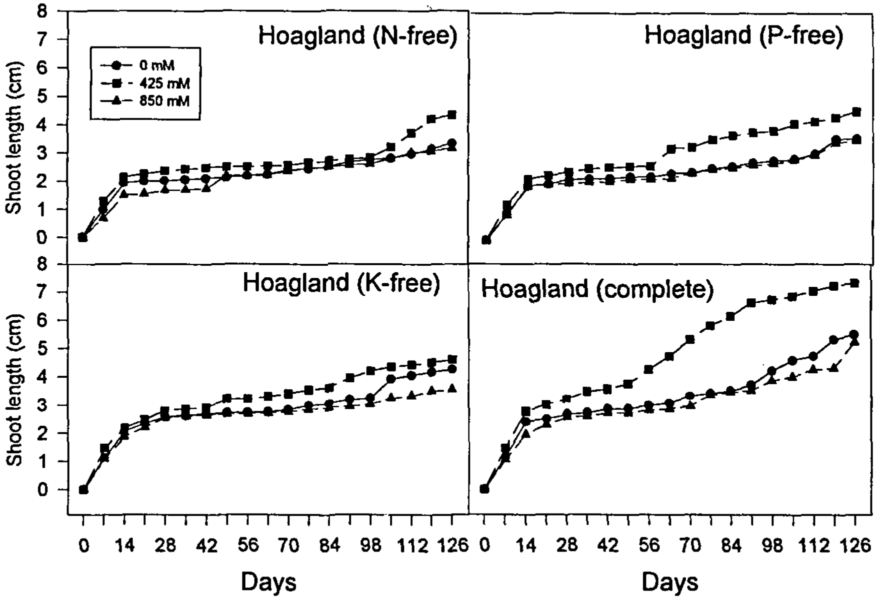

FIGURE 1. Shoot growth of *Cressa cretica* grown at 3 plant pot^{1} at 7 day intervals for 126 days at various salinity and nutrient regimes.

during the intermediate phase (Figure 1). There was no significant difference between two density treatments. At all nutrient regimes, 425 mM NaCl promoted growth in comparison to non-saline control whereas no significant ($P>0.05$) difference was found between control and 850 mM NaCl treatment. At low salinity, the complete Hoagland solution significantly promoted growth in comparison to nutrient free solutions. The results presented in Figure 2 showed that in P and N-free solutions rhizome length at all salinity treatments was significantly ($P<0.001$) increased. Rhizome length was greater at moderate salinity and there was no significant ($P>0.001$) difference between the non-saline control and the high salinity (850 mM) treatments.

Cressa cretica allocated about half of its biomass to below-ground parts (Figure 3), however, allocation to above-ground and reproductive biomass varied with the deficient nutrient. In the N-free treatment, allocation to reproduction was significantly ($P<0.001$) increased at the cost of above-ground vegetative biomass. There was some increase in reproductive allocation in P-free treatments, however, reproductive allocation increased in K-free treatment. There was no effect of density in any of these treatments.

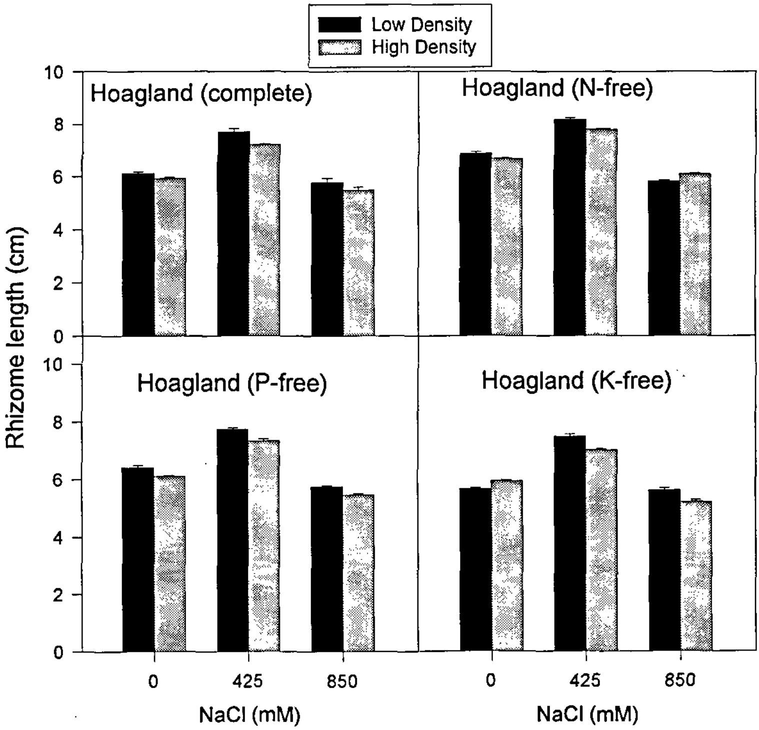

FIGURE 2. Rhizome length of *Cressa cretica* after 126 days of growth at various salinity, nutrient regimes, and densities. Bar represents standard error.

The number of seeds per plant was significantly (P<0.001) reduced when the solution was K-free (Figure 4). However, number of seeds was significantly higher in the N-free solution. Higher density resulted in reduced seed production especially in the N-free treatment. Phosphorus-free plants produced more seeds than the complete Hoagland solution (Figure 4).

Chlorophyll a production was significantly reduced in K-free treatment (Figure 5). All other treatments did not differ. Low salinity either had no effect or increased production of chlorophyll a. *The highest salinity concentration (850 mM)* substantially inhibited chlorophyll a production. High plant density slightly inhibited the production of chlorophyll a. Chlorophyll b production was significantly (P< 0.001) promoted in plant grown in P-free solution while substantial inhibition was noted in K-free treatments (Figure 6). Increase in plant density had no effect on plants grown in the complete Hoagland treatment, but had significant

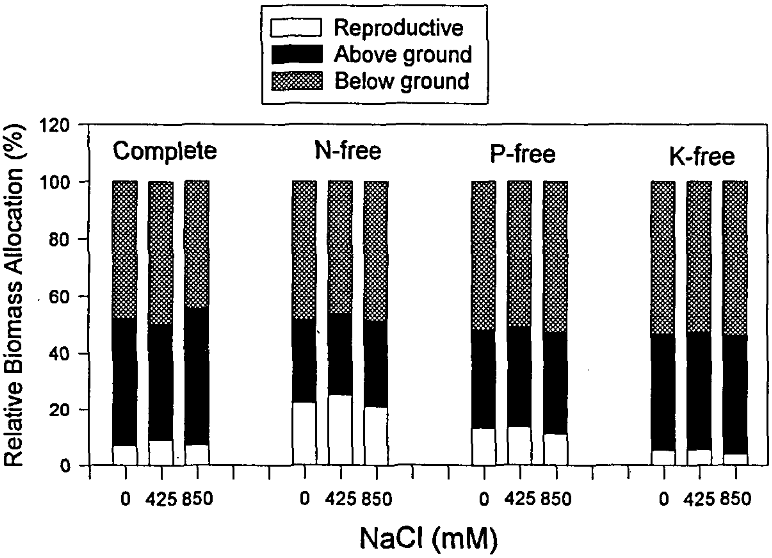

FIGURE 3. Relative biomass allocation of *Cressa cretica* after 126 days of growth at various salinity and nutrient regimes.

inhibitory effects on all the other salinity and nutrient treatments. There was an increase in chlorophyll b production in plants grown in the moderate salinity treatment and inhibition at highest salinity (850 mM NaCl) at all nutrient treatments except in the case of K-free treatment (Figure 6).

Proline content was significantly ($P<0.001$) higher in both low and high density treatments in complete Hoagland solution (Figure 7). High density significantly inhibited proline production in the P-free treatment. Proline production was substantially reduced in N-free treatment. At the highest salinity treatment, higher density had substantially increased proline production (Figure 7). Proline production in K-free solution increased with an increase in salinity and higher density treatments produced substantially higher amounts of proline.

Water soluble oxalate contents in the above-ground showed no effect of salinity and density treatments except in K- free treatment where no water soluble oxalate was detected at high salinity treatment (Table 1). Acid soluble oxalate was significantly reduced in plants grown under the highest salinity concentration in all treatments (Table 1). There was no effect of plant density except in the complete nutrient solution and no oxalate was reported in K-free high density treatments.

The acid and water soluble oxalate production in below-ground parts were similar to those of above-ground tissues in all the treatments studied (Table 2). However,

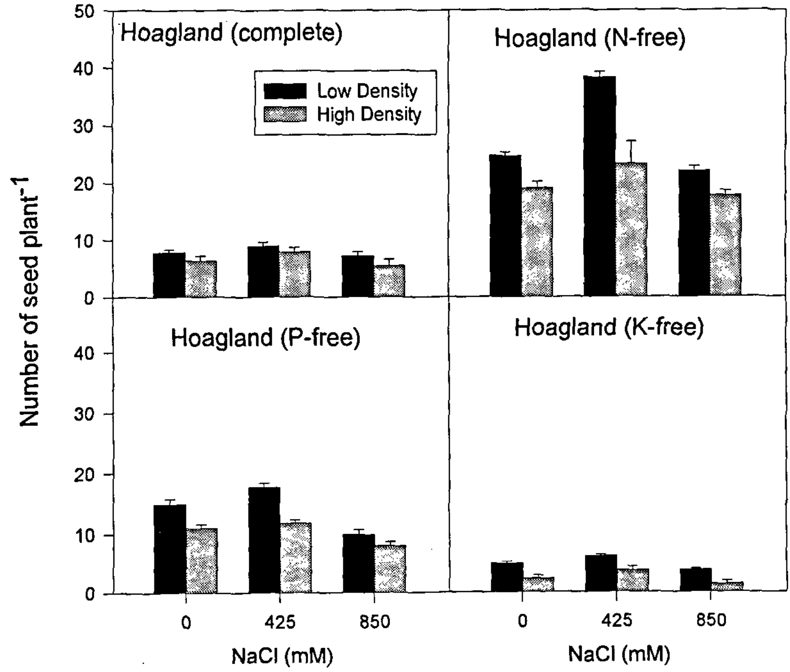

FIGURE 4. Number of seeds per plant of *Cressa cretica* after 126 days of growth at various salinity, nutrient regimes, and densities. Bar represents standard error.

the amount of acid and water soluble oxalates isolated were, in general, much lower than those found in above-ground tissues (Table 2).

DISCUSSION

Cressa cretica is a perennial halophyte, which dominates both inland and coastal marshes and deserts around Karachi, Pakistan. This species grows along the coast, which receives seasonal inundation and inland areas where the water table is less than 15 cm deep. They are propagated primarily through the rhizomes forming an extensive network particularly in coastal marshes. The aerial part of the plant usually dies after about130 days of growth and reproduction. *Cressa cretica* produces a large number of seeds but are poorly represented in the soil (seed bank) (Aziz and Khan, 1996; Zaman and Khan, 1993) and are believed to disappear quickly from the soil (transient seed bank) (Khan, *1991b*; *1993*). *Seeds have* seed coat dormancy that could be broken by acid scarification (Khan, 1991a). Seeds can germinate in up to 850 mM NaCl, which is one of the highest concentrations,

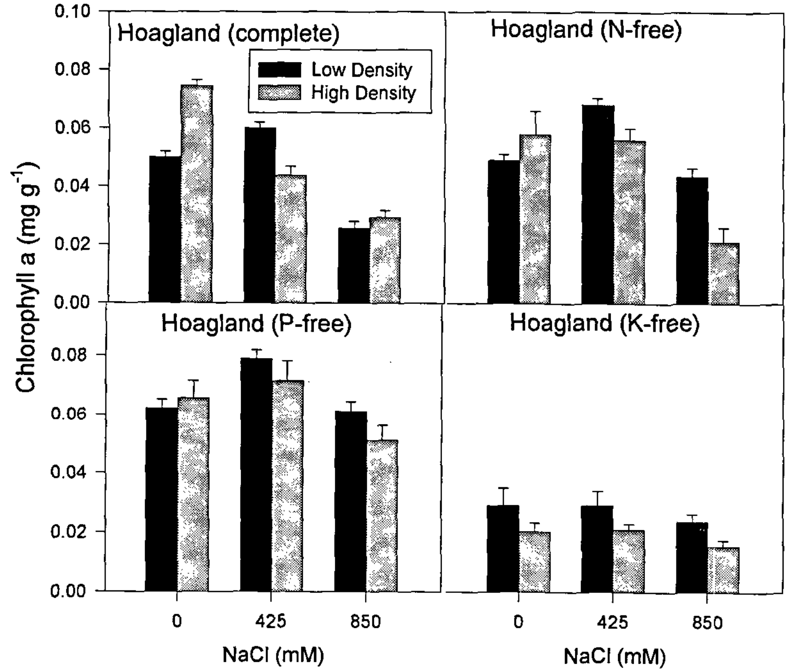

FIGURE 5. Chlorophyll a contents of *Cressa cretica* after 126 days of growth at various salinity, nutrient regimes, and densities. Bar represents standard error.

reported for germination of a halophyte. The present study shows that growth of *Cressa cretica* is promoted at 425 mM NaCl, which is a highly injurious concentration for most halophytic species. However, at the highest salinity (850 mM), the growth performance was not significantly different from the non-saline control indicating an obligate requirement for salinity. It appears that both absence of salt and presence of very high concentrations of salt has similar effects. Salt tolerance studies of 29 halophytic species showed that for 22 species death occurred at a salinity below 500 mM NaCl (Patridge and Wilson, 1987). Best dry mass yield was obtained for all species at below 150 mM NaCl and for half of the species studied it was reached in the nutrient controls. Patridge and Wilson (1987) reported that some species, such as, *Suaeda novae zelandica* and *Salicornia quinquifolia,* maintained 50% of the maximal yield at salinities greater than 600 mM NaCl.

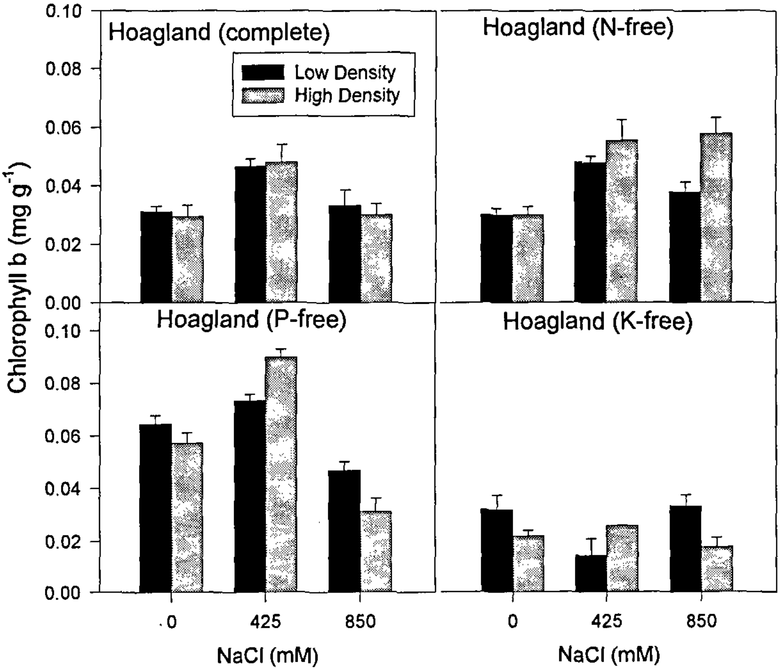

FIGURE 6. Chlorophyll b contents of *Cressa cretica* after 126 days of growth at various salinity, nutrient regimes, and densities. Bar represents standard error.

Maximum number of flowers or fruits was produced in low salinity, while at the high salinity level flower or fruit production was greatly reduced. Our results are similar to those of Okusanya and Ungar (1984), who reported a decrease in the percentage of flowering in *Spergularia rupicola* as salinity increased. In our experiment, salinity did not affect the time of flower initiation. A high number of ramets were formed in the low salinity pots, mainly because of the increased rhizome growth that provided a large surface area for nutrient absorption.

Higher plant density did not have any significant effect on the growth of *Cressa cretica* plants under various salinity stress treatments. However, seed production was significantly decreased with the increases in salinity. Intraspecific competition may affect the survival, growth, and fecundity of populations in saline habitats (Ungar, 1991). Mortality in halophytes growing in inland and coastal marshes was probably due to physical factors in the highly stressful salt marsh environment, such as flooding, drought, and high salinity, rather than competition (Jefferies et al., 1983; Ungar, 1987). Drake and Ungar (1989) reported that reproductive effort was not significantly affected by density in the field experiment of *Atriplex*

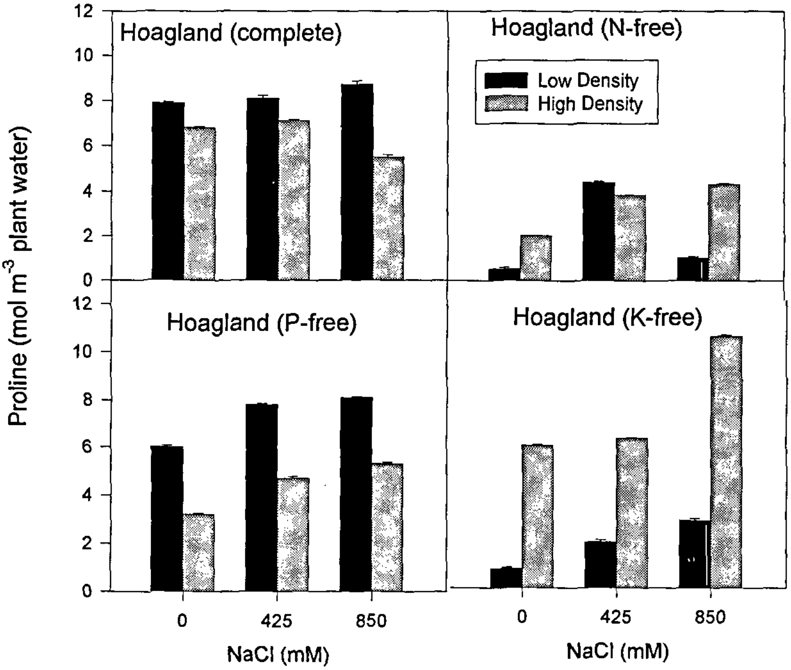

FIGURE 7. Proline contents of *Cressa cretica* after 126 days of growth at various salinity, nutrient regimes, and densities. Bar represents standard error.

triangularis. They concluded that persistence of the population was unlikely to be influenced by variation in the level of seed production among individuals. Khan (1987) was able to demonstrate, using both field and laboratory experiments, that density-dependent factors played a significant role in determining the total biomass yield, reproductive output, and fecundity of individual plants. He concluded that both density-independent soil salinity stress and density-dependent factors were involved in regulating the biomass production in populations of *Atriplex triangularis.*

Nutrient deficiency had significant effects on the growth and reproduction of *Cressa cretica.* Absence of N caused an increase in rhizome length and a decrease in shoot length. Total dry weight of N-free plants was higher than other element free treatments. Potassium deficiency significantly inhibited the growth and reproduction. An individual *Cressa cretica* plant produces a ramet before dying and that ramet bears a new plant in the next growing season. Sandy beaches are the most physically stressful places in which a plant can begin its life. Salt spray, sand burial, dryness, high light intensity, high temperature, wind exposure, soil

TABLE 1. Effect of salinity, density, and nutrient on the water and acid soluble oxalate (meq L^{-1}) of the above-ground part of *Cressa cretica* L. (± standard error).

Hoagland	NaCl (mM)	Oxalate			
		Water-soluble		Acid-soluble	
		Low density	High density	Low density	High density
Complete	0.0	32.8 ± 0.60^{a}	34.2 ± 0.96^{a}	12.2 ± 0.53^{a}	3.9 ± 0.07^{a}
	425	32.5 ± 0.46^{a}	31.2 ± 0.62^{a}	10.3 ± 0.13^{a}	3.7 ± 0.09^{a}
	850	31.2 ± 0.63^{a}	32.7 ± 0.63^{a}	7.8 ± 0.13^{b}	2.7 ± 0.03^{a}
N-free	0.0	27.9 ± 0.13^{a}	26.6 ± 0.50^{a}	7.1 ± 0.60^{a}	3.9 ± 0.07^{a}
	425	27.7 ± 0.12^{a}	27.0 ± 0.64^{a}	7.2 ± 0.53^{a}	4.3 ± 0.04^{a}
	850	26.0 ± 0.27^{a}	26.7 ± 0.80^{a}	4.3 ± 0.11^{b}	4.2 ± 0.06^{a}
P-free	0.0	35.0 ± 0.26^{a}	16.9 ± 0.43^{a}	5.4 ± 0.09^{a}	5.3 ± 0.08^{a}
	425	24.0 ± 0.27^{a}	12.8 ± 0.41^{a}	2.8 ± 0.70^{b}	4.3 ± 0.06^{a}
	850	21.5 ± 0.27^{a}	11.9 ± 0.45^{b}	4.1 ± 0.03^{a}	4.8 ± 0.07^{a}
K-free	0.0	18.0 ± 0.30^{a}	0	5.4 ± 0.84^{a}	0
	425	17.4 ± 0.73^{a}	0	4.5 ± 0.74^{a}	0
	850	16.3 ± 0.53^{a}	0	3.7 ± 0.06^{a}	0

Values in each column with the same letter are not significantly different $P>0.05$, Bonferroni Test.

salinity, and nutrient deficiency are among the major stresses imposed in coastal dune environment (Hesp, 1991). It has been shown that plants deficient in N, P, and K will exhibit slow growth, chlorosis, death of lower leaves and change in root/shoot ratio (Hawke and Maun, 1988; Pemadasa and Lovel, 1974; Russel, 1977). Hawke and Maun (1988) reported one of the most obvious differences among species was their response to the no K treatment. In *Oenothera biennis*, the lack of K promoted leaf growth and higher dry biomass production in comparison to N and P deficient treatments, whereas, there was no effect of K deficiency in *Ammophila arenaria* and *Cakile maritima.*

In a complete nutrient solution, chlorophyll a content of *Cressa cretica* substantially decreased at the highest salinity (850 mM NaCl). Plant density had a significant effect on chlorophyll production in non- and low-saline treatments but no difference in the high salinity treatment. Absence of K from the medium substantially inhibited the chlorophyll a production in all salinity and density

TABLE 2. Effect of salinity, density, and nutrient on the water and acid soluble oxalate (meq L^{-1}) of the below-ground part of *Cressa cretica* L. (± standard error).

Hoagland	NaCl (mM)	Oxalate			
		Water-soluble		Acid-soluble	
		Low density	High density	Low density	High density
Complete	0.0	12.5±0.13^{a}	10.02±0.71^{a}	5.3±1.1^{a}	2.7±0.07^{a}
	425	10.9±0.30^{a}	9.0±0.09^{a}	5.2±0.34^{a}	2.2±0.06^{a}
	850	11.2±0.23^{a}	8.8±0.20^{a}	5.3±0.05^{a}	0.7±0.03^{a}
N-free	0.0	10.3±0.12^{a}	6.8±0.13^{a}	4.4±0.05^{a}	6.3±0.07^{a}
	425	9.1±0.04^{a}	7.9±0.64^{a}	2.7±0.08^{b}	1.8±0.07^{a}
	850	9.0±0.09^{a}	6.6±0.15^{a}	3.5±0.10^{b}	2.2±0.05^{b}
P-free	0.0	9.2±0.05^{a}	5.8±0.15^{a}	1.6±0.85^{a}	1.60±0.06^{a}
	425	8.6±0.04^{a}	4.8±0.13^{a}	1.7±0.34^{a}	0.98±0.05^{b}
	850	7.6±0.07^{a}	3.4±0.27^{b}	1.3±0.05^{a}	1.5±0.08^{a}
K-free	0.0	6.9±0.04^{a}	0	0.9±0.04^{a}	0
	425	3.6±0.06^{b}	0	1.3±0.03^{b}	0
	850	3.0±0.06^{b}	0	1.4±0.05^{b}	0

Values in each column with the same letter are not significantly different $P>0.05$, Bonferroni Test.

regimes tested. Production of chlorophyll b was significantly promoted at the P-free treatment and substantially inhibited at K-free plants. Karimi (1984) reported increase in chlorophyll content with increase in NaCl salinity in *Atriplex triangularis*. Higher chlorophyll content per unit leaf area was recorded in P deficient solutions (Hecht-Benholtz, 1967; Tombesi et al., 1969), however, photosynthetic efficiency was decreased.

Proline production was significantly ($P<0.05$) inhibited in all nutrient free treatments and this effect was more substantial in the N-free treatment. In the K-free treatment, high plant density produced significantly higher proline and this concentration increased with an increase in salinity. Storey and Wyn Jones (1977) studied the 14 species of halophytes, semi-resistant glycophytes, and salt sensitive glycophytes and reported that all accumulate proline on the exposure to NaCl stress. It has been suggested that proline acts as an important osmoticum at the cellular level (Chandler and Thrope, 1987).

Water soluble oxalate content in the above-ground tissue did not change with increase in salinity or density in all nutrient treatments except in the case of K-free treatment where no water soluble oxalate was detected in the high salinity treatments. Acid soluble oxalate was significantly reduced in the highest salinity concentrations in all the treatments. No oxalate was formed in the high density K-free solution. Below-ground oxalate production was much lower in comparison to above ground tissues. Reduction in oxalate content under high salinity conditions has been reported for *Atriplex* sp. (Osmond, 1963), *Salicornia europaea* (Austenfeld, 1974) and *Atriplex traingularis* (Karimi, 1984).

Cressa cretica plants were found to complete their life cycle in the 850 mM NaCl treatment and show a significant growth promotion in low salinity (425 mM) treatments. *Cressa cretica* appears to be one of the most tolerant salt species identified so far. Density did not significantly affected the growth but seed production was significantly ($P<0.001$) inhibited. Nutrient deficiency has varied effects on the growth and reproduction of *Cressa cretica*. Although concentration of osmoticas increased with increase in salinity, their concentrations were not high enough to play any significant role in osmoregulation.

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