

# Effect of Salinity and Waterlogging on Growth and Survival of *Salicornia europaea* L., an Inland Halophyte<sup>1</sup>

CAROLYN HOWES KEIFFER, BRIAN C. MCCARTHY, AND IRWIN A. UNGAR, Department of Environmental and Plant Biology, Ohio University, Athens, OH 45701

**ABSTRACT.** *Salicornia europaea* seedlings were exposed to various salinity and water depths for 11 weeks under controlled, growth chamber conditions. Weekly measurements were made of height, number of nodes, and number of branches per plant. Growth and survival of plants grown with the addition of NaCl were significantly greater ( $P < 0.0001$ ) than for plants which were not given a salt treatment. Although there were no significant ( $P > 0.05$ ) growth differences among plants under different water level conditions within the salt treatment group, plants which were grown without NaCl demonstrated significant decreases in growth in higher water levels, with the greatest growth occurring in the low water treatment group. All plants given a salt treatment survived until the end of the experiment. However, high mortality occurred among the plants that were not salt-treated, with all plants grown under waterlogged conditions dying by week six. The high mortality exhibited by this treatment group indicates that *Salicornia*, which is typically found in low marsh or inland salt marsh situations, was unable to overcome the combined stress of being continuously waterlogged in a freshwater environment.

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## INTRODUCTION

The distribution of plant species in saline environments of inland North America is closely associated with soil water potentials and other factors influencing the level of salinity stress, including microtopography, precipitation, and depth of the water table (Ungar et al. 1979). The influence of salinity as a factor in determining the level of germination of seeds, growth, and distribution of halophytes has been documented by Adam (1990). Because of sporadic precipitation during the growing season and its influence on soil water potential, inland saline environments tend to be more variable in soil salinity concentrations than coastal marshes which are regularly exposed to tidal action (Ungar 1970, 1974).

Inland salt marshes are often characterized by having high water tables that can result in the soils becoming waterlogged throughout the year. Except for a thin oxygenated zone at the surface, flooded soil becomes completely anaerobic within a few hours to several days, because the soil pore space is filled with water, and the remaining oxygen is depleted by respiration of plant roots and micro-organisms (Koncalová 1990, Van Diggelen 1991). Oxygen diffusion from the atmosphere is too slow to replenish oxygen at depths exceeding 5 to 10 mm (Van Diggelen 1991).

When a soil becomes saturated with water, a complex sequence of interrelated physiochemical and microbiological changes occurs such as the disappearance of oxygen, accumulation of CO<sub>2</sub>, anaerobic decomposition of organic matter, transformation of nitrogen, and reduction of manganese, iron, and sulfate (Armstrong 1975, Gambrell and Véber 1978, Ponnampereuma 1984). In salt marshes, sulfate reduction is the terminal process of anaerobic mineralization of organic

matter and methane formation is the terminal process in fresh water marshes (Van Diggelen 1991). Therefore, plants living in saline waterlogged soils face four major problems: 1) inhibition of aerobic root respiration which may interfere with the uptake and transport of nutrients and also with the exclusion of sodium chloride in roots of salt marsh plants (Chapman 1974, Waisel 1972); 2) high metabolic cost of maintaining a greater vacuole osmotic potential than the surrounding saline soil solution; 3) excessive uptake of reduced iron and manganese (Adam 1990); and 4) disturbance of hormonal metabolism and photosynthesis (Ungar 1991).

Previous studies in coastal saltmarshes indicated that tidal action and waterlogging stimulated the growth of *Salicornia* species (Langlois 1971, Cooper 1982). However, very little work has been done with inland populations which are subject to waterlogging. *Salicornia europaea*, a member of the family Chenopodiaceae, an obligate halophyte, is prevalent in coastal and continental saline habitats throughout the world and usually occupies the zones of highest salinity (Chapman 1960, Waisel 1972, Ungar 1974). *S. europaea* is a leafless, succulent-stemmed, herbaceous annual. The jointed stems of this plant are usually freely branched with most branches terminating in fruiting cymes.

*Salicornia* is rather unusual amongst wetland plants in having little aerenchyma (3-6% gas-filled root volume), even under hypoxia (Pearson and Havill 1988). As a consequence, metabolic adaptations to flooding may be of significant interest. Schat et al. (1987) demonstrated that *S. europaea* seedlings from the waterlogged soils in the lower and upper marsh were not affected by anaerobiosis. Additionally, *S. europaea* has been determined to be extremely tolerant of sulfide ion accumulation (Ingold and Havill 1984).

Although considerable data are available for growth responses to salinity and waterlogging for coastal populations of *S. europaea* (Langlois 1971, Cooper 1982),

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little is known of the effect of these factors on inland populations. The purpose of our investigation was to determine the combined effects of salinity and waterlogging on various growth parameters and survival of *S. europaea* from an inland saline location.

### MATERIALS AND METHODS

*Salicornia europaea* seeds were collected from an inland salt marsh located on the property of the Morton Salt Company in Rittman, Wayne County, OH. Seeds were given a 30 day wet/cold treatment at 5° C. The seeds were then placed on filter paper in petri dishes and immersed in a 0.5% NaCl solution. Seeds were maintained at 15° C, 12 hour days (PAR, 25  $\mu\text{mol}/\text{m}^2/\text{s}$ ) and 5° C, 12 h nights in a lighted incubator (Percival™, DesMoines, IA) until germination occurred. Seedlings were transplanted into 7.5 cm diameter x 10 cm tall plastic pots containing Ball® commercial potting soil and allowed to grow 30 days prior to treatment.

The pots of seedlings were randomly transferred into trays containing saline and non-saline treatment solutions at various water levels ( $n = 7$ ). A half-strength Hoagland's nutrient solution was used as the non-saline treatment solution and the same solution containing 1% NaCl was used as the saline treatment solution. Three water levels were maintained (low = 2.5 cm standing water, medium = 5 cm standing water, and high = 10 cm of standing water) by adding distilled water daily, with a complete solution change every 2 weeks to provide a non-limiting supply of major nutrients. Plants receiving the high water treatment were considered to be waterlogged since the water level was always above the soil surface. The plants were placed in growth chambers (Environmental Growth Chambers, Chagrin Falls, OH) for 11 weeks at 25° C, 15 h days (PAR, 250  $\mu\text{mol}/\text{m}^2/\text{s}$ ) and 15° C, 9 h nights. The height, number of nodes, and number of branches were recorded weekly.

Statistical analysis was done using Friedman's two way analysis by ranks and the Kolmogorov Smirnov two-sample test (Sokal and Rohlf 1981).

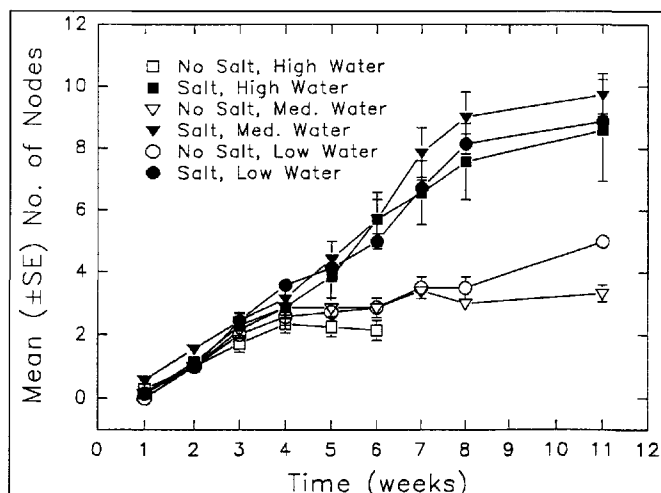


FIGURE 1. Mean ( $\pm$  S.E.) weekly node production of *Salicornia europaea* grown in 1% NaCl and distilled water under various waterlogging levels (low = 2.5 cm standing water, medium = 5.0 cm standing water, and high = 10 cm standing water).

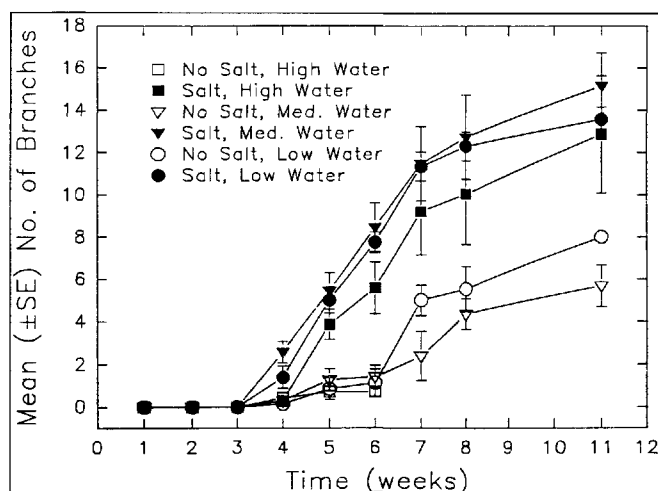


FIGURE 2. Mean ( $\pm$  S.E.) weekly branch production of *Salicornia europaea* grown in 1% NaCl and distilled water under various waterlogging levels (low = 2.5 cm standing water, medium = 5.0 cm standing water, and high = 10 cm standing water).

### RESULTS

Because there was 0% survival in the non-saline waterlogged treatment group and low survivorship ( $n = 1$ ) in another non-saline treatment group, it was impossible to perform standard parametric statistical analyses. Friedman's two way analysis by ranks of the branch, node, and height data (Figs. 1-3), revealed that plants from the saline and non-saline treatment groups were significantly different ( $P < 0.0001$ ) from each other. Pairwise Kolmogorov Smirnov two-sample tests were then performed, and plants grown in the three water levels under saline conditions were not significantly different from each other ( $P > 0.05$ ). However, plants grown without the addition of salt were significantly different ( $P = 0.01$ ) from each other at the various water levels, with the greatest number of nodes ( $8.57 \pm 1.64$ ), branches ( $12.86 \pm 2.76$ ), and height ( $13.37 \pm 2.38$  cm) being produced by plants grown in the lowest water level (Table 1).

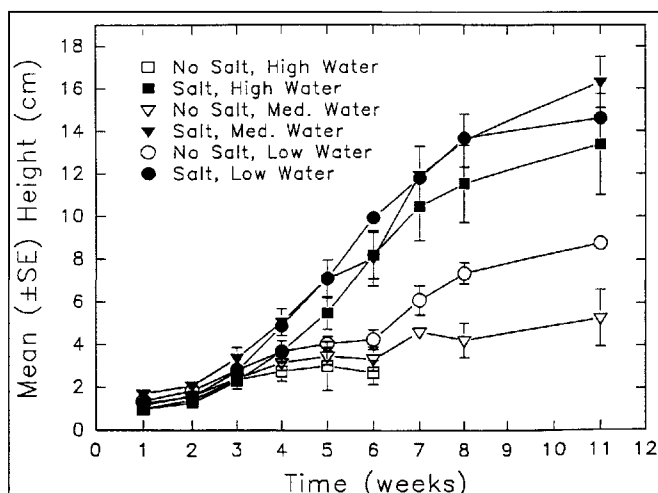


FIGURE 3. Mean ( $\pm$  S.E.) weekly height (cm) of *Salicornia europaea* grown in 1% NaCl and distilled water under various waterlogging levels (low = 2.5 cm standing water, medium = 5.0 cm standing water, and high = 10 cm standing water).

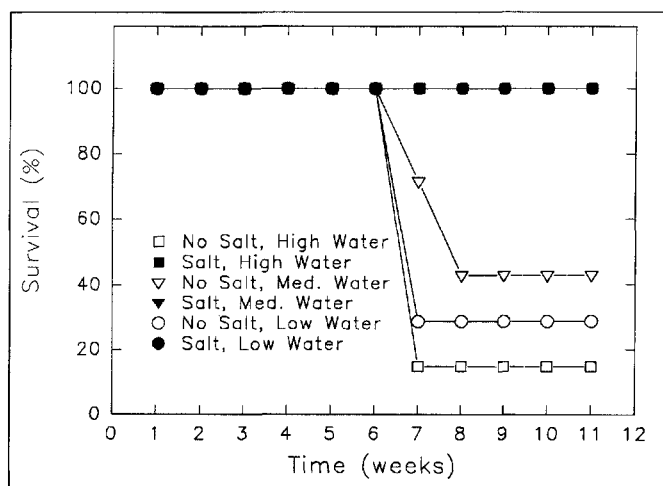


FIGURE 4. Percentage of *Salicornia europaea* plants surviving at week 11 after being grown in 1% NaCl and distilled water under various waterlogging levels (low = 2.5 cm standing water, medium = 5.0 cm standing water, and high = 10 cm standing water).  $n = 7$  plants per treatment combination.

Node productivity of plants from the saline and non-saline treatment groups were significantly different ( $P < 0.0001$ ); however, only the plants grown in the non-saline treatment groups were significantly different ( $P = 0.01$ ) from each other at the various water levels (Fig. 1). Branch and node production of plants from the saline and non-saline treatment groups were also significantly different ( $P < 0.0001$ ); however, only the plants grown in the non-saline treatment groups were significantly different ( $P = 0.01$ ) from each other at the various water levels (Figs. 1, 2).

Height of plants from the saline and non-saline treatment groups followed a similar pattern and were also significantly different from each other ( $P < 0.0001$ ). Plant heights from individuals grown in the non-saline treatment groups were also determined to be significantly different ( $P = 0.01$ ) from each other at the various water levels with the greatest height being obtained by plants receiving the low water treatment (Fig. 3).

All plants in saline treatments survived until the end of the experiment, however, 100% mortality occurred in the

non-saline waterlogged treatment group by week 7 (Fig. 4). Mortality occurred to a lesser extent in the other non-saline treatment groups, with the greatest percentage of plants (43%) surviving in the medium water level.

## DISCUSSION

Flooding tolerance has been associated with the development of aerenchyma tissue in roots which increases the pore space for air flow to tissues. According to Justin and Armstrong (1987), flooding tolerance in wetland species with low root porosity depends on shallow rooting and a preference for more aerated wetland sites. The latter does not apply for *Salicornia* spp., which occur in the pioneer zone of the lower marsh (Adam 1990). In the black anaerobic soil of these tidal sites, the root tips of *Salicornia* spp. die off from anoxia and mechanical damage, resulting in shallow rooting (Cooper 1982). Despite this damage to the root system and impaired growth by anoxia, *Salicornia* spp. manage to survive and reproduce (Schat et al. 1987). Survival and growth of *S. europaea* in the pioneer zone may be related to its tolerance of ferrous iron buildup (Van Diggelen 1991) and resistance to high sulfide concentrations (Ingold and Havill 1984).

Waisel (1972) classified *S. europaea* as an obligate halophyte because growth was stimulated by NaCl increments. The greatest number of nodes were formed by plants growing in saline solutions, but the differences between water level treatments were not significant ( $P > 0.05$ ). Node production of plants was inhibited in non-saline treatments, with 68% fewer being produced than in saline treatments.

The greatest number of branches (15/plant) were produced in the low water level under saline conditions. Free-form branching habit is one of the most important measures of growth in *S. europaea*, since the production of a large number of branches is associated with increases in its biomass accumulation (Langlois 1971). Branching patterns followed the same trend as node production, with optimum branching occurring in saline treatments, and limited branching (<9/plant) occurring in all non-saline treatments.

Langlois (1971) demonstrated that waterlogging of

TABLE 1

Mean ( $\pm$  S.E.) for three morphological traits by treatment combination after 11 weeks.

Solution Level*	Non-Saline Solution			1% NaCl Solution		
	Low	Medium	High	Low	Medium	High
Morphological Trait						
Number of Branches	8.80 $\pm$ 0.00 <sup>a</sup>	5.67 $\pm$ 0.98 <sup>b</sup>	0.00 $\pm$ 0.00 <sup>**</sup>	13.57 $\pm$ 0.56 <sup>a</sup>	15.14 $\pm$ 1.58 <sup>a</sup>	12.86 $\pm$ 2.76 <sup>a</sup>
Number of Nodes	5.00 $\pm$ 0.00 <sup>a</sup>	3.30 $\pm$ 0.27 <sup>b</sup>	0.00 $\pm$ 0.00 <sup>**</sup>	8.85 $\pm$ 0.24 <sup>a</sup>	9.71 $\pm$ 0.69 <sup>a</sup>	8.57 $\pm$ 1.64 <sup>a</sup>
Plant Height (cm)	8.75 $\pm$ 0.00 <sup>a</sup>	5.30 $\pm$ 1.31 <sup>b</sup>	0.00 $\pm$ 0.00 <sup>**</sup>	14.60 $\pm$ 0.26 <sup>a</sup>	16.30 $\pm$ 1.21 <sup>a</sup>	13.37 $\pm$ 2.38 <sup>a</sup>

\*Low = 2.5 cm; Medium = 5 cm; High = 10 cm standing water.

\*\*100% mortality by week 11.

Means with the same superscript letter within a row by saline treatment are not significantly different ( $P > 0.05$ ).

Pairwise Kolmogorov Smirnov tests were used to compare solution levels within saline treatments.

*S. europaea* plants with artificial tides stimulated growth of individuals from a coastal population. The increase in growth as measured by plant height was also greatest in the saline treatments. Anoxic conditions brought about by soil waterlogging were shown to induce high levels of anaerobic respiration which can cause a toxic buildup of metabolic products in the plant (Van Diggelen 1991). Mortality and reduced growth in freshwater treatments were caused by a negative interaction between the freshwater medium and waterlogging of *S. europaea* plants. Obligate halophytes such as *S. europaea* have a salt requirement for optimal growth. Plants from coastal populations are stimulated by flooding, while plants from inland populations are negatively affected by long periods of flooding.

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## The 1993 Paper of the Year Award

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Ohio Wesleyan University  
Delaware, Ohio  
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for their paper:

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