Di Pattern of Salicornia Vegetative Growth in Relation to Fertilization

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ABSTRACT

Salicornia bigelovii Torr. was considered a potentially valuable new oil-seed crop for direct seawater irrigation. The purpose of this study was to investigate the growth curve of Salicornia in relation to nutrient requirements by conducting field and hydroponics experiments. The field data were for seawater irrigated and N-fertilized Salicornia. The hydroponics data were for Salicornia grown in seawater enriched to ½ strength Hoagland solution under continuously- and monthly-fertilized treatments with pH and salinity monitoring. The mean relative growth rate, based on organic matter weight, was 464 Gs^{-1} during the vegetative stage in the field. This rate value fell within the range normally reported for glycophytes (347 to 4398 Gs^{-1}). Salicornia seemed to have a di-pattern growth-curve made of 'slow' and 'rapid' growth phases during the vegetative stage. The 'slow' growth mechanism seemed to operate at very low concentrations of nutrients, very low transpiration rate, and inactive H^+-ATPase pumps. The 'rapid' growth mechanism seemed to operate at high concentrations of nutrients, high transpiration rates, and was employing active H^+-ATPase pumps. To optimize fertilizer use, environmental impact and economic benefits, fertilizer requirements could be changed with plant development. Without fertilizer application, especially during the 'rapid' growth phase, the growth rate of Salicornia might become so slow as to preclude their use as a crop species.

INTRODUCTION

The terrestrial halophyte *Salicornia bigelovii* Torr. is considered a potentially valuable new high-yielding oilseed crop for direct seawater irrigation (Glenn et al., 1991). Cultivation of Salicornia has been tried in Kuwait (Riley and Abdal, 1993) and in Ras Al Zawr, Saudi Arabia (Hodges et al., 1993). In Ras Al Zawr, conceptual plans are being developed for a completely new integrated rural and urban community based on seawater, with 15 000 ha of sea water-irrigated Salicornia farms (Hodges et al., 1993). However, the lack of soil/water management information about halophytes in general and Salicornia in particular is slowing its development (O'Leary, 1985; Alsaeedi and Elprince, 2000).

Weeks (1986) described the development of Salicornia at Estero Morua estuary (about 6-km southeast of Puerto Penasco, Sonora, Mixico). The normal development of Salicornia always proceeds through the following stages: (i) seed is dehisced into the estuary (late August and September); (ii) seed germination (after several days); (iii) seedlings (October until March); (iii) relatively rapid growth (April and several months); (iv) inflorescence (flowering) tissue begins to appear and develops determinately at each branch and with grain filling until senescence overtakes the entire plant and seed once again released into the estuary (June until September).

Several questions require answers before the actual seawater farming of Salicornia becomes a reality. One of these questions is whether the growth rate of Salicornia is so slow as to preclude their use as crop species. Another question is whether the fertilizer requirement changes with plant development as to optimize fertilizer use and economic benefits. The purpose of this research is to investigate the growth curve of Salicornia in relation to nutrient requirements in the field and hydroponics.

MATERIALS AND METHODS

Field Experiment

The two seasons (1993-94 and 1994-95) field data were from the Salicornia farm located in Ras Al Zawr on the Arabian Gulf, Saudi Arabia. The soil was Torripsament. The farm was daily seawater-irrigated using a center pivot. The root zone was never allowed to dry. Sowing (seeding) was on late September and the experiments terminated on early September. Urea (46% N) fertilizer was dissolved in irrigation water and applied at a rate of 15-kgN ha^{-1} $week^{-1}$ for a 20-week period starting one month from sowing. Plant sampling was done by randomly applying a square frame (0.25 m x 0.25 m) three times within the treatment plots and examining, randomly chosen, 5 plants per frame. Growth monitoring included the length of the main stem (plant height) and dry weights.

Estimation of Relative Growth Rate: The relative growth rate, R_r was estimated using the equation:

$$R_r(h) = (1/h).(dh/dt) = dlnh/dt = lnh_2 - lnh_1 / t_2 - t_1, \quad [1]$$

where t is time in seconds. Plant height, h (cm) seemed a good measure for Salicornia growth since branching pattern of Salicornia was governed by the growth of the main stem (Ellison and Niklas, 1988). The field data (Fig. 1) showed that h was correlated strongly with biomass dry weight, W_d (g/plant) by the power regression:

$$W_d = 0.0012\ h^{2.4856},\ (R^2 = 0.9756). \quad [2]$$

Subsequently, relative growth rate based on organic matter, $R_r(W_o)$ was estimated using Eq.[1], Eq.[2], and the observed ash content value (0.49-kg ash/kg dry matter) by Weeks (1986). This ash content value was the mean value for the vegetative stage of development with a standard deviation equal to 0.04 kg ash/kg dry matter (Weeks, 1986).

Hydroponics Experiment

Source of Seedlings: Salicornia seedlings (age about 2 months) from BEHAR farm at Al-Jubail, Saudi Arabia, were received at the greenhouse of the Water Studies Center, Al-Hassa, Saudi Arabia on Dec. 23, 1997. The seedlings were irrigated twice daily (morning and afternoon) with a standard seawater (3.5%) diluted with tap water at 1:1 ratio and on Tuesday of each week by tap water only. The seawater sample was from Uqair Bay on the Arabian Gulf, Saudi Arabia, the salinity of which was 66 dSm^{-1} while the tap water (well water) was 1.34 dSm^{-1}. The seawater was diluted by the tap water to a standard seawater salinity (53 dSm^{-1} = 3.5%) before the preparation of the 1:1 irrigation water. After two weeks, seedlings were gently removed from the soil in-groups and the roots washed free of the soil by dipping in tap water. Only uniform and healthy seedlings of the same size were selected for transplanting.

Transplanting: Seedlings selected for transplanting were transplanted into their respective pots on Jan. 3, 1998. The seedlings were transplanted into polystyrene rings, the diameters of which were 6 cm outside, 1.5 cm inside, and 2.5 cm in thickness. Non-absorbent-cotton supported the seedlings within the rings. Rings and seedlings were taken at random and set into covers made of 2.5 cm thick polystyrene insulation material which served as lids for the buckets. The seedlings were grown with their roots submerged in 20-L plastic buckets (white from outside and black inside) under continuous aeration. Each pot contained 4 plants. Each plant was supported in place by the rings which encompassed the stem and was inserted into a hole in the cover. Nutrient solution was a modified half strength Hoagland nutrient solution (Epstein, 1972) salinized with the seawater from Uqair Bay on the Arabian Gulf which was diluted to 53 dS/m using tap water. Two different nutrient-fertilization treatments were applied. The first treatment was addition of two-ml. stock nutrient- solution per pot three times a week (Sat., Mon., and Wed.) which would be referred to as continuous fertilization. The second treatment is addition of equivalent volume of the stock nutrient-solution per month, which will be referred to as the monthly fertilization treatment. The control was standard seawater without any nutrient additions. The treatments were replicated two times and were arranged in a growth chamber in a randomized complete block design. The plant growth chamber was equipped with banks of long cool white fluorescent tubes used to maintain 14-hours photoperiod under 550-μE m^{-2} s^{-1} photosynthetically active radiation (425 – 700 nm). The temperature was 24 C during the day and 20 C at night.

EC and pH Monitoring: EC monitoring was carried out using a portable conductivity meter (Model CO150, Hach Europe, Belgium). pH monitoring was carried out using a portable pH meter (Model EC10, Hach Europe, Belgium). Monitoring of the pH and EC were done every two weeks during the period from March 28 to May 9.

Growth Monitoring: The length of the main stem, h was measured for each plant at the start of the experiment and every 14 days thereafter. The experiment was terminated on June 3, 1998 (after two days from first spike appearance).

RESULTS AND DISCUSSION

Growth-Curve of Field-Grown Salicornia

Figure 2 shows changes in plant height of field-growing Salicornia for two successive seasons. Weeks (1986) description, for the development of Salicornia at Estero Morua estuary, seems applicable for the field Salicornia at Ras Al Zawr. The following sequential growth stages were identified (Fig. 2): (i) seed was sowed into the field (late September); (ii) seed germination (after several days); (iii) vegetative growth (April and several months); (iv) inflorescence (flowering) tissue began to appear and develop determinately at each branch and with grain filling until senescence which is a period of decline growth or negative growth rate.

Mean relative growth rates, based on organic matter weight, is 464 ± 190 Gs^{-1} (Table 1) during the vegetative stage which is much less than the rate values for the three salt tolerant species: *Suaeda maritime*, *Elymus oliveri*, and *Puccinellia maritima* (Flowers, 1985). Nevertheless, it falls within the range normally reported for glycophytes, namely 347 to 4398 Gs^{-1} (Hunt, 1982).

Growth-Curve of Hydroponics-Grown Salicornia

Figure 3 shows part of the growth-curve that represents the vegetative growth stage in hydroponics. The vegetative stage form di-pattern changes in growth, which may be related to two underlying cellular and physiological mechanisms responsible for such changes. No significant differences in plant height existed between the continuously and monthly fertilized plants during both the 'slow' and 'rapid' growth phases (Table 2). Comparison of the fertilized and unfertilized plants indicated insignificant differences in plant heights during the 'slow' phase and significant differences during the 'rapid' phase of growth (Table 2). The slow growth mechanism which affects the growth over the 'slow' phase range of time seems to operate at very low concentration of nutrients in the medium as indicated by the insignificant differences between mean plant heights of the fertilized and unfertilized hydroponics (Table 2). On the other hand, the rapid growth mechanism only comes into action at high concentrations of nutrients; enough to meet the demands for vigor growth otherwise death occurs and mortality percent increases with time (Table 2).

The mean relative growth rates, based on organic matter weight, during the vegetative stage are 124 ± 57 Gs^{-1} and 104 ± 81 Gs^{-1} for the fertilized and unfertilized hydroponics, respectively (Table 3). These very low rate values seem due to the low light intensity in the hydroponics growth chamber (about 45% the light intensity in the field). Nevertheless, they are clearly indicating that adequate fertilization increases significantly the relative growth rate especially during the 'rapid' phase of the vegetative stage (Table 3).

pH Changes During the Slow and Rapid Growth Periods

During the slow growth mechanism the median pH values are 8.09, 7.02, and 7.00 for the unfertilized, continuously, and monthly fertilized hydroponics, respectively. During the rapid growth mechanism the median pH values have decreased by 0.09, 0.34, and 0.59 for the unfertilized, continuously-, and monthly-fertilized hydroponics, respectively. It seems that the rapid growth mechanism is employing active H^+-ATPase pumps which are pumping protons out of the cytoplasm into the cell wall and the media. The H^+-ATPase on the plasma membrane and vacuolar membranes in Salicornia are important in salt tolerance (Lerner, 1985; Ayala et al., 1996).

EC Changes During the Slow and Rapid Growth Periods

Changes in the EC values, of the nutrient solutions, seem insignificant during the slow growth period due to minimum transpiration. On the other hand, a pronounced increase in the EC value is associated with the rapid growth mechanism due to high evapotranspiration. These incremental values are 7.3, 8.1, and 12.5 dSm^{-1} for the unfertilized, continuously-, and monthly-fertilized treatments, respectively. Since during the 'rapid' growth phase most of the internodes of the control plants become woody, the 7.3 dSm^{-1} increase is essentially due to evaporation. Subtracting 7.3 dSm^{-1} from 8.1 dSm^{-1} and 12.5 dSm^{-1} yields the increments 0.8 dSm^{-1} and 5.2 dSm^{-1} due to transpiration from the continuously- and monthly-fertilized pots. Thus, by employing a salt balance equation, the calculated transpiration rates (T_r) are 62 and 416-g_{water} h^{-1} $g_{dry\ m.}^{-1}$ for continuously- and monthly-fertilized plants, respectively. We can not explain, at present time, why T_r values under monthly fertilization are about 6 times higher than under continuous fertilization. However, the T_r value under continuous fertilization is within range for crop plants under salt stress (Gorham et al., 1985).

CONCLUSIONS

Salicornia seems to have a di-pattern growth curve made of ‘slow’ and ‘rapid’ growth phases during the vegetative stage with a mean relative growth rate which falls within the range normally reported for glycophytes. The ‘slow’ growth mechanism seems to operate at very low concentration of nutrients, very low transpiration rate, and inactive H^+-ATPase pumps. The ‘rapid’ growth mechanism seems to operate at high concentrations of nutrients, high transpiration rates, and is employing active H^+-ATPase pumps, which are pumping protons out of the cytoplasm.

To optimize fertilizer use, environmental impact, and economic benefits, fertilizer requirements could be changed with plant development. Without fertilizer application, especially during the ‘rapid’ growth phase, the growth rate of Salicornia may become so slow as to preclude their use as a crop species.

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الشكل الثنائى للنمو الخضرى للساليكورنيا وعلاقته بالتسميد

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الملخص :

اعتبرت الساليكورنيا محصول بذور زيتي جديد يروى مباشرة بمياه البحر .وتهدف هذه الدراسة الى فحص منحنى النمو للساليكورنيا وعلاقته بالاحتياجات الغذائية وذلك باجراء تجربة حقلية وأخرى فى بيئة مائية. إن النتائج الحقلية المتحصل عليها كانت لساليكورنيا رويت بماء البحر ،أما نتائج الزراعة في البيئات المائية فهي لساليكورنيا نامية في مياه بحر أضيف إليها عناصر مغذية مكافئة لنصف قوة محلول هوجلاند المغذى مع التسميد المستمر أو التسميد الشهري مع متابعة قيم الأس الهيدروجينى والملوحة . إن متوسط معدل النمو النسبي على أساس وزن المادة العضوية كان ٤٦٤ (جيجاثانية) $^{-1}$ أثناء فترة النمو الخضري وهذه القيمة تقع في المدى المتعارف عليه والمسجل للنباتات غير الملحية [٣٤٧ إلى ٤٣٩٨ (جيجاثانية) $^{-1}$]. ويبدو أن منحنى النمو للساليكورنيا له شكل ثنائي مكون من مرحلة نمو بطيء ومرحلة نمو سريع وذلك أثناء فترة النمو الخضري. ويبدو أن آلية النمو البطيء تعمل تحت ظروف تركيزات منخفضة من العناصر المغذية ومعدل نتح منخفض جداً ومضخات H^+-ATPase غير نشطة. أما آلية النمو السريع فتعمل تحت ظروف تركيزات عالية نسبيا في العناصر المغذية ومعدل نتح مرتفع وتوظف مضخات H^+-ATPase والتي تضخ بروتونات خارج السيتوبلازم .وللاستعمال الأمثل للسماد ولتقليل التأثير البيئي مع تعظيم الفوائد الاقتصادية فإنه يمكن تغيير الاحتياجات السمادية تبعا لتطور نمو النبات. فبدون إضافة السماد وبالذات أثناء فترة النمو السريع فإن معدل نمو الساليكورنيا قد يصبح بطيء لدرجة تمنع استعمالها كمحصول متعارف عليه.

Table 1. Plant height and relative growth rate of field-grown Salicornia. Time is from sowing

Time, d	h, cm	$R_r(Wo)$, Gs^{-1}
155 - 169	5.5 - 7.0	486
169 - 186	7.0 - 10.5	694
186 - 200	10.5 - 11.6	208
200 - 215	11.6 - 16.0	625
215 - 229	16.0 - 20.2	486
229 - 243	20.2 - 22.4	208
243 - 260	22.4 - 30.8	544
Mean [St. dev.]		464 [190]

Table 2. Salicornia growth and plant mortality in ½ strength Hoagland solution salinized with seawater under continuous and monthly-feeding. Control is seawater without any nutrient addition.

Time from transplanting, d.	Mean plant height *± Stand. dev., cm			Mortality, %		
	Control	Continuos	Monthly	Control	Continuos	Monthly
14	7.5±0.6a	7.4±0.8a	7.8±1.0a	0	0	0
28	8.3±0.8a	8.5±1.0a	9.3±1.4a	0	0	0
42	9.0±1.0a	9.5±1.0a	10.1±1.7a	0	0	0
56	9.6±1.2a	10.3±1.1a	10.8±1.8a	0	0	0
70	9.9±1.6a	11.2±1.3a	11.4±2.1a	0	0	0
84	9.8±2.2a	11.7±1.6a	11.9±2.3a	0	0	0
98	10.7±1.5a	12.2±1.7a	12.3±2.6a	25	0	0
112	11.9±2.0a	13.6±1.7a	13.7±2.7a	25	0	0
140	12.6±1.9b	17.4±2.8a	17.5±3.1a	25	0	12.5

* Within rows, means followed by the same letter are not significantly different at the 0.05 probability level (Analytical Software, 1996).

Table 3. Salicornia relative growth rates in ½ strength Hoagland solution salinized with seawater under continuous and monthly-feedings. Control is seawater without any nutrient addition.

Time from transplanting, d.	Relative growth rate, $R_r(Wo)$, Gs^{-1}		
	control	continuous	monthly
0-14	46	46	35
14-28	104	139	185
28-42	162	231	174
42-56	127	162	139
56-70	58	174	116
70-84	-23	93	93
84-98	185	81	69
98-112	220	220	220
112-140	58	255	255
Mean 'slow' phase[st.dev,n]	81[69,6]	127[58,7]	116[46,7]
Mean 'rapid' phase[st.dev,n]	150[81,3]	243[23,2]	243[23,2]
Mean vegetative stage[st.dev,n]	104[81,9]	124[57,18]	

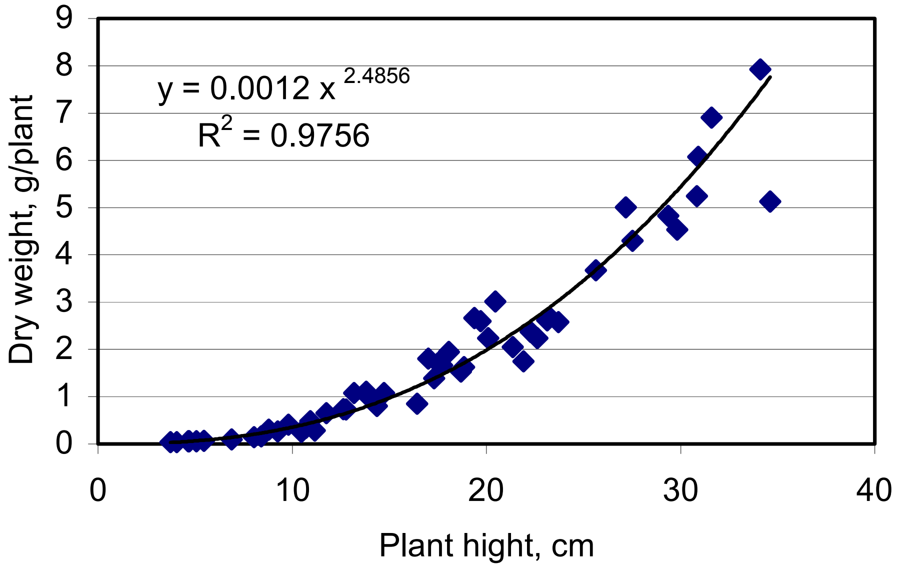

Fig. 1. Biomass dry weight against plant height
for a field-grown Salicornia.

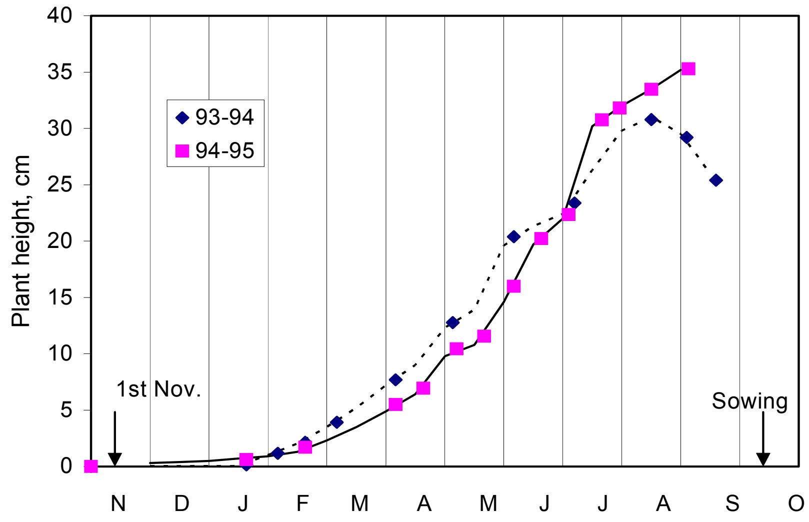

Fig. 2. Growth-curves of seawater irrigated Salicornia in the field for two seasons.

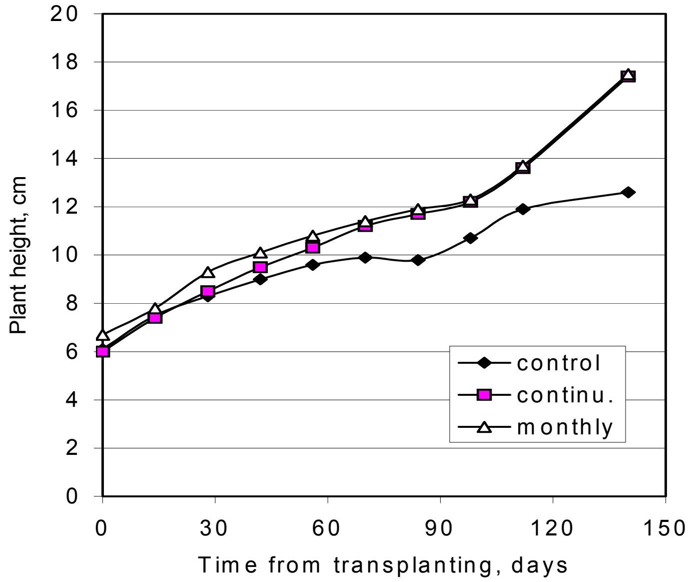

Fig. 3. Part of the growth curve which represent the transition from 'slow' to 'rapid' growth phases for unfertilized, continuously-, and monthly-fertilized hydroponics-grown Salicornia.