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Original Article

How Does Nitrogen and Irrigation Change the Productivity of *Salicornia europaea* in Saline Soil?

Toran Nasiri[1], Alireza Pirzad[2*] and Jalal Jalilian[3]

[1] *Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia-Iran*
[2]*Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia-Iran*
[3]*Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia-Iran*

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Abstract

Glasswort (*Salicornia europaea* L.) as an important halophyte plant is capable to accumulate NaCl in aboveground part (fully edible) in considerable quantity. To evaluate the effect of irrigation levels and nitrogen fertilizer on the yield of seed and oil, and also harvest index of Glasswort, a split plot experiment was conducted based on randomized complete block design with three replications at the Lake Urmia marginal in 2012. Treatments were irrigation regimes (irrigation after 20, 40, 80 and 120 mm of evaporation from a Class A pan) as main plot and amount of nitrogen spraying (0, 5, 10, 15, 20 percent of Urea (V/V) as sub plot. Results indicated the significant interaction effect between irrigation and nitrogen on the yield of seed and oil, biological yield and harvest index of seed and oil. In well irrigated plants (irrigation after 20 mm evaporation), higher concentration of nitrogen spraying up to 10% caused to raise the yield of seed and oil, and biological yield. These yields were raised up by application of 15% nitrogen and then they were decreased. A significant increasing of yield (seed and oil) was observed at 15% of nitrogen spraying for the mild and mid (irrigation after 40 and 80 mm evaporation, respectively) water deficit stress. In conclusion, we found the foliar application of nitrogen (low environmental contamination) benefit for Glasswort production, but in different optimum amount for each irrigation interval.

Key words: Glasswort, Halophytes, Lake Urmia, Seed oil, Urea

Introduction

Salinity in soil or water as one of the major stresses is a widespread root medium problem limiting productivity of crops worldwide [1]. Halophyte plants, compared with Glycophytes, are more tolerant to salinity, so some halophytes can support a concentration of salts close to 400 mM of NaCl without showing effects in 80% of its germination [2], growth and yield [3]. So, the annual, oilseed halophyte *Salicornia bigelovii* Torr. produced 18.0 t ha^{-1} of biomass and 2.00 t ha^{-1} of seed over a 200-day growing cycle [3]. *Salicornia* L. (glasswort, pickleweed, and marsh samphire) is a genus of succulent, halophyte plants that grow in salt marshes, on beaches and among mangroves. *Salicornia* species are native to North America, Europe, South Africa, and South Asia. Plants grow as pure stands on open tidal mudflats and are also present in the upper levels of salt marshes. *Salicornia europaea* L. plants are capable to accumulate NaCl in aboveground part in considerable quantity, at the same time the aboveground part of this plant is fully edible [4]. The seeds of *S. europaea* contained 30% protein, 28% oil, and only 5% fiber and 5% ash; the oil was high in polyunsaturated fatty acids, particularly linoleic acid (74% of total) [5].

Water is one of the most important ecological factors determining crop growth and development. Therefore water deficit plays a very important role

*Corresponding author: Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia-Iran. Postal code: 5715944931
Email Address: a.pirzad@urmia.ac.ir

in inhibiting the yields of crops by restricting plant growth and crop productivity in the majority of agricultural fields of the world [6]. Arid regions of the world occupy up to 35% of the earth's surface, the basis of various definitions of climatic conditions, vegetation types or potential for food production. Due to their high ecological value, monitoring of arid regions is necessary and modern vegetation studies can help in the conservation and management of these areas [7].

Nitrogen is one of the elements which its deficiency is noticeable in arid/semi-arid regions, because the amounts of organic matter which are the main source of nitrogen storage are very low in this region [8]. When fed to roots and leaves, urea is absorbed by plants in greater amounts and is faster converted into proteins than other forms of nitrogen. Presumably, glasswort plants can also be included into this group, since the biomass of plants grown on media with urea, was higher than in the plants, which used nitrogen in the nitrate form [9].

Because nitrogen (N) is the most important macronutrient for plant growth, it is necessary to find how *S. europaea* grows under high NaCl conditions in relation to its N nutrition. Based on our knowledge, information about the response of *S. europaea* plant to varying amounts of nitrogen (in spraying form because of inefficiency of soil application of nitrogen) under different water supply is scarce. Therefore, the main objective of the present study was to find out the effect of nitrogen foliar application on the yield (seed and oil) of *S. europaea* in different conditions of water availability.

Material and Methods

In order to study the effect of irrigation levels and nitrogen on Glasswort (*Salicornia europaea* L., from Chenopodiaceae family) a field experiment was carried out as split plot based on randomized complete block design with three replications at the marginal lands around the Lake Urmia (latitude 37°.42 N, 45°.19 E, and 1267 m above sea level), in 2012. Urmia (or Orumiyeh) salt Lake, is one of the largest permanent hypersaline lakes in the world and resembles the Great Salt Lake in the western USA in many respects of morphology, chemistry and sediments and lies in Northwest of Iran. The lake is between the provinces of West Azerbaijan and East Azerbaijan, West of the Southern portion of the similarly shaped Caspian Sea. Salt marshes and saline flats are covered by halophilous vegetation dominated by Chenopodiaceae species [10] such as *Salicornia*.

Treatments were irrigation regimes (irrigation after 20, 40, 80 and 120 mm of evaporation from a Class A pan) as main plots and amount of nitrogen (0, 5, 10, 15, 20 percent of $CO(NH_2)_2$) as sub plot. Irrigation regimes were done after appearance of cotyledon's leaves. Urea was sprayed in above mentioned concentrations at flower initiation twice with two-week interval. Seeds were sown on flat lands around the Lake Urmia by spreading *S. europaea* seeds on no tillage field. Seeds were sown on to a clay loam soil (21% sand, 48% silt and 31% clay) with EC 33.8 ds m^{-1}, pH 8.81, 3.7 ppm of phosphorus and 0.01% nitrogen. The size of main plots and sub plot were 2×12 m and 2×2 m, respectively. After seed emergence, seedlings were set to density of 135 plant m^{-2}. To determine the yield of seed, plants were harvested from 2 m^2 of each plot. To determine the yield of seed oil, 2 g of powdered seed was placed in Soxhlet extractor and added N-Hegzan to the samples. After 6 hours, *S. europaea* oil was accumulated in the Erlenmeyer flask of Soxhlet extractor [11]. The yield of seed oil was calculated by the following formula: Oil yield = Oil percentage×Seed yield.

Harvest index, the rate of economic to biological yield, was calculated by using the below formula and expressed in percentage. Harvest index of seed (HI seed) and oil (HI oil) were calculated as seed and oil weight divided by total above-ground plant dry weight, respectively**.** Analysis of variance (ANOVA) on data was performed using the general linear model (GLM) procedure in the SAS 9.1 software. The Student-Newman Keul's test (SNK) was applied to compare treatment means using the MSTATC software package ($P \leq 0.05$).

Results

Results of ANOVA showed the significant ($P \leq 0.01$) interaction effect between irrigation and nitrogen spraying on the yield of seed and oil, biological yield, harvest index of seed and oil (Table 1).

Table 1 Variance analysis of some agronomic traits and yield of *Salicornia europaea* L. under different irrigation regimes and nitrogen amounts

Source of variation		Yield			Harvest index	
	df	Seed	Oil	Biomass (biological)	Seed	Oil
Replication (R)	2	427855.88 ^{ns}	35644.11 ^{ns}	9073015.4 *	29.85 ^{ns}	2.43 ^{ns}
Irrigation (I)	3	187823.55 ^{ns}	15104.14 ^{ns}	44951888.4 **	848.86 **	72.86 **
Whole-plot error	6	209611.74	17236.56	1858745.2	38.31	3.14
Nitrogen (N)	4	126187.55 *	10821.04 *	15455100.2 **	347.24 **	29.79 **
I×N	12	164170.87 **	14211.40 **	5406247.2 **	226.23 **	19.39 **
Split-plot error	32	49514.02	4115.89	1354517.6	11.73	0.97
Coefficient of variation (%)		21.91	21.88	19.79	16.83	16.75

*, **: Significant at $P≤0.05$ and $P≤0.01$, respectively; df; degree of freedom

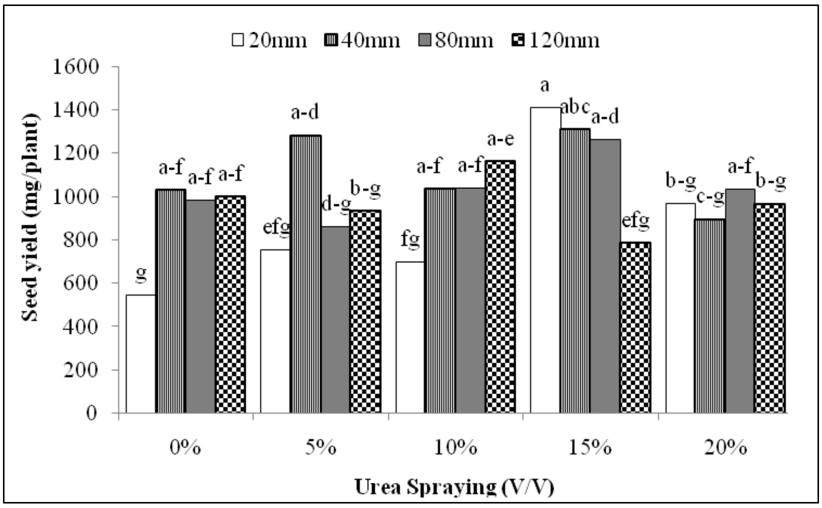

Fig. 1 Means comparison of the seed yield in *Salicornia europaea* L. under different irrigation regimes and varying amount of nitrogen (Urea) spraying. The same letters show non-significant differences at P ≤0.05.

Means comparison indicated that the highest yield of seed (1410 mg plant^{-1}) was obtained from plants irrigated after 20 mm of evaporation from a Class A pan with 15% of urea spray. The lowest yield of seed (545.8 mg plant^{-1}) belonged to plants irrigated after 20 mm of evaporation without nitrogen application. In well watered plants (irrigation after 20 mm of evaporation from a Class A pan), increasing of nitrogen concentration up to 15% increased the yield of seed. In mild and mid water deficit stress (irrigation after 40 and 80 mm of evaporation from a Class A pan, respectively), varying amounts of nitrogen produced the same yield of seed. In strength water deficit stress (irrigation after 120 mm of evaporation), the highest yield of seed (1162 mg plant^{-1}) was observed in 10% of nitrogen spraying, but other amounts of nitrogen produced the same yield of seed (Fig. 1).

The highest yield of seed oil (412.4 mg plant^{-1}) was obtained from plants irrigated after 20 mm of evaporation from a Class A pan with 15% of nitrogen spray as same as irrigation after 40 and 80 mm evaporation of this nitrogen level. The lowest yield of oil (157.8 mg plant^{-1}) belonged to plants irrigated after 120 mm evaporation and sprayed by 10% nitrogen. In well watered plants and mild water deficit stressed plants, increasing of nitrogen concentration up to 15% increased the yield of oil. In mid water deficit stress, varying amounts of nitrogen produced the same yield of seed oil, except 15% spraying. These same yields showed the light raising of oil yield in higher nitrogen availability. In strength water deficit stress, two points of highest yield of seed oil were observed in 5 and 20% of nitrogen spraying, and the other treatments led to lower yield (Fig. 2). It seems that the well watering need to higher amounts of nitrogen to implement a satisfying production of *Salicornia* seed oil (Fig. 2).

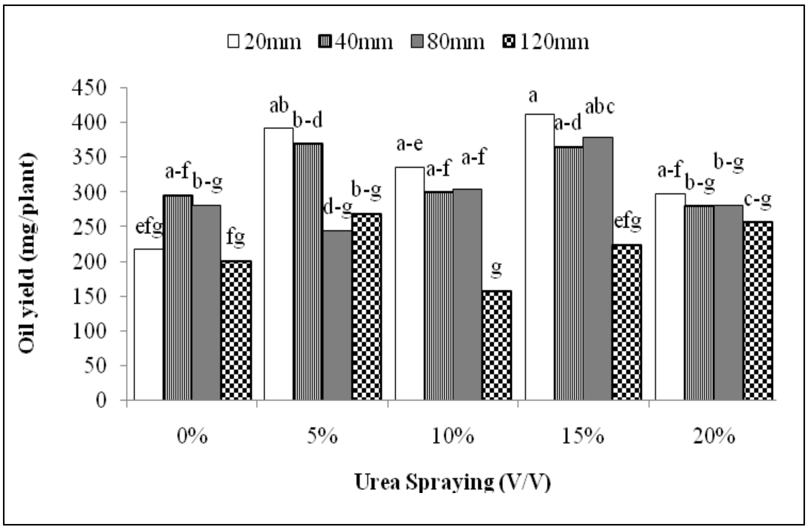

Fig. 2 Means comparison of the oil yield in *Salicornia europaea* L. under different irrigation regimes and varying amount of nitrogen (Urea) spraying. The same letters show non-significant differences at *P* ≤0.05.

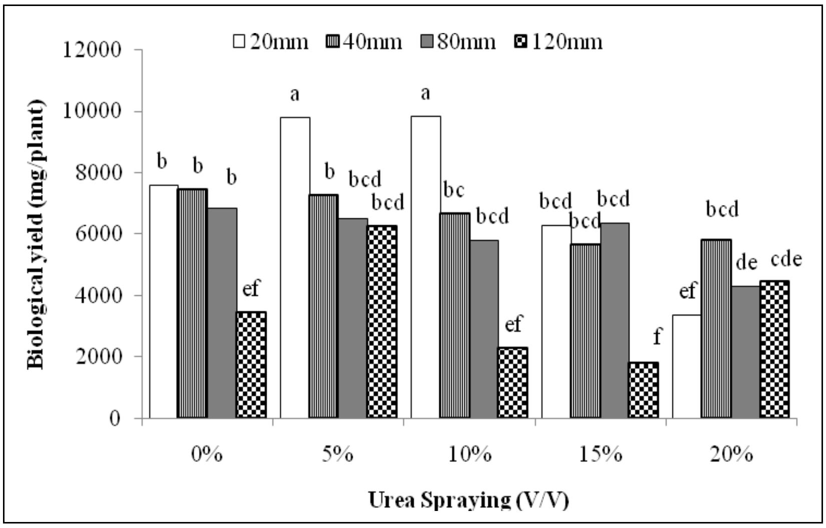

Fig. 3 Means comparison of the biological yield in *Salicornia europaea* L. under different irrigation regimes and varying amount of nitrogen (Urea) spraying. The same letters show non-significant differences at *P* ≤0.05.

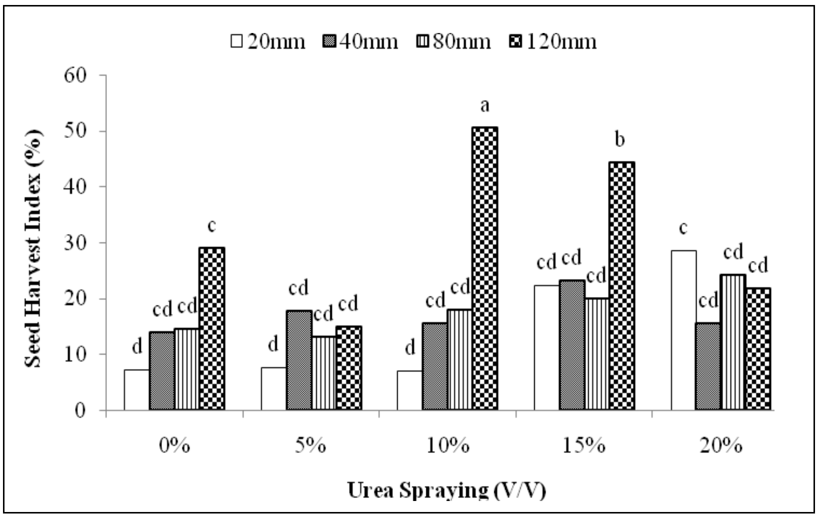

Fig. 4 Means comparison of the HI seed in *Salicornia europaea* L. under different irrigation regimes and varying amount of nitrogen (Urea) spraying. The same letters show non-significant differences at *P* ≤0.05.

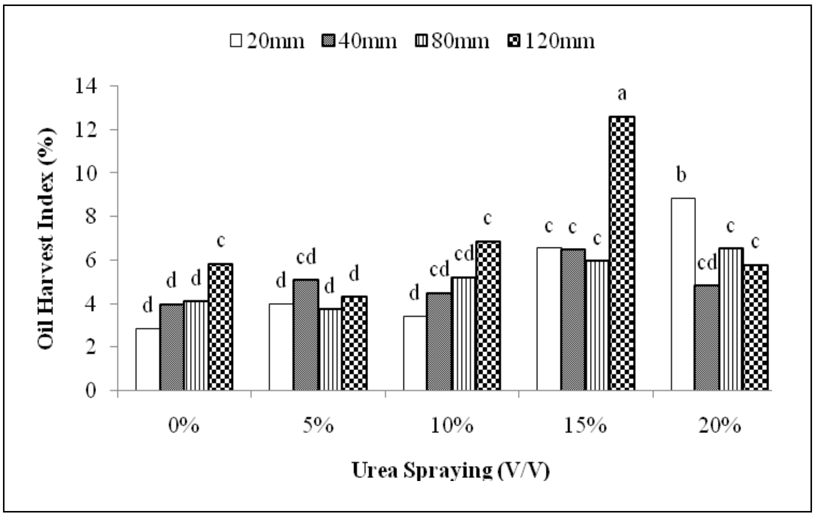

Fig. 5 Means comparison of oil harvest index in *Salicornia europaea* L. under different irrigation regimes and varying amount of nitrogen (Urea) spraying. The same letters show non-significant differences at $P \leq 0.05$.

The highest biological yield (9837 and 9788 mg plant^{-1}) was obtained from plants irrigated after 20 mm of evaporation from a Class A pan with 5 and 10% nitrogen spraying, respectively. The lowest biological yield (1776 mg plant^{-1}) belonged to plants irrigated after 120 mm of evaporation from a Class A pan with 15% nitrogen spraying. In well watered (excess watered) plants increasing of nitrogen concentration up to 10% of Urea increased the biological yield. In mild and mid water deficit stress, increasing of nitrogen concentration cannot affect the biological yield. In strength water deficit stress, increasing of nitrogen concentration caused to descending trend of biological yield (Fig. 3).

The highest ratio of harvest index (HI) of seed (50.63%) was obtained from irrigation after 120 mm of evaporation with 10% followed by 15% of nitrogen spraying. The lowest seed HI (7.11%) belonged to plants irrigated after 20 mm of evaporation with 10% nitrogen application as same as 0 and 5% nitrogen. In well watered plants increasing of nitrogen concentration increased the harvest index of seed by more concentrated than 15% of nitrogen spraying. In mild and mid water deficit stress, increasing of nitrogen concentration caused to a light rising up the harvest index of seed. In strength water deficit stress, increasing of nitrogen concentration raised up the harvest index of seed by more concentrated than 10% of nitrogen spraying (Fig. 4).

The highest harvest index (HI) of oil (12.62%) was obtained from irrigation after 120 mm of evaporation from a Class A pan with 15% nitrogen spraying. The lowest HI oil (2.86%) belonged to plants irrigated after 20 mm of evaporation without nitrogen spraying as same as all irrigation levels of 0 and 5% nitrogen spraying. The same trends in harvest index of seed and seed oil represents a large portion of biological yield as component of HI (Fig. 5).

Discussion

The higher yield of seed for stressed (120 mm of evaporation) plants was obtained from 10% nitrogen, which it is less than nitrogen requirements of other irrigation levels (The highest yields was observed in 15% nitrogen for irrigation after 20, 40 and 80 mm of evaporation). Our results showed the same trends in the yield of seed and oil along with irrigation and nitrogen treatments (Fig.s 1, 2). Based on these results, *Salicornia* plants need to higher nitrogen in well watered and stressed condition. So, nitrogen can reduce the damage of water deficit stress especially for oil yield. *Salicornia* spp. are used for both food and forage, being promising crops in salt-affected soils, in that high Cl^{-} inhibits nitrate (NO^{-3}) uptake in halophyte plant species [12]. Also, it was reported that the percentages of organic nitrogen mineralization at the end of 12 months in irrigated soils (average 54%) were significantly different from values in non-irrigated soils (average 64%) [13]. The higher yield of oil with shorter interval of irrigation was due to higher seed yield (Fig. 2). In more amounts of nitrogen, investment of photosynthetic materials are increased in leaf, stem and eventually accumulated material are increased in the grain. Singh and Ramesh [14] reported that water deficit stress reduced the oil yield of rosemary

(*Rosmarinus officinalis* L.) on a hectare basis. Shokrani and Pirzad [15] showed the significant interaction effect between irrigation and biological nitrogen on yield of Pot marigold (*Calendula officinalis* L.) oil. They reported that the highest yield of oil belonged to control treatment of irrigation (without disruption) by using nine liter per hectare of biological nitrogen compared with disruption of irrigation without nitrogen application. The highest and lowest essential oil yield was reported in German chamomile (*Matricaria chamomilla* L.) by irrigation after 50 and 100 mm of evaporation from a Class A pan, respectively [16].

Results of this study indicated that biological yield was ameliorated by nitrogen increasing up to 10% for all irrigation levels, that it was lesser than optimal nitrogen for seed and oil production (Fig. 1, 2, 3). That these trends led to higher ratio of harvest index for seed and oil in great amounts of nitrogen consumption e.g. 15 and 20% (Fig. 4, 5). The maximize yield of seed in middle stress (irrigation disruption at third harvest) explain that the partitioning of organic matter changed to seeds as a great sink. But, this condition for oil production need a severe (long time) water deficit in comparison with seed productivity. The greatest biomass of German chamomile was observed at 25 mm of evaporation, as well as irrigation at 50 and 75 mm. This higher biomass significantly differs from biological yield obtained from stressed condition (irrigation after 100 mm of evaporation from pan) [17]. There are several reports on significant effects of irrigation on biological yield of some plants. Shokrani *et al*. [18] indicated that the highest biomass yield in Pot marigold was obtained from irrigation disruption at second harvest and 6 liters per hectare of biological nitrogen application, and the lowest biomass was obtained from irrigation disruption at first harvest without nitrogen. The harvest index may be reduced with decreasing water supply as the result of our research. Begdelo *et al*. [19] reported the significant reduction of harvest index in Turnip rape by increasing irrigation interval from irrigation after 50 to 140 mm of evaporation from a Class A pan. They reported that harvest index significantly increased by nitrogen application as harvest index of 50, 100 and 150 kg ha^{-1} of nitrogen treatments were higher than control treatment [19]. Shokrani *et al*. [20] reported that the highest oil harvest index in Pot marigold belonged to irrigation disruption at first harvest (longer water deficit stress) with nine liters per hectare of biological nitrogen. The highest seed harvest index belonged to irrigation disruption after third harvest (mid water deficit stress).

Conclusions

Generally, significant interaction effect between nitrogen and irrigation on the yield (seed, oil and biomass) of *S. europaea* shows different responses of this plant to nitrogen in varying irrigation levels. The yield of seed and oil were increased by nitrogen spraying up to 15% in excess water, mild and mid water deficit (irrigation after 20, 40 and 80 mm of evaporation from a Class A pan). While the optimal yield in severe stress (irrigation after 120 mm of evaporation from a Class A pan) was observed in lower amounts of nitrogen (10% of Urea spraying). But, the nitrogen requirement for biological yield was less than seed and oil production.

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