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Atriplex halimus (Chenopodiaceae): A Halophytic Species for Restoration and Rehabilitation of Saline Degraded Lands

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Abstract: The product of biomass and the accumulation of the inorganic ions of seven Moroccan provenances of *Atriplex halimus,* treated with different concentrations of NaCl (0, 1, 2, 3 and 3.5%) was carried out. The study has shown a highly significant effect of provenance, salinity and their interaction (provenance x salinity). The production of the most significant biomass was recorded at 1 and 2% NaCl concentrations. High NaCl concentrations (3 and 3.5%) induce a reduction of the biomass. Among all the studied provenances, those Sidi Bouzid and Marrakech have shown the highest values of the biomass. As for the inorganic ions, the increase of salinity have generate an accumulation of Na^+ and Cl^- with a reduction of K^+. This accumulation of the inorganic ions under salt stress was variable between provenances. This variability appears in relation with the polymorphism, which characterize the species. On the seven studied Moroccan provenances, those of Sidi Bouzid and Marrakech have shown a particular eco-physiological behaviour with a significant biomass production under salt stress.

Key words: *Atriplex halimus* L., NaCl treatment, biomass product, inorganic ions, polymorphism

INTRODUCTION

The presence of salt in soil is one among other problems affecting arid countries including Morocco. The salinity that covers a large area and which is remarkably amplified with severe drought, represents the main edaphic constraint limiting plant growing[1]. This situation entails a considerable reduction of fertile soils (arable), generating a substantial socio-ecological disequilibrium. One way to rehabilitate and reclaim these soils is the planting of salt-tolerant forage species[2]. Among these species, the genus *Atriplex* has thus raised a particular interest. Some 100000 ha have been planted in the Mediterranean basin. Species of the genus *Atriplex* are known for their high tolerance to aridity and salinity[2,3] and also their use for forage[4,5]. These are capable of high production of nitrogen-rich forage, either under rain fed or irrigation conditions including several Mediterranean zones where rainfalls were as low as 150 mm per year[2].

In Morocco, a particular attention is being attributed to *Atriplex halimus* L. due to its xero-halophytic character. Its palatability and its satisfactory appetability make it a very appreciated fodder to camels, ovines and caprines essentially during the drought period[6]. It represents for the livestock a very significant source of minerals, vitamins and proteins[7,8]. Moreover, its ligneous wood constitutes a very interesting energizing source. Endowed with an important aerial biomass and a complex root system, the species represent an efficient and relatively non-expensive tool in the rehabilitation of degraded lands and in fighting against erosion and desertification[2,9]. However, *A. halimus* is characterized by a significant polymorphism mainly dependent on its broad ecological amplitude[6,10,11]. The eco-physiological behaviour of the species under salt stress in relation with this polymorphism is not well understood. That, selection for salinity tolerant ecotypes is of interest to support the programmes of restoration and rehabilitation of degraded lands in arid and semi arid Mediterranean regions by this halophytic species. Thus, the objective of this work were to study the eco-physiological behaviour of seven *A. halimus* Moroccan provenances to salt treatment. The growth, the productivity (fresh and dry biomass) and the accumulation of inorganic ions by young seedlings subjected to regular irrigation by various salt concentrations were here studied.

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MATERIALS AND METHODS

Fruits (seeds with enclosing bracts) were collected in December 2002 from seven *A. halimus* natural populations (Fig. 1). After removal of the bract, the seeds were germinated in polyethylene bags (14x20 cm) containing sand and peat (2 : 1, v/v) and then placed in a shad house at the Faculté des Sciences Semlalia, Marrakech-Morocco arranged for this purpose. During the experimental period, the temperatures under shad house have been variable between 16 and 32°C (night/day). The relative humidity range was 38-65 %. Two months after sowing, seedlings having uniform height (around 8 cm) were selected for the experiment. An organic fertilizer NPK (14:28:14) was supplied once a week. For each provenance, two plants per pot and six pot by salt treatment were used. The treatment has consists on an irrigation every two days with 200 ml of salt solutions containing different NaCl concentrations (0, 1, 2, 3 and 3.5 %). At the initiation of the experiment, salinity concentrations were gradually increased by 0.5 % NaCl at 2-days intervals to reach the maximum salinity level of 3.5 %. Plants were harvested after seven weeks (end of June 2003) and the fresh and dry biomass of roots, leaves and stems were determined separately. Dried leaf and root samples were ashed in a muffle furnace for 6 h at 550°C. Ashed plant material was dissolved in 20 % sulphuric acid and diluted in distilled water for analysis. Na^+, K^+ and Ca^{++} concentrations were assayed by flame-photometer. Mg^{++} were quantified by atomic absorption spectrophotometer and Cl^- by argentometry method[12], respectively.

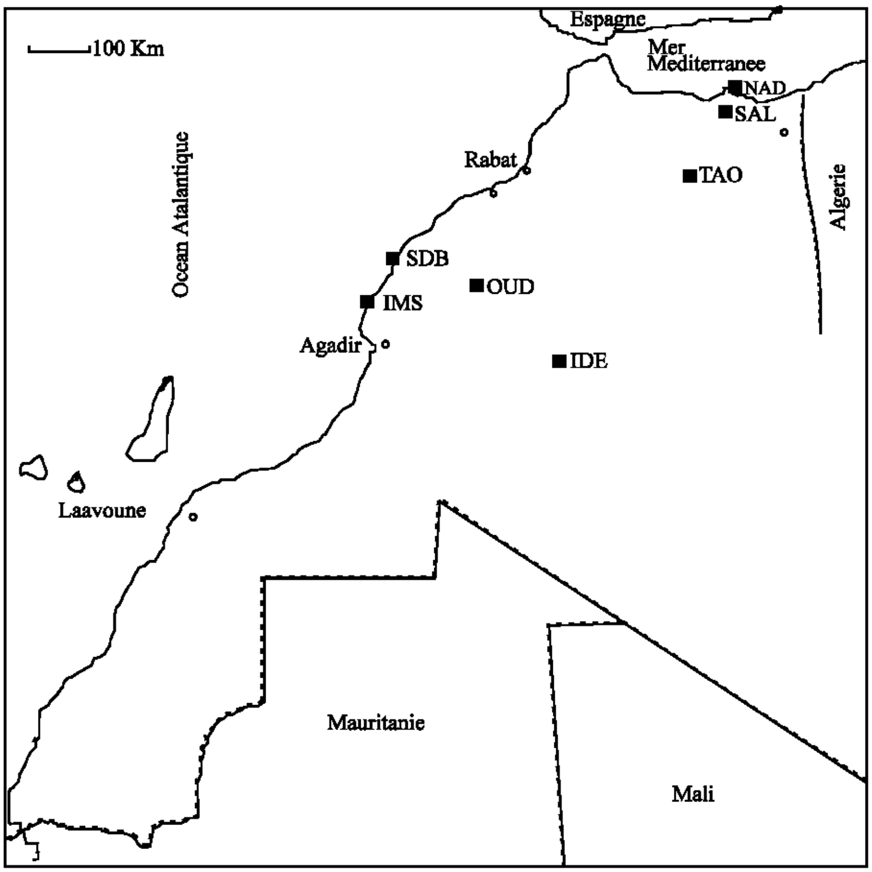

Fig. 1: geographical situation of different studied *Atriplex halimus* provenances (■)

SDB : Sidi Bouzid provenance
IMS : Imssouane provenance
OUD: Oudaya provenance
SAL : Salouane provenance
NAD: Nador provenance
TAO: Taourirt provenance

The collected data were subjected to the analyses of variance (ANOVA) using SPSS v.11[13]. $P<0.05$ was used to define statistical significance. When significant differences were detected among means, a Student-Neuman-Keuls (SNK) test was used to purchase pairwise comparisons among individual treatments.

RESULTS

Production of biomass: The analyses of variance have shown a highly significant effect ($P<0.001$) of provenance, salinity and their interaction (provenance x salinity) on the total shoot biomass (fresh and dry), root dry biomass and foliar biomass (fresh and dry ;Table 1). Indeed, the high NaCl concentrations (3 and 3.5 %) have induced a reduction of the total shoot and foliar biomass (Table 3). The highest values of biomass were recorded generally for 1 and 2% of NaCl concentrations (Table 3). This situation is more obvious at the Sidi Bouzid and Idelssen provenances. For the five studied biomass parameters, the Taourirt provenance did not shown any significant variation according to the increase of salinity. Considering only the foliar dry biomass, the effect of salinity was not significant for the Imssouane, Selouane and Oudaya provenances. The ratio of the total shoot dry biomass (TDB) on the total shoot fresh biomass (TFB) depends significantly only on salinity. Among all provenances, the increase in salinity generates an increase in ratio TDB/TFB probably in relation with water reduction in plants (Table 3). Taking into account the root dry biomass and except for Idelssen provenance, all others provenances did not shown a great sensitivity to salinity.

Inorganic ions accumulation: The contents of inorganic ions have shown a significant variability depending on the provenance, salinity, the interaction between them and the vegetable organs (leaves or roots) taken into account (Table 2). Under salt conditions, the leaves have accumulated generally high contents of Na^+ (Fig. 2). Inversely, the roots have presented more significant contents of Ca^{++} and Cl^- (Fig. 3 and 4). For a given NaCl concentration, the inorganic ions contents were variable according to the provenances as well as vegetable organs (leaves or roots). For Ca^{++}, this variation was not significant on the leaves (Table 2). Generally, the increase of salinity has generated a significant accumulation of Na^+ and Cl^- and a reduction of K^+. The K^+/Na^+ ratio has decreased also with the salinity increasing. The effect of salinity on Ca^{++} and Mg^{++} has depends partly on the vegetable organ. In leaves, the increase of salinity has generated a reduction of the Mg^{++} contents, whereas the Ca^{++} contents has not presented any significant variation. This tendency is reversed in the roots (Fig. 4). In the same way, the effect of salinity on the Na^+ accumulation and the K^+ reduction were more significant in the leaves than in the roots. This situation is marked by a K^+/Na^+ ratio relatively higher for roots and lower for leaves (Fig. 3). The response of the provenances to the increase of salinity was also variable. In the leaves, the reduction of K^+ under salt stress was more significant for the Nador and Imssouane provenances. For Na^+, accumulation was more significant for the Imssouane provenance. For Cl^-, the highest contents under salt conditions were observed in the roots for the Nador and Imssouane provenances and in the leaves for the Sidi Bouzid and Idelssen provenances. For Ca^{++}, accumulation in the roots was more significant for the Idelssen and Imssouane provenances whereas the reduction of Mg^{++} in the leaves was more obvious at the Sidi Bouzid, Selouane, Idelssen and Taourirt provenances.

DISCUSSION

Seedlings of *A. halimus* have shown a great tolerance to salinity since even if they were irrigated with 3.5% of NaCl, they have presented an important production of biomass. This production was maximal with 1 and 2% of NaCl mostly for all the studied provenances. These values of salinity were previously reported in other studies as the optimal concentrations of the species growth[14,15]. That confirms the preferential halophytic character of *A. halimus* describes by Gale and Poljakoff-Mayber[16], Le Houerou[2]. With high NaCl concentrations, the growth expressed by the total shoot biomass and the foliar biomass of the species decrease for the majority of the studied provenances. Such effect of salinity on the reduction of the biomass was reported for many species of the genus *Atriplex*[15,17-19]. Some authors have suggested that the reduction of the growth would be due primarily to the reduction of the absorption of water under the effect of salt[15,20,21]. Indeed, parallel to this reduction of the biomass under salt stress, we have observed an increase of the total shoot dry biomass on the total shoot fresh biomass ratio. However, the degree of this reduction was variable between the studied provenances suggesting so that an involvement of intrinsic mechanisms of the plant. This variability in the response to the salinity observed on the scale of the species was described elsewhere as a result of variable genotypic behaviour related mainly to the difference in stomatal conductance[22,23]. This stomatal conductance affect on the growth of the plant act by a variation of the photosynthetic activity[24]. With regard to the root dry

Table 1: Analyses of variance of the growth parameters of seven *A. halimus* provenances treated with various NaCl concentrations

Source of variance	df	F: FFW	FDW	RDW	TFB	TDB	TDB/TFB
Provenance	6	19.1***	17.44***	3.305**	15.16***	12.52***	0.875
Salinity	4	29.16***	9.53***	3.84**	26.26***	9.24***	3.24*
Provenance/Salinity	24	2.72***	2.09**	1.69*	2.45***	1.94**	0.85

Df: degree of freedom; (*) $P<0.05$; (**) $P<0.01$; (***) $P<0.001$

FFW: Foliar fresh weight; FDW: Foliar dry weight; RDW: Roots dry weight; TFB: Total shoot fresh biomass; TDB: Total shoot dry biomass

Table 2: Analyses of variance of the chemical parameters analyzed on the leaves (a) and on the roots (b) of seven *A. halimus* provenances treated with various NaCl concentrations

Source of variation	df	F: Ca	Na	K	Cl	Mg
(a) Leaves						
Provenance	6	1.284	2.35*	7.035***	15.06***	6.278***
Salinity	4	1.968	45.228***	12.475***	30.267***	42.175***
Provenance/Salinity	24	1.193	1.567	1.37	2.712***	1.414*
(b) Roots						
Provenance	6	3.7**	4.18**	2.49*	17.048***	4.278***
Salinity	4	6.37***	2.034	1.7	24.08***	0.435
Provenance/Salinity	24	1.43	1.61*	1.35	1.86*	2.175**

(*) $P<0.05$; (**) $P<0.01$; (***) $P<0.001$; Ca: Calcium; Na Sodium; K: Potassium; Cl: Chloride; Mg: Magnesium

Table 3: Biomass yield of different provenances of *A. halimus* at varying levels of salinity

Provenance salinity (%)	Shoot mass (g plant^{-1}) Fresh	Dry	Dry/fresh of shoot mass	Root dry weight (g plant^{-1})	Leave fresh weight (g plant^{-1})	Leaves dry weight (g plant^{-1})
Prov. NAD						
0 (control)	5.3b	1.58b	0.311	0.505a	2.42bc	0.53b
1	8.61a	2.54a	0.295	0.663a	4.68a	1.06a
2	7.39a	2.43ab	0.331	0.658a	3.78ab	0.96ab
3	4.29b	1.7ab	0.403	0.603a	2.06c	0.61ab
3.5	4.82b	1.79ab	0.377	0.6a	2.31bc	0.73ab
Prov.IMS						
0 (control)	10.23a	3.84a	0.36	0.674a	4.76ab	1.42a
1	9.92a	3.44a	0.34	0.615a	5.54a	1.55a
2	6.62ab	2.19a	0.33	0.488a	3.65ab	1.04a
3	4.98b	1.86a	0.7	0.463a	2.84ab	0.86a
3.5	4.91b	1.9a	0.39	0.515a	2.36b	0.79a
Prov. TAO						
0 (control)	8.73a	3.12a	0.359	0.58a	4.21a	1.21a
1	9.17a	3.24a	0.348	0.70a	4.79a	1.4a
2	9.07a	3.31a	0.356	0.64a	4.93a	1.42a
3	6.65a	2.64a	0.397	0.49a	3.88a	1.27a
3.5	6.38a	2.71a	0.429	0.58a	3.36a	1.23a
Prov. SDB						
0 (control)	12.83b	4.21b	0.33	0.81a	7.02b	1.91b
1	18.04a	5.82a	0.32	0.88a	10.58a	2.99a
2	11.66bc	3.8b	0.32	0.61a	7.28b	2.02b
3	8.81c	3.47b	0.39	0.62a	4.75b	1.66b
3.5	8.39c	3.47b	0.41	0.59a	4.93b	1.81b
Prov. SEL						
0 (control)	8.95a	3.72a	0.41	0.62a	4.74a	1.61a
1	10.62a	3.89a	0.366	0.63a	5.9a	1.79a
2	8.74a	3.15ab	0.36	0.56a	4.8a	1.45a
3	7.9a	3.23ab	0.407	0.59a	4.47a	1.58a
3.5	4.67c	2.02b	0.44	0.53a	2.25b	0.86a
Prov. MAR						
0 (control)	10.06ab	3.71a	0.39	0.775a	5.61ab	1.61a
1	11.9a	4.6a	0.36	0.578a	6.3a	1.99a
2	9.5ab	3.52a	0.37	0.64a	4.67ab	1.61a
3	7.01b	3.09a	0.44	0.53a	3.56b	1.27a
3.5	8.62ab	3.59a	0.42	0.68a	4.13ab	1.42a
Prov. IDE						
0 (control)	6.4b	2.29b	0.35	0.38b	4.12b	1.07b
1	12.73a	4.05a	0.31	0.69a	7.88a	2.09a
2	10.21a	3.69ab	0.36	0.62a	6.23a	1.83ab
3	6.67b	2.8ab	0.42	0.47ab	3.97b	1.35ab
3.5	5.61b	2.49ab	0.44	0.49ab	3.08b	1.15b

Values followed with the same letters are not different significantly at P = 0.05

(NAD: Nador; IMS: Imssouane; TAO: Taourirt; SDB: Sidi Bouzid; SEL: Selouane; MAR: Marrakech; IDE: Idelssen)

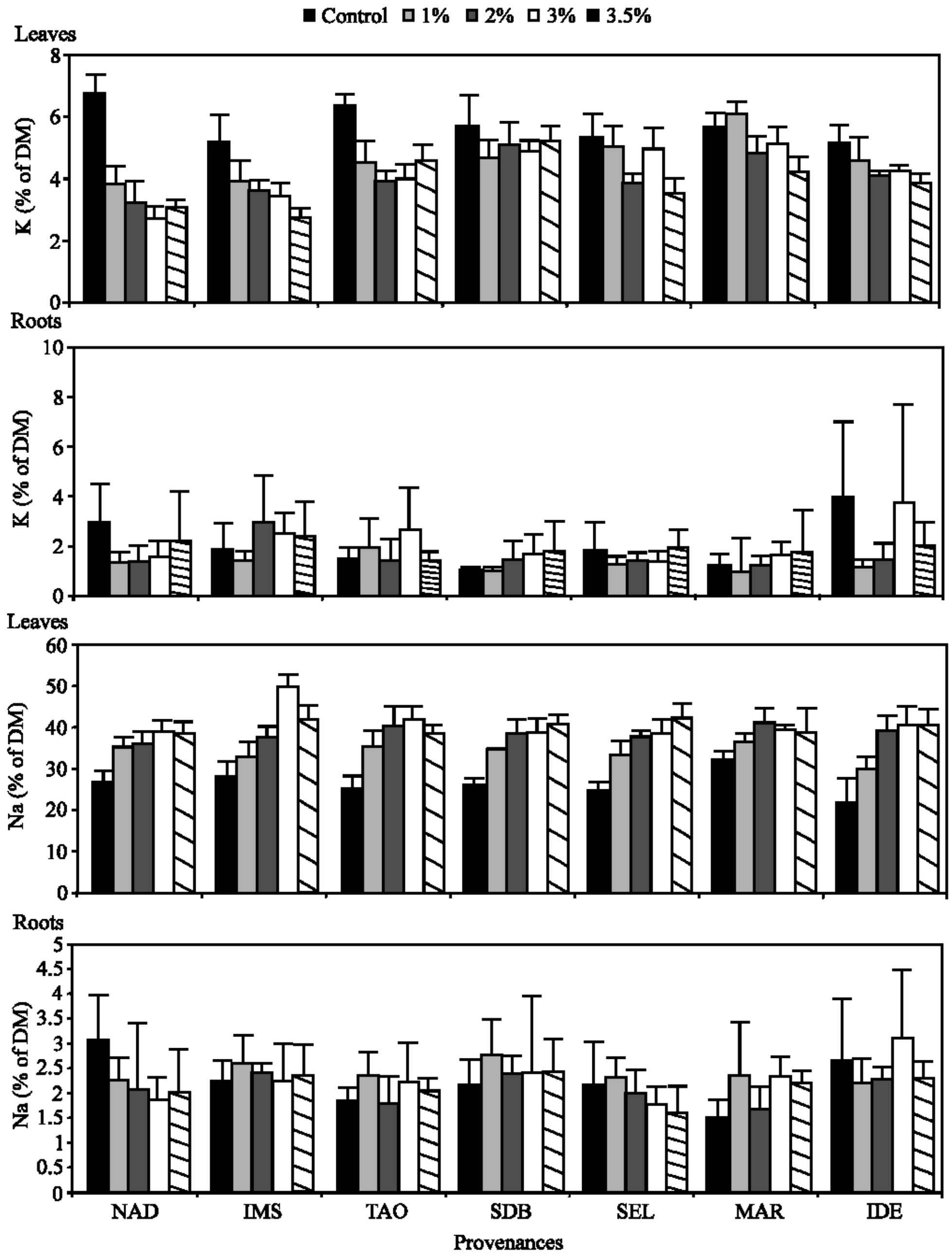

Fig. 2: Sodium and Potassium Contents (% of Dry Matter) of leaves and roots of seven A. *halimus* Moroccan provenances treated with various NaCl concentrations (NAD: Nador; IMS: Imssouane; TAO: Taourirt; SDB: Sidi Bouzid; SEL: Selouane; MAR: Marrakech; IDE: Idelssen)

biomass, the six provenances here studied did not shown any significant reduction under salt stress. This situation suggests that the salt stress affects much more the aerial part of the plant. This observation was also described for the same species[15] and for others[17,22].

Concerning the inorganic ions, the provenances have shown under salt conditions a very significant Cl^- and Na^+ accumulation. This situation, common for the majority of dicotyledonous halophytes confirms that *A. halimus* presents an inclusive mechanism. However, the various studied provenances have presented a significant variation in the contents of the inorganic ions accumulated, which confirms the existence of variable genotypic behaviour within the species. This genotypic difference in salt accumulation behaviour was observed for other species of the genus *Atriplex* such as

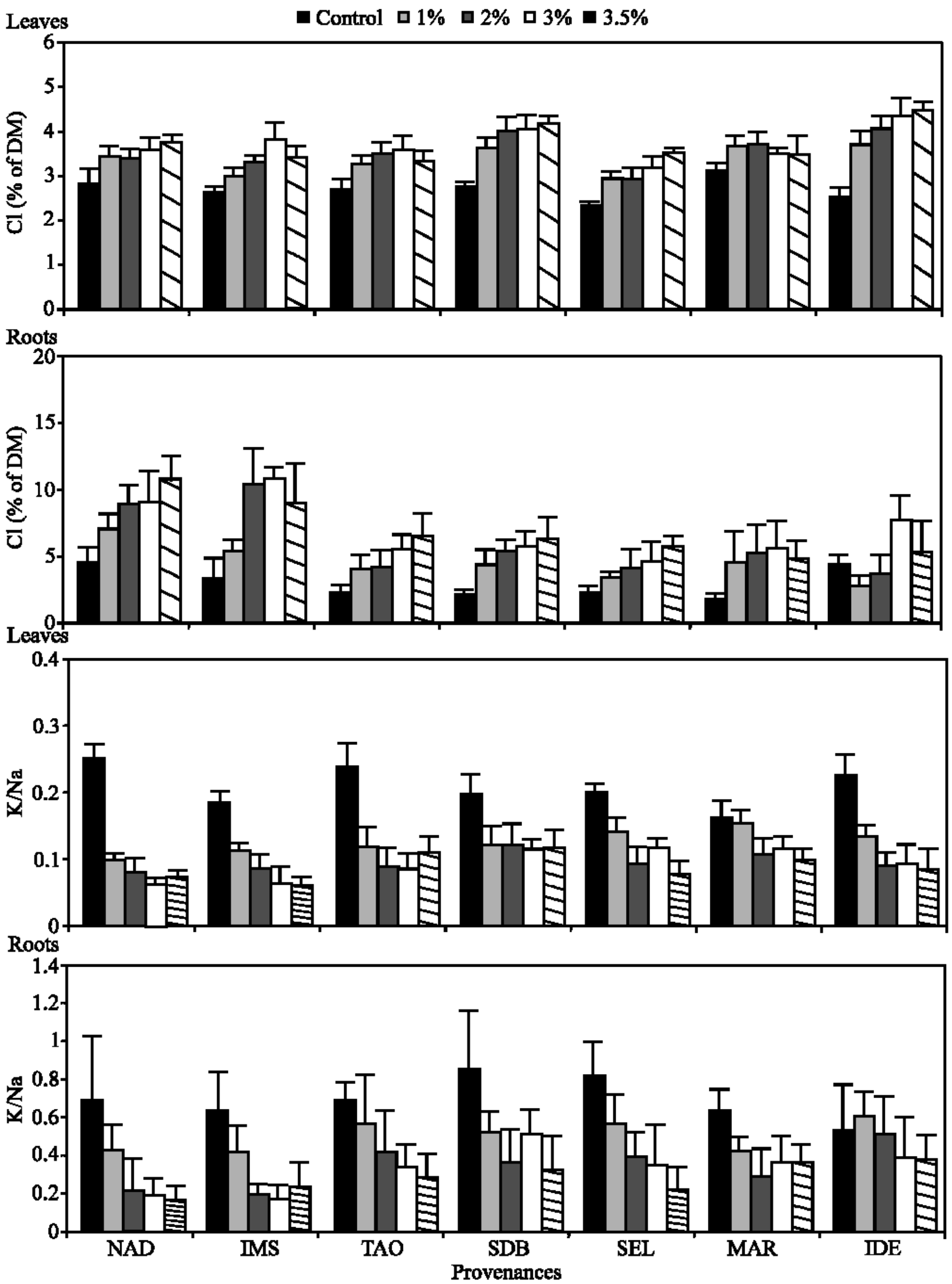

Fig. 3: Cl contents (% of Dry Matter) and variation of the K/Na ratio of leaves and roots of seven *A. halimus* Moroccan provenances treated with various NaCl concentrations (NAD: Nador; IMS: Imssouane; TAO: Taourirt; SDB: Sidi Bouzid; SEL: Selouane; MAR: Marrakech; IDE: Idelssen)

A. canescens[25] and other vegetable species[21,22,26]. Parallel to this significant accumulation of Na^+ and Cl^- under saline conditions, we have noted a significant reduction of K^+ among all the studied provenances. This reduction of K^+ was observed also for several halophytes[17,18,24,27,28] and for some glycophytes[22,29] was explained by the competitive effect between Na^+ and K^+[30, 31]. Many authors have shown that this reduction of the K^+ assimilation presents a negative effect on the plant growth[31,32]. In the present study and among all the studied provenances, this reduction of K^+ assimilation was variable and could be related to the differences in production of biomass observed. Indeed, the provenances which have accumulated, under salt conditions, a significant K^+

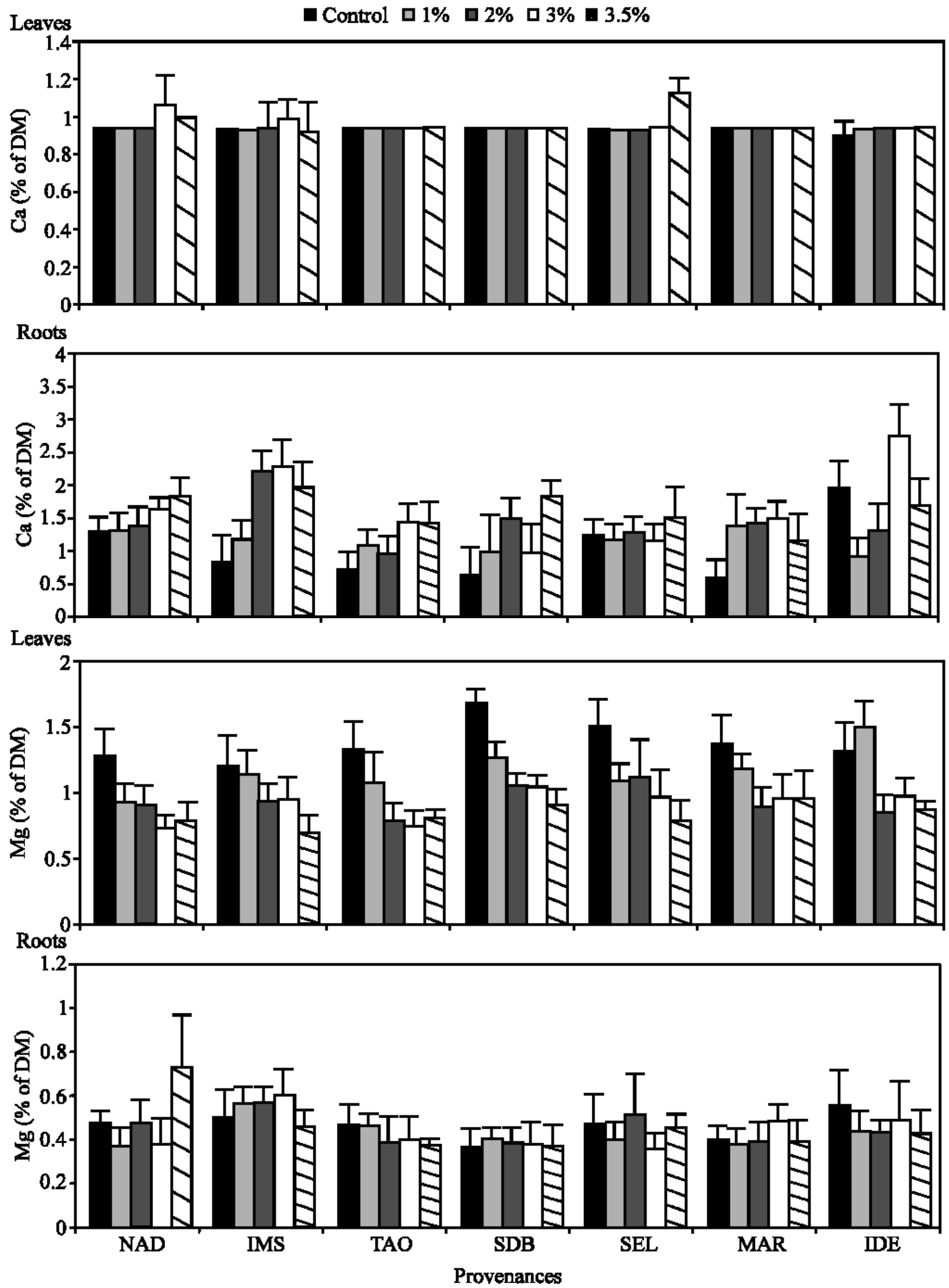

Fig. 4: Calcium and Magnesium Contents (% of Dry Matter) of leaves and roots of seven A. *halimus* Moroccan provenances treated with various NaCl concentrations (NAD: Nador; IMS: Imssouane; TAO: Taourirt; SDB: Sidi Bouzid; SEL: Selouane; MAR: Marrakech; IDE: Idelssen)

contents essentially at the foliar level, have presented on average a relatively more significant production of biomass. This situation is observed essentially for the Sidi Bouzid and Marrakech provenances, which have presented in spite of the reduction of their biomass under salt conditions, relatively high values of K^+ contents. These two provenances have presented also under salt conditions the highest K^+/Na^+ ratios. Inversely, the Nador and Imssouane provenances have shown under salt stress a low K^+ accumulation resulting in a weaker K^+/Na^+ ratio. These two provenances have presented under salt conditions the lowest values of biomass.

The *A. halimus* provenances subjected here to a salt treatment have presented variable behaviours in the growth and in the inorganic ions accumulation. This variability related mainly to the geographical origin of the used material testifies of the existence of a significant polymorphism within the species. This work have pointed out the importance that must be accorded to the development of a basic research directed towards agronomic aspects for the rehabilitation of salt rangelands by *A. halimus*. This first work have already allowed the selection of two provenances (Marrakech and Sidi Bouzid) among the seven studied taking account their performance in term of biomass production under salt conditions. These two ecotypes could hence contribute to the rehabilitation of some salted lands. With term, one can hope for an extremely significant reduction of salinity degree of these lands *via* an export of salt up ground parts of the plant.

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