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EFFECTS OF SALINITY AND NITROGEN ON LETTUCE UNDER ARID CONDITIONS

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ABSTRACT

Two pot experiments were conducted on a sandy soil to study the response of romaine lettuce (*Lactuca sativa* L.) cv. Parris Island to salinity and N fertilization rates and forms under the arid conditions. Equivalent amounts of 1:1 ratio Na:Ca in chloride forms were added to the water source of 1.4 dS m^{-1} to reach the desired salinity. Four salinity levels of irrigation water were obtained: 1.5, 3, 6, and 9 dS m^{-1} in 1997, and the latter level raised to 12 dS m^{-1} in 1998 winter season. The corresponding soil salinity measured on saturated soil paste extracts at harvesting were 2.6, 3.8, 6.2, and 10.1 dS m^{-1} in 1997 and 3.1, 4.9, 7.8, and 13.6 dS m^{-1} in 1998. Nitrogen fertilizers were added at 0, 150, and 300 kg N ha^{-1} rates in four forms: ammonium nitrate (AN), calcium nitrate (CaN), di-ammonium phosphate (DAP), and urea (UR) under each level of salinity.

Data indicated significant reductions in lettuce yield and yield characteristics with increasing soil salinity. Application of 150 kg N ha^{-1} was adequate for romaine lettuce in sandy soils and no benefits were obtained with higher rates. Overall seasons, non of the N forms showed absolute superiority on yield or yield parameters and their significance were different between seasons of study. Romaine lettuce found to be moderately sensitive to salinity under the arid conditions. Its response function to salinity was developed.

Keywords: Romaine lettuce, *Lactuca sativa* L., salt stress, nitrogen fertilizer.

INTRODUCTION

Vegetable production in arid and semi-arid regions is sensitive to excessive soil/water salinity, water stress, and deficiencies of plant nutrients, especially N. The effect of increasing salinity on plants is clearly observed as growth suppression due to the osmotic stress developed by the concentrations of soluble salts in the soil solution (Bielorai *et al.,* 1978; Hoffman *et al.,* 1983; Al-Harbi, 1995). Typically, plant growth decreased linearly as salinity increased beyond a threshold salinity level (Hoffman *et al*., 1983; van Genutchen and Hoffman, 1984; Francois, 1994 & 1995). Therefore, yield and quality characteristics of the crop will be reduced.

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Many investigators have studied the effects of different forms (Pew *et al.*, 1983 & 1984; El-Fakharani and Al-Redhaiman, 1999) and rates (Van Der Boon *et al.,* 1990; Huett and Dettmann, 1992; Martinetti, 1996; El-Fakharani and Al-Redhaiman, 1999) of N fertilizer on lettuce growth. The most important for proper growth and maximum yield under the arid and semi-arid conditions is the availability of N and its adequate supply.

There is a lack of information pertaining to the response of lettuce to salinity especially in the arid and semi-arid regions where irrigation water is gradually becoming more saline. So, salt tolerance data of lettuce are not available to adequately predict yield response under these conditions. Also, the performance of lettuce with different N rates and sources need to be assessed more specifically under salinity stress conditions. The objective of this study is to determine the yield and yield characteristics of lettuce as affected by increasing levels of salinity and different N forms and rates under arid conditions.

MATERIALS AND METHODS

Two pot experiments were conducted on lettuce (*Lactuca sativa* L.) during the winter seasons of 1997 and 1998 at the station (26º18´N, 43º58´E) of the College of Agriculture and Veterinary Medicine, King Saud University, Al-Qassim, Saudi Arabia. The quality of irrigation water in the central region of Saudi Arabia was classified as moderate saline to very saline water (Abdel-Aal *et al.,* 1997). Average annual rainfall of the area is 57.4 mm. The mean daily temperatures were 17.2 and 20.8ºC in November and 12.7 and 16.1ºC in December of 1997 and 1998, respectively. A split plot design was used with three replications assigning salinity of irrigation water to main plots and rate and source of N fertilizers to sub-plots. Four levels of water salinity were obtained by adding 1:1 equivalent amount of Na and Ca in chloride forms to the water source of 1.4 dS m^{-1} (Table 1) to reach 1.5, 3, 6, and 9 dS m^{-1} in 1997, and the first three levels plus 12 dS m^{-1} in 1998. The resultant soil salinity measured on saturated soil paste extracts at harvesting were 2.6, 3.8, 6.2, and 10.1 dS m^{-1} in 1997 and 3.1, 4.9, 7.8, and 13.6 dS m^{-1} in 1998. Four sources of N fertilizers: ammonium nitrate (AN), calcium nitrate (CaN), di-ammonium phosphate (DAP), and urea (UR), each with three levels of 0, 150, and 300 kg N ha^{-1} were tested under each level of salinity. Fifteen kg of surface 0-25 cm sandy soils (hyperthermic Typic Torripsamments) were packed in plastic pots (20 cm in diameter and 25 cm in height). The characteristics of soil used were determined according to Page *et al.* (1982) and listed in Table 1. The soil received a pre-sowing dose of 138 kg ha^{-1} P_2O_5 in the form of triple phosphate (46% P_2O_5). Two seedlings of romaine lettuce (cv. Parris Island) were transplanted in each pot on October 20 and 29 in 1997 and 1998, respectively. The pots were then daily irrigated with the water source of 1.4 dS m^{-1}up to one week, and thereafter with the assigned salinity level. The amount of applied water was calculated as 1.2 times the evaporation of class A pan plus 20% for salt leaching. The seedlings were thinned to one per pot at the end of the first week and all pots received a dose of 100 kg ha^{-1} K_2O in the form of K_2SO_4 (48% K_2O) and N treatments were daily applied in dissolved forms through the irrigation water. The rate of N was sequentially divided throughout the season to 10, 15, 25, 30, and 20% per week in 1997 and 15, 25, 35, and 25% per week in 1998 seasons. To allow the plants to adjust osmotically, irrigation water salinity was increased in one-third increments over one week until desired salinity was achieved. Plants were harvested by cutting above the ground on December 27 and 26 in 1997 and 1998, respectively for the first and second seasons. Plant fresh weight, height, and number of leaves were recorded, and the first matured-leaf was collected for leaf area and succulence determination. Dry weight of plant was recorded after drying at 65ºC to a constant weight. Data were statistically analyzed using SAS (1988) software package.

Table 1: Source of irrigation water and pre-sowing soil characteristics[1] used in the current study.

Parameter	Source water	Soil	
		1997	**1998**
EC (dS m^{-1})	1.4	2.3	2.1
PH	7.8	8.5	8.4
Anions (mol m^{-3})			
Cl^-	6.5	7.4	6.8
SO_4^{2-}	3.0	6.5	6.6
HCO_3^-	2.1	1.9	1.7
Cations (mol m^{-3})			
Ca^{2+}	2.5	5.7	5.3
Mg^{2+}	1.4	2.5	2.4
Na^+	6.2	5.8	5.2
K^+	0.2	0.8	0.7
Inorganic N (µg g^{-1})			
NO_3-N	ND[2]	19.6	9.9
NH_4-N	ND	5.6	14.6
Available K (µg g^{-1})	ND	86.7	78.8
Available P (µg g^{-1})	ND	3.3	3.4
OM (%)	ND	0.09	0.11

[1]EC, pH, anions, and cations were measured in saturated soil paste extracts.
[2]ND=not determined.

RESULTS AND DISCUSSION

Soil salinity was positively linear related to the salinity of irrigation water. The relation between soil salinity (EC_e) and irrigation water salinity (EC_i) is given as:

$$EC_e = 1.251 + 1.002\ EC_i \qquad (r = 0.989)$$

The mean salinity of the root zone was considered as the effective salinity on plant growth (Shalhevet *et al*., 1969; Frenkel and Meiri, 1985). As the salinity increased, more moisture was retained in the soil and became less available to the plant (Fig. 1). Hence, less uptake of water by plant was assumed due to the decrease (*i.e.* more negative) in osmotic potential of the root zone as the soil salinity increased (Shalhevet and Bernstein, 1968; Shalhevet and Yaron, 1973; Bielorai *et al*., 1978; Frenkel and Meiri, 1985).

In a side experiment, two methods of N application were compared in 1998 season (Table 2) at the rate of 150 kg N ha^{-1} as AN namely; classical soil dressing (dose splitted and added at 2*nd* and 4*th* week) and fertigation (soluble N fertilizer daily applied through irrigation water). Consistent increases in fresh and dry weights and number of leaves were observed with fertigation as compared to soil dressing N application especially with increasing soil salinity. The corresponding range of increases in fresh and dry weights and number of leaves were 121.2-199.8, 101.0-285.8, and 91.4-174.0 % with the averages of 164.2, 158.7, and 119.4 %, respectively. This indicates the advantage of using fertigation on lettuce yield through the optimization and adequate supply of N at the root zone especially in sandy soils.

Table 2: Yield data of lettuce fertilized with ammonium nitrate at the rate of 150 kg N ha^{-1} applied by traditional soil dressing and by fertigation as influenced by levels of soil salinity at the 1998 season.

Soil EC[1] (dS m^{-1})	Fresh wt. (g)		Dry wt. (g)		No. of leaves	
	Applied N					
	Soil dressing	Ferti-gation	Soil dressing	Fertigation	Soil dressing	Ferti-gation
3.1	12.76a[2]	15.47a	1.38a	1.39a	11.7a	10.7a
4.9	7.10b	13.57b	0.72b	1.05b	9.0b	9.7b
7.8	7.18b	10.39c	0.71b	0.73c	7.0c	7.3d
13.6	4.73c	9.45d	0.35c	1.00b	5.0d	8.7c

[1] Electrical conductivity of saturated soil paste extract.
[2] Means for each factor followed by the same letter/s are not significantly different at 0.05 level of probability.

Tables 3 and 4 depicted the effects of soil salinity and the rates and forms of N fertilizer on the yield and its components of romaine lettuce for the two seasons of study. Yield and yield characteristics of romaine lettuce except % dry matter were significantly decreased with increasing soil salinity. However, fresh weight and number of leaves per plant in both growing seasons, and dry weight and plant height in 1997 season showed no significant differences at EC_e either lower than 3.8 and 4.9 or higher than 6.2 and 7.8 dS m^{-1} in 1997 and 1998, respectively. No significant differences in dry weight at EC_e higher than 4.9 dS m^{-1} and in plant height between 4.9 and 7.8 dS m^{-1} in 1998 season. The highest significant percentages of dry matter were observed with EC_e 6.2 and 13.6 dS m^{-1} in the first and second seasons, respectively. The first matured-leaf and total leaf areas were significantly higher under the lowest soil salinity and the reduction was insignificant and significant with increasing soil salinity in 1997 and 1998 seasons, respectively. The reduction in leaf area with increasing soil salinity will decrease transpiration and consequently crop growth (Shalhevet and Yaron, 1973). Less fresh weight and leaf area and taller plants were observed in the

Fig1+2

second season due to the relatively short growing period and the unfavorable warm weather causing a rapid enhancement in plant elongation as compared to the first season. The variation in head lettuce yield between different growing seasons was also observed by many investigators (Pew *et al*., 1983; Nagata *et al.*, 1992; Walworth *et al.*, 1992). This was expected since vegetable crops vary in their yields depending on climate, soil condition, and culture practice (Francois, 1995; Sanchez and El-Hout, 1995). The reduction in the first matured-leaf succulence with increasing soil salinity was more explicit in the second than the first season. This reduction comes in parallel to the above-mentioned assumption of reduced water uptake by plant and the climatic effect. The yield reduction was primarily due to the significant less number of leaves, leaf area, and plant height at higher soil salinity. This could be explained as salinity retards cell enlargement and cell division, the production of proteins and nucleic acids, photosynthesis process, and the rate of increase in plant mass (Hoffman *et al.*, 1983). The application of N fertilizer at any rate and form resulted in significant higher yield and yield components, except % dry matter, than the control. However, raising the applied N fertilizer from 150 to 300 kg ha^{-1} did not significantly increase- but sometimes lowered- the yield and its characteristics with all forms of N fertilizers in both seasons. Many investigators (Francois, 1994 & 1995; Al-Harbi, 1995; Martinetti, 1996) reported general reductions in yield and growth characteristics with high N application rates. Also, several studies showed that unutilized N increased with increasing the applied N where losses were quite high (*e.g.* Scaife *et al.,* 1986; Thompson and Doerge, 1995). Thus, application of 150 kg N ha^{-1} seems to be adequate for romaine lettuce grown in sandy soils under the arid conditions. Similar results were obtained on lettuce with Scaife *et al*. (1986) and El-Fakharani and Al-Redhaiman (1999). Thompson and Doerge (1995) found that the maximum crop yield and yield quality of romaine lettuce grown in sandy loam soil occurred at N rates of 156 to 193 kg ha^{-1}. Also, the greatest fresh yield of lettuce was reported at 143 (El-Sherbieny *et al.,* 1989), at 112 (Walworth *et al.*, 1992), and at 100 kg N ha^{-1} (Martinetti, 1996). Eventhough, growers frequently apply more than the recommend dose, which is costly and time consuming. Applying UR and DAP at the rate of 150 or 300 kg N ha^{-1} resulted – with no significance differences between them- in the highest fresh weights in the 1997 season. AN at 150 kg N ha^{-1} gave the highest fresh weight with no significant differences with CaN and DAP at the same rate and AN, CaN, and UR at 300 kg N ha^{-1} in 1998 season. Walworth *et al.* (1992) found little effect from N source on head weight of lettuce and the inconsistant significance of N sources on fresh yield in our study may support their findings. The highest dry weight was obtained with UR at 150 kg N ha^{-1} rate with no significant differences with DAP at 150 and CaN, DAP, and UR at 300 kg N ha^{-1} in 1997 season. No significant differences in the highest dry weights of AN, CaN, and DAP at 150 and AN and UR at 300 kg N ha^{-1} in 1998 season. The dry matter showed the highest percentages with AN and CaN at 300 kg N ha^{-1} rate with no significant differences from control on both seasons, and from UR at 150 and DAP and UR at 300 kg N ha^{-1} in 1998 season. The applications of DAP resulted in the tallest plants with no significant differences from CaN or UR at all N rates in

1997 season. UR at the rate of 300 kg N ha^{-1} resulted in the tallest plants with no significant differences from AN at the same rate and AN, CaN, and DAP at 150 kg N ha^{-1} rate in 1998 season. The highest average number of leaves was observed with UR at 150 with no significant differences than DAP or UR at 300 kg N ha^{-1} rate in 1997 season. No significant differences were noticed in the average number of leaves among N forms at any rate over the control in 1998 season. Similar to fresh weight, first matured-leaf and total leaf areas were significant higher under DAP and UR than AN and CaN at all N rates in 1997 season. AN and DAP at 150 and AN and UR at 300 kg N ha^{-1} resulted in the higher first matured-leaf and total leaf areas in 1998 season. The first matured-leaf succulence was highest with UR at 300 kg N ha^{-1} in both seasons. However, no significant differences were observed from this highest succulence with control, CaN, DAP, and UR at 150 in 1997 season, and AN, CaN, and DAP at 150 and AN at 300 kg N ha^{-1} in 1998 season.

Table 3: Yield and yield characteristics of lettuce as affected by different salinity levels and N fertilizer rates and forms at harvesting of the 1997 season.

Soil EC[1] (dS m^{-1})		Fresh wt. (g/pot)	Dry wt. (g/pot)	Dry matter (%)	Plant height (cm)	Avg. no. of leaves	First matured leaf area (cm^2)	Leaf area (cm^2 /pot)	First matured leaf Succulence (mg/ cm^2)
2.6		47.68a[2]	5.44a	11.40c	24.8a	17.3a	69.9a	811.6a	45.7a
3.8		41.94a	4.97a	11.84bc	23.2ab	15.9a	52.8b	569.5b	45.5a
6.2		28.31b	3.72b	13.14a	21.0c	13.3b	54.9b	494.6b	41.4b
10.1		27.10b	3.29b	12.14b	21.7bc	12.7b	56.7b	498.3b	44.0ab
$LSD_{0.05}$		6.88	1.03	0.68	1.8	1.8	7.2	120.5	2.8
N Fertilizer									
Rate (kg ha^{-1})	Form[3]								
0		9.05e	1.21d	13.34a	15.3c	9.7d	34.3d	228.2c	45.2abc
150	AN	33.78d	3.96c	11.72c	21.8b	15.1bc	57.9bc	583.4b	43.1bc
	CaN	35.15d	4.13c	11.76c	23.1ab	14.3c	54.3c	530.6b	43.8abc
	DAP	44.29ab	4.92abc	11.11c	25.3a	15.5bc	72.7a	765.5a	45.5ab
	UR	46.91a	5.62a	11.98bc	23.9ab	16.8a	65.0ab	726.9a	44.8abc
300	AN	32.50d	4.26c	13.10ab	22.4b	14.5c	51.3c	496.1b	43.3bc
	CaN	35.67cd	4.81abc	13.49a	23.8ab	14.8c	59.6bc	592.8b	42.2c
	DAP	42.92abc	4.81abc	11.20c	24.8a	16.2ab	66.2ab	701.0a	42.8bc
	UR	46.05a	5.36ab	11.64c	23.9ab	16.3ab	66.0ab	717.0a	46.6a
$LSD_{0.05}$		7.52	0.96	1.17	2.3	1.4	9.6	105.8	3.1
EC × Fertilizer		NS[4]	NS	*	NS	NS	NS	NS	**

[1] Electrical conductivity of saturated soil paste extract.
[2] Means for each factor followed by the same letter/s are not significantly different at 0.05 level of probability.
[3] AN=ammonium nitrate, CaN=calcium nitrate, DAP=di-ammonium phosphate, and UR=urea
[4] NS, *, and ** = not significant, significant at 0.05, and at 0.01 levels of probability, respectively.

The soil/water salinity × N fertilizer interactions were insignificant on fresh weight and all other yield characteristics except the percentage of dry matter and first matured-leaf succulence in both seasons and average number of leaves in 1998 season.

Table 4: Yield and yield characteristics of lettuce as affected by different salinity levels and N fertilizer rates and forms at harvesting of the 1998 season.

Soil EC[1] (dS m^{-1})		Fresh wt. (g/pot)	Dry wt. (g/pot)	Dry matter (%)	Plant height (cm)	Avg. no. of leaves	First matured leaf area (cm^2)	Leaf area (cm^2 /pot)	First matured leaf succulence (mg/ cm^2)
3.1		30.67a[2]	2.97a	9.69bc	38.7a	14.3a	57.9a	552.9a	25.2a
4.9		31.65a	2.88ab	9.11c	33.2b	14.0a	56.1a	507.9a	24.7a
7.8		23.12b	2.62ab	11.33b	29.4b	11.4b	50.9b	416.4b	22.8b
13.6		18.13b	2.42b	13.35a	22.9c	11.0b	42.7c	312.6c	10.9c
$LSD_{0.05}$		6.47	0.53	1.71	5.3	1.2	4.8	64.9	1.6
N Fertilizer									
Rate (kg ha^{-1})	Form[3]								
0		8.20d	0.89d	10.83ab	17.1d	9.9b	45.2cd	374.5cd	19.2cd
150	AN	30.56a	3.08abc	10.07b	34.2abc	13.6a	56.7ab	501.5ab	21.1abc
	CaN	30.09ab	3.06abc	10.18b	35.1ab	13.3a	38.6e	365.8cd	20.9abc
	DAP	30.02ab	2.99abc	9.97b	35.3ab	12.9a	61.9a	536.0a	23.0ab
	UR	24.87bc	2.57c	10.32ab	28.1c	13.3a	51.2bc	437.9bc	20.2bcd
300	AN	29.98ab	3.52a	11.73ab	32.1abc	13.9a	59.4a	573.3a	22.8ab
	CaN	25.59abc	3.04abc	11.87ab	30.5bc	12.4a	43.9de	336.9d	17.6d
	DAP	22.66bc	2.77bc	12.22a	28.2c	12.6a	48.1cd	373.7cd	20.1bcd
	UR	31.06a	3.48ab	11.22ab	38.7a	12.6a	62.2a	527.7a	23.3a
$LSD_{0.05}$		8.42	0.72	1.94	6.5	1.8	6.4	88.2	3.0
EC × Fertilizer		NS[4]	NS	*	NS	*	NS	NS	**

[1] Electrical conductivity of saturated soil paste extract .
[2] Means for each factor followed by the same letter/s are not significantly different at 0.05 level of probability.
[3] AN=ammonium nitrate, CaN=calcium nitrate, DAP=di-ammonium phosphate, and UR=urea
[4] NS, *, and ** = not significant, significant at 0.05, and 0.01 levels of probability, respectively.

The crop response to salinity is the basis for crop selection and management under given saline and growing conditions. Fresh yield data for each season were statistically analyzed with a piecewise linear response model (van Genuchten and Hoffman, 1984). The data indicated tolerance thresholds (the maximum allowable soil salinity without yield reduction) of 1.9 and 3.2 dS m^{-1} and yield decline of 10.9 and 6.6 % per unit increase in soil salinity above the thresholds in the first and second seasons, respectively (Fig. 2). Relative yield (RY) can be calculated as a function of soil salinity (EC_e) above the threshold with:

$$RY = 100 - 8.8 (EC_e - 2.6)$$

Different threshold values strongly reflect the changes in environmental conditions (Frenkel and Meiri, 1985). Our threshold data places romaine lettuce as a moderately sensitive crop to salinity and tends to agree with Mass and Hoffman (1977) and Hoffman *et al*. (1983).

As expected, less significant yield and yield components were noticed with the increase in soil/water salinity. Although this study shows that romaine lettuce is moderately sensitive crop, 50% yield could be achieved at soil salinity 8.3 dS m^{-1}. Still, the need to maintain low soil salinity level is essential for maximum yield. The application rate of 150 kg N ha^{-1} was sufficient for maximum growth in sandy soils and excess application will not be economical. Generally speaking over the two seasons of study, no clear-cut in lettuce performance was found with different N sources. This may suggests that various N sources in soluble forms provide acceptable supply of N for lettuce growth in sandy soils.

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تأثيرات الملوحة و النيتروجين على الخس تحت ظروف المنطقة الجافة

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أجريت تجربتان على تربة رملية في أصص لدراسة استجابة الخس الروميني للملوحة ونوعية ومعدل التسميد النيتروجيني تحت ظروف المنطقة الجافة. أضيفت كميات مكافئة من الصوديوم والكالسيوم في صورة كلوريدات بنسبة ١:١ إلى مصدر المياه ذات ١,٤ ديسيسيمنز/م للوصول إلى مستويات ملوحة مياه الري ١,٥ ، ٣ ، ٦ ، ٩ في الموسم الشتوي ١٩٩٧ وقد تم زيادة المستوي الأخير إلى ١٢ ديسيسيمنز/م في الموسم الشتوي ١٩٩٨. كانت ملوحة التربة المطابقة عند الحصاد والمقاسة في مستخلصات عجينة التربة المشبعة هي ٢,٦ ، ٣,٨ ، ٦,٢ ، ١٠,١ في موسم١٩٩٧ ، ٣,١ ، ٤,٩ ، ٧,٨ ، ١٣,٦ ديسيسيمنز/م في موسم ١٩٩٨. شملت الدراسة أربعة أنواع من السماد النيتروجيني هى نترات الأمونيوم ، نترات الكالسيوم ، فوسفات ثنائي الأمونيوم ، و اليوريا وذلك بثلاثة مستويات هي صفر ، ١٥٠ ، ٣٠٠ كجم ن/هكتار تحت كل مستو من مستويات الملوحة.

أظهرت النتائج معنوية مرتفعة في نقص المحصول الكلى وكل الصفات المحصولية مع زيادة ملوحة التربة. وتعد إضافة ١٥٠ كجم ن للهكتار كافية للخس الروميني بالتربة الرملية ولا توجد فوائد مع إضافة معدلات أعلى. لم تُظْهر أي نوعية من السماد النيتروجيني تفوقاً مطلقاً في المحصول أو الصفات المحصولية خلال موسمي الدراسة وكانت الزيادات المعنوية بينها مختلفة الترتيب من عام لأخر. وجد أن الخس الروميني متوسط الحساسية للملوحة تحت ظروف المنطقة الجافة وتم إيجاد دالة استجابته للملوحة.