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Effects of Salinity and Specific Ions on Seedling Emergence and Growth of Onions

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Texas Water Resources Institute
make every drop count

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Unit Conversion

1 $m^3\ s^{-1}$ = 2.64 Mm^3/mo = 86,400 m^3/day	1 me L^{-1}	Na = 23 mg L^{-1}
1 Mm^3 = 811 acre-ft		Ca = 20 mg L^{-1}
1 Mm^3/mo = 8.66 MGD		Mg = 12.1 mg L^{-1}
1 MGD = 694 GPM = 1.55 cfs = 3.07 AF/day	1 dS m^{-1} = 635 ~ 700 mg L^{-1}	

EFFECTS OF SALINITY AND SPECIFIC IONS ON SEEDLING EMERGENCE AND GROWTH OF ONIONS

S. Miyamoto, I. Martinez and G. Niu

SUMMARY

The concentrate from nanofiltration is usually enriched with divalent ions, such as Ca, Mg and SO_4. Since divalent ions are less hazardous to soils and plants, it was hypothesized that the disposal of nanofiltration concentrate to irrigation water may not be deleterious, especially for growing crops sensitive to specific effects of Na and/or Cl. This study examined the above hypothesis by observing the effect of salinity and ion composition of irrigation water on seedling emergence, survival and growth of onions. Onions are an important winter crop grown in the Rio Grande Valleys, and are regarded as being sensitive to Cl ions.

Two soil types (Harkey silt loam and Bluepoint loamy sand) were used for a greenhouse experiment involving two onion cultivars 'BR-1' and 'Chaco'. Harkey silt loam had three levels of initial soil salinity (3.9, 2.2 and 0.6 dS m^{-1}). They were placed in pots, seeded and irrigated for 4 ½ months using nine types of saline solutions. The first four solutions had four levels of salinity: 1.0, 1.8, 3.7 and 5.2 dS m^{-1} (or 630, 1200, 2500 and 3700 ppm) at a constant ionic ratio of 1:1 for Na: Ca + Mg, and Cl: SO_4, and other solutions had three levels of ionic concentration ratios; 3:1, 1:1, and 1:3 at fixed levels of salinity, either 20 or 40 me L^{-1}. The last solution was prepared by adding Ca and SO_4 at 20 me L^{-1} to the 2.2 dS m^{-1} solution. Seedling emergence, survival and growth were measured along with soil salinity, and Na Ca and Cl contents of the plant tissue.

Results have shown that seedling emergence and survival were affected by watering methods and soil types, especially by the initial soil salinity levels, besides salinity of the irrigation solutions. In surface-irrigated loamy sand, seedling emergence and survival were excellent, regardless of the saline solutions used. In surface-irrigated silt loam, seedling emergence was low (< 20%), presumably due to soil crusting. In subirrigated silt loam, seedling emergence and survival were reduced by increasing initial soil salinity and salinity of the irrigation solutions, but not by the ion composition. Seedling growth was also reduced by increasing salinity and Cl/SO_4 ratios when Cl concentration exceeded 10 me L^{-1} in irrigation water. The addition of Ca and SO_4 to an irrigation solution (2.2 dS m^{-1}) reduced seedling growth. The tissue Na and, to some extent, Cl concentration increased with increasing Na/(Ca + Mg) ratio in irrigation water. A similar trend was found for the Cl to SO_4 ratios, while tissue Ca concentrations remained relatively stable. The Cl concentration of the plant top was higher than that in the roots, when its concentration in the irrigation solution exceeded approximately 10 me L^{-1}.

Although onions were shown to accumulate Cl ions in plant top, the deleterious effect of Cl seems to appear after seedling growth is first curtailed by salinity. The establishment of onion crops are controlled largely by soil salinity, soil types and management practices rather than ionic composition. The application of nanofiltration concentrate to irrigation water inevitably increases salinity, and for this reason, it is unlikely to be beneficial for onion crop production under the prevailing furrow-irrigated conditions of the Rio Grande Valleys.

INTRODUCTION

The concentrate from nanofiltration (NF) is usually enriched with divalent ions, such as Ca, Mg, and SO_4. This led to the thought that irrigation water receiving the concentrate could have the sodium adsorption ratio (SAR) lower than the initial SAR of the irrigation water (e.g. Turner, et al., 2002). Since it is widely acknowledged that irrigation water with low SAR is preferred over the water with high SAR, application of the concentrate from nanofiltration to irrigation water was initially viewed as a possible disposal option.

The analysis shown in our earlier report (Miyamoto, 2008), however, indicates that the changes in SAR depend not only upon the membrane type used, but also upon quality of feed water. When the feed water consists predominantly of Na and SO_4 ions, the SAR of the concentrate remains essentially unchanged, mainly because of the high rejection rate of SO_4, which necessitates the rejection of Na in order to satisfy the charge balance. In addition, the increase in salinity (or the total dissolved salts) increases the SAR by its definition. The effective SAR adjusted to the activity of dissolved ions (which governs the cation exchange reaction in soils) further increases due to increased SO_4 ion-pair formation with Ca and Mg ions (Rao, et al., 1968). The composition of the feed water being studied at El Paso falls into the category of high Na and SO_4 contents.

The major change in ionic composition resulting from the nanofiltration process is a significant increase in SO_4 to Cl ratios, and a decrease in Na to Ca + Mg ratios. These changes do not occur in the RO concentrate, and could favorably affect growth of crops which are sensitive to Na and/or Cl. Onion (*Allium cepa L.*), an important winter crop grown in the El Paso Valley is, for example, classified as being sensitive to specific effects of Cl ions (Maas, 1990). This classification is based on field reports, but not upon controlled studies. Another important crop grown in the El Paso Valley is alfalfa (*Medicago sativa L.*) A previous study indicates that the growth response of alfalfa is controlled mainly by the electrical conductivity of culture solutions (which is approximately equal to ionic concentrations), regardless of Cl or SO_4 proportions (Soltanpour, et al., 1999). Another important crop for the El Paso Valley is pecans (*Carya Illinoensis K.*). Our earlier study indicates that growth of this crop suffers from salinity and specific effects of Na and Cl ions (Miyamoto et al., 1985). However, this crop is rarely irrigated during winter months, except for special circumstances, such as for salt leaching or for irrigation of transplants.

The study reported here was performed for evaluating onion crop response to salinity and ion composition. Onion crops in the El Paso Valley are grown mostly during a period of October through May using winter irrigation returnflow with the electrical conductivity (EC) of 1.5 to 2.0 dS m^{-1}, then with the project water after the first release in March. Crop beds receive preplanting furrow irrigation, and are left to dry until the soil moisture level becomes suitable for reshaping the bed into a vegetable bed. This reshaping operation (referred to by some as decapping or drugging) removes soluble salts accumulated at the ridge. As soon as the bed is reshaped, seed is planted shallow (usually about ½ cm deep) followed by the second furrow irrigation. It is a challenge for onion growers to obtain adequate uniform stands under furrow irrigation. Crop establishment involving seedling emergence and growth is indeed a critical step for growing onions.

Previous studies indicate that onion seeds can germinate in saline solutions with an EC of 27 dS m^{-1}, although the rate of germination can be significantly reduced when salinity of incubating solutions exceeds 14 dS m^{-1} (Miyamoto, 1989). Seedling emergence from sandy soils slowed when salinity of the saline solutions used for subirrigation increased from 2.8 to 4.9 dS m^{-1}, and the final emergence counts declined as salinity of subirrigation solution increased from 4.9 to 7.6 dS m^{-1} (Miyamoto, 1989). These observations seem to indicate that poor emergence reported in the field when irrigated with the returnflow could be related to on-farm soil and water management practices as much as quality of irrigation water used. The saline solutions used in these experiments had a Na/(Ca + Mg) ratio of 1.8 (or SAR of 5 to 15), and a Cl/SO_4 ratio of 1.45 in chemical equivalent. A pioneer work of Bernstein and Ayers (1953) indicates that growth of onion bulbs may be reduced starting at 1.2 dS m^{-1} (measured in the soil saturation extract), and may result in a 50% reduction in bulb weight at 4.1 dS m^{-1}. A more recent study by Wannamaker and Pike (1987) also indicates that seedling growth of onions is reduced significantly at salinity of culture solutions as low as 2 dS m^{-1} in a sand culture experiment. The solution used for this experiment contained NaCl and $CaCl_2$, but not SO_4 salts.

The study reported here was for evaluating the effect of salinity and ionic composition on seedling emergence, mortality, growth, and ion uptake of two onion cultivars: New Mexico 'BR-1', and New Mexico 'Chaco'. Both cultivars are an intermediate-day yellow onion, and bulbs of 'Chaco' are usually larger than those of 'BR-1'. Some growers indicated that 'Chaco' appears to be more salt-tolerant than 'BR-1', but others indicate little difference in salt tolerance. We used subirrigation, as well as surface application to simulate the salt distribution under furrow or sprinklers using two soils (silt loam and loamy sand). Results are relevant for assessing potential impacts of concentrate disposal into irrigation water on onion crop establishment.

MATERIAL AND METHODS

Two soil types were used: Harkey silt loam (calcareous, typic Torrifluvent, Entisol) and Bluepoint loamy sand (calcareous, Torripsamment, Entisols). Harkey silt loam is used extensively for irrigated crop production, mostly under surface irrigation in the middle Rio Grande Valley. Harkey silt loam was collected in September of 2006 from the A_P horizon of a field planted to cotton in previous years at two locations; the middle of a disked field, and a flat water check-in basin. These samples are numbered 1 and 2, respectively (Table 1). In addition, the third soil sample designated as Harkey silt loam 3 was used after leaching a check-in basin with tap water in October, 2006 in order to have a soil sample with low salinity. These samples were air-dried, and passed through a 4 mm screen. Bluepoint loamy sand, similar to Vinton loamy sand (calcareous, Torrifluvent) present in limited areas of the valley, was used for comparison. The sample was collected from a nonirrigated area where soil salinity is known to be low. All samples were analyzed for salinity, and ion composition of the saturation extract,

Table 1. Salinity and ion composition of soil samples used for the onion experiment.

Soil Type	SWC	EC_e	Na	Ca	Mg	Cl	SO_4	SAR
	kg/kg	dS m^{-1}	--------------------	me L^{-1}	--------------------			
Harkey silt Loam (Typic Torrifluvent)								
1.	0.39	3.9	19.0	18.4	6.0	20.5	10.0	5.4
2.	0.39	2.2	12.6	8.2	2.7	16.7	10.9	5.4
3.	0.39	0.6	0.9	2.5	0.9	0.4	4.2	0.7
Bluepoint Loamy Sand (Torripsament)								
	0.20	1.2	0.8	8.2	1.8	4.4	2.7	0.4

using the method given by Rhoades and Miyamoto (1990). Soil salinity of these samples ranged from 0.7 to 3.9 dS m^{-1} with the sodium adsorption ratio (SAR) of 0.7 to 6.1 (Table 1). Soil salinity of cotton field at harvest in this valley is variable, but is usually higher than 3.0 dS m^{-1}, except for in sandy soil series, such as Vinton loamy sand and Gila sandy loam.

Salinity and ion composition of saline solutions used for this study are shown in Table 2. The first four solutions had increasing levels of salinity, while the Na to Ca + Mg and the Cl to SO_4 ratio were maintained at a constant ratio of 1:1. The next four solutions had varying levels of Na to Ca + Mg or Cl to SO_4 ratios, while maintaining the cation or the anion total at 20 me L^{-1} or 40 me L^{-1}. The lower concentration (20 me L^{-1}) was used for Harkey silt loam 2 and 3. Solution 9 was meant to represent a case of gypsic water, or the situation where the concentrate from nanofiltration of gypsic water (high in divalent ions) is blended with Solution 2. These saline solutions were enriched with the Peters nutrient solution at 70, 23, and 23 mg L^{-1} of N, P_2O_5 and K_2O, respectively, starting three weeks after planting.

Preliminary Experiments: The following preliminary experiments were performed using Solution 1 in a greenhouse. The ambient temperature of the greenhouse was regulated at 26 ^oC, and 12.8 ^oC during day and night hours, respectively. The first preliminary experiment was conducted for determining the vertical distribution of soil salinity and moisture, using subirritated soil columns. The soil samples (air-dried and passed through a 4 mm screen) were placed in duplicates in PVC pipes (5.2 cm ID) to a depth of 18 cm at bulk density of 1.32 kg L^{-1} for Harkey silt loam, and 1.38 kg L^{-1} for Bluepoint loamy sand. They were subirrigated once with Solution 1. Soil samples were taken one week after the subirrigation from the soil depths of 0-1, 1-3, 3-5, 5-8, 8-11, and 11-15 cm, and were analyzed for soil moisture and salinity of the saturation extract (Rhoades and Miyamoto, 1990).

The second preliminary test was to evaluate the effect of initial soil salinity on seedling emergence, using two seeding methods. Air-dry samples of Harkey silt loam 1, 2 and 3 samples (<4 mm fraction) and Bluepoint loamy sand were placed in 7.5 liter plastic containers (21 cm deep, 21.7 cm ID at the top, 18.5 cm at the bottom) to a depth of 15.5 cm over a 3.0 cm layer of coarse sand placed at the bottom. The potted soil (7.5 kg of the silt loam or 8.7 kg of the loamy sand) was then placed on greenhouse benches and seeded with 50 seed per pot. The first seeding method involved the removal of 5 mm soil, seeding, and back-filling with the 5 mm layer of the soils previously removed. This seeding procedure provided good control of seeding depth, and was used for Harkey silt loam 3, and Bluepoint loamy sand. The second seeding method consisted of two steps: the first step was identical to the first seeding method, and the second step consisted of placing a layer of fiberglass screen on the surface of potted soils, followed by a placement of a 2 cm layer of soil (<2 mm size) over the fiberglass screen. The extra soil added on the screen was to be removed once soluble salts are transported to the surface layer upon subirrigation, and this step may represent removal of salt crust formed at the ridge of furrow bed. The second seeding method was used for Harkey silt loam 1 and 2, because of the concern that seedling emergence can be limited in these soils with elevated salinity. These potted soil samples were subirrigated overnight by placing the pots in a shallow pan. In the cases involving the second seeding method, the top layer of soil was removed 9 days after planting by lifting the fiberglass screen. Subirrigation was applied on the 8th day, then weekly. In addition, potted Bluepoint loamy sand and Harkey silt loam 1 were surface-irrigated weekly for comparison. Seedling emergence was monitored for the next three weeks. In the meantime, seed lots (50 seed each) of 'BR-1' and 'Chaco' were placed in glass petri–dishes containing two sheets of filter paper. Solution 1 was added to the petri–dishes every other day, and the germinated seed counted. The seed was considered germinated when the radicle broke through the seed coat. The seed germination test was conducted in triplicates.

The third preliminary test was for determining the seedling root and top length ratio. Seed was placed in a mixture of perlite and vermiculite placed in tall plastic cups with several drain holes. Ten cups were prepared for each cultivar, and each cup contained approximately 10 seeds. Upon seedling emergence, seedlings were gently removed from the potting media by discarding two of the cups per observation. The lengths of the shoots (below the bend) and the roots were measured on five occasions. The root/shoot length ratio was computed from the length of shoots and roots.

Seedling Emergence, Mortality and Growth Experiments: Formal testing of salt effects on seedling emergence and growth was conducted in a greenhouse during November 2006 to March 2007 for a period of 4.5 months (20 weeks), using Harkey silt loam 1 and 2, and Bluepoint loamy sand (Table 1). The temperature of the greenhouse was set at three regimes; 26 to 16 ^oC during the first month, 16 to 7 ^oC for the next two and a half months, and 29 to 18 ^oC for the final month. Harkey 3 soil was later added to the emergence experiment which extended for 40 days starting in December of 2006 in a separate greenhouse with the temperature regimes used for Harkey 1 and 2 soils. No additional measurement was taken from Harkey 3 soil beyond the 40-day period. The pots were arranged to conform to the split plot design with the soil types or the cultivars as the main, and the saline treatments as subplots with four replications. The potted soils were irrigated weekly for the first month, every 10 to 14 days for the next two and a half months, and 7 to 10 days during the last month. The timing of irrigation was at 25% depletion of soil water for the first one month. Thereafter, irrigation was initiated at 50% depletion of soil water in Harkey silt loam, and a greater depletion in the loamy sand. The total number of irrigation amounted to 13 times during the 20 week test period.

Seedling emergence from potted soils was observed under subirrigation. In addition, Bluepoint loamy sand seeded with 'BR-1' was surface-irrigated approximately at the same

Table 2. Salinity and ionic composition of saline solutions used for the experiment. The numbers in parenthesis apply to Harkey silt loam 2 and 3.

	EC	ΣC	Na:CM	Cl:SO_4	SAR	Na	CM[1]-	Cl	SO_4
	dS m^{-1}	me/L				me/L			
1	1.0	10	1:1	1:1	3.2	5	5	5	5
2	1.8	20	1:1	1:1	4.5	10	10	10	10
3	3.7	40	1:1	1:1	6.3	20	20	20	20
4	5.2	60	1:1	1:1	7.7	30	30	30	30
5	4.1 (2.1)	40 (20)[2]-	3:1	1:1	13.4	30 (15)	10 (5)	20 (10)	20 (10)
6	3.4 (1.7)	40 (20)	1:3	1:1	2.6	10 (5)	30 (15)	20 (10)	20 (10)
7	3.9 (2.0)	40 (20)	1:1	3:1	6.3	20 (10)	20 (10)	30 (15)	10 (5)
8	3.6 (1.8)	40 (20)	1:1	1:3	6.3	20 (10)	20 (10)	10 (5)	30 (15)
9	2.8	40	1:3	1:3	2.6	10	30	10	30

[1] - CM = Ca + Mg 1:1

[2] - Used in Harkey loam 2 and 3.

intervals as the subirrigated cases at a leaching fraction of 30%. (No surface irrigation was used in the silt loam as the preliminary test indicated difficulties of emergence). Under subirrigation, the first seeding method (used in the preliminary experiment) was employed for Harkey silt loam 3, and Bluepoint loamy sand, and the second seeding method for Harkey silt loam 1 and 2. Subirrigation was made by placing pots overnight in a shallow pan containing one of the nine solutions shown in Table 2. In the case of Harkey silt loam 1 and 2 (which used the second seeding method), the second irrigation was made ten days after the first irrigation, just prior to removing of the top soil layer, followed by the third irrigation in 5 days to minimize crusting. Seedlings emerged were counted for the next 20 days. The number of seedlings which have died was also recorded. Seedlings were grown until the end of March, using the nutrient solution, and were cut 1 cm above the ground level, and dry weights of the top measured.

The roots (or below the ground surface portion) of onion seedling (BR-1) were collected by washing loamy sand out. Some onion seedlings just began to show bulb formation, but they shaped more like green onions. They were dried at 60 C, and weighted.

Plant Tissue Analyses: The plant tops from Harkey silt loam 1, and Bluepoint loamy sand were washed with distilled water, and dried at 60^{o}C. The dried tissue was ground by a Wiley mill with a 40 mesh screen, acid digested , and analyzed for Na and Ca with an inductively coupled plasma (ICP) at the Soil and Water Analysis Lab, New Mexico State University, and Cl with an ion chromatograph (EPA method 600/4-79-020, U.S. EPA, 1983). The root samples of 'BR-1' from subirrigated loamy sand were also washed, ground and analyzed for the same elements. All of the tissue analyses were also replicated four times.

S***tatistical Analyses:*** The means, the standard deviation, and the coefficient of variability (CV) were computed from the replicated measurements. In some cases, the least significant difference (LSD) was computed at a 5% level. For the analysis of variance, a split plot design (Little and Hills, 1972) was used for evaluating main and subplot effects on seedling emergence, seedling growth, and ion concentration.

RESULTS

Preliminary Experiments: Soil salinity of the top 1 cm measured in the saturation extract one week after subirrigation with Solution 1 ranged from 5 to 19 dS m^{-1} in Harkey silt loam, and was 10 dS m^{-1} in Bluepoint loamy sand (Fig. 1). The coefficient of variability (CV) among the triplicate measurements ranged from 3 to 5% at the top 1 cm, and 5 to 8% at deeper depths. Note that the initial salinity were 0.6, 2.2, and 3.9 dS m^{-1} in Harkey silt loam, and 1.2 dS m^{-1} in Bluepoint loamy sand (Table 1), and was distributed uniformly over the soil depth. Soil salinity at the top 1 cm increased many fold upon the subirrigation. Soil salinity at a depth of 1 to 3 cm was approximately equal to the initial soil salinity of the soil columns, except for Harkey silt loam 1, which had the highest salinity (Fig. 1). These salt distribution patterns reflect the transfer of soluble salts with the upward capillary flow of water.

Soil moisture contents measured one week after the first subirrigation was relatively uniform; 0.22 kg kg^{-1} at the top 1 cm, and 0.26 kg kg^{-1} at the bottom of the soil column filled with Harkey silt loam 1. The soil moisture distribution in the loamy sand was 10 kg kg^{-1} at the top 1 cm, and 14 kg kg^{-1} at the deepest depth (Fig. 1). The coefficient of variability (CV) of soil moisture was low, 3 to 6%.

When incubated in Solution 1, seed of both cultivars began germinating in two to three days, and its germination reached 90% in six days (Fig. 2). Germination of 'Chaco' was slightly faster than that of 'BR-1' (dotted lines of Fig. 2).

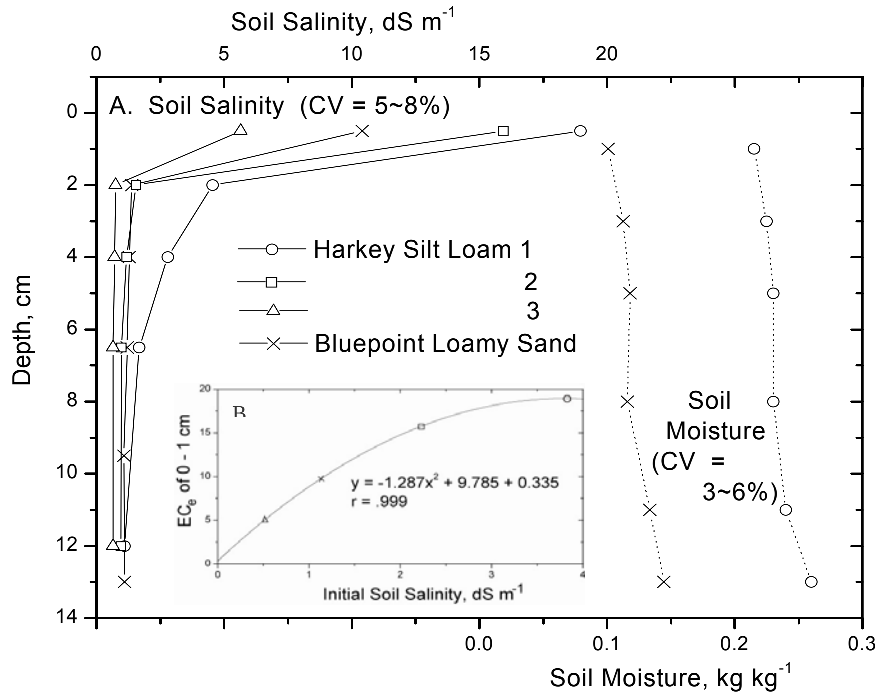

Fig. 1. Soil salinity and soil moisture distribution one week after subirrigation with Solution 1 (A), and soil salinity of the top 1 cm layer as related to initial soil salinity (B): the preliminary experiment.

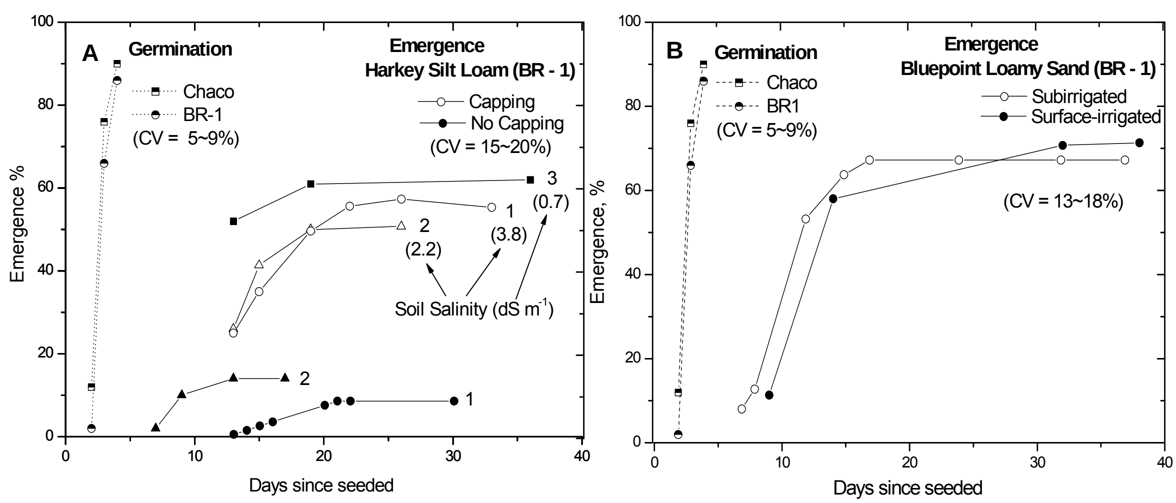

Fig. 2. Seed germination and seedling emergence of onion cultivar BR–1 from subirrigated Harkey silt loam (A) and Bluepoint loamy sand (B). The numbers in Fig. 2A denote the soil sample number and soil salinity in parenthesis.

Only less than 20% of the seeds planted emerged from Harkey silt loam 1 and 2 without the placement of an additional layer of soil (solid symbols, Fig. 2A). This finding may indicate that the salts accumulated near the soil surface deterred emergence. In fact, many hypocotyls were salt-burned, and lost cotyledon. Seedling emergence has improved when the second seeding method was used (open symbols, Fig. 2A). Only a few seedlings emerged from the silt loam when surface-irrigated, presumably because of soil crusting (data are not shown in Fig. 2A). In the loamy sand, seedlings of 'BR-1' began to appear seven days after seeding (Fig. 2B). Emergence from the surface-irrigated loamy sand was slower by several days as compared to the subirritated loamy sand (Fig. 2B). Soil temperature of surface-irrigated soils is usually lower than subirrigated soils.

Seedling emergence from the vermiculite and perlite mixture began day six or seven. Thereafter, the shoot length elongated rapidly (Table 3). Seedling roots have elongated longer than the shoot for the first two weeks, then became nearly equal or slightly less thereafter.

Table 3. Top and root lengths measured periodically for 35 days.

	Top Length[1]		Root Length[1]		Root/Shoot	
	BR - 1	Chaco	BR - 1	Chaco	BR - 1	Chaco
Days	---------------------cm-----------------------					
7	0.5	0.7	2.3	2.4	5.0	3.4
14	5.2	4.1	6.3	5.6	1.2	1.3
21	6.7	6.4	8.1	7.6	1.2	1.2
28	10.0	9.0	10.6	9.2	1.1	1.0
35	14.3	13.1	12.9	11.2	0.9	0.9

[1] - The CV of shoot and root length ranged from 5 to 10%.

Seedling Emergence: Seedlings from the second seeding method (capping) used in Harkey silt loam 1 and 2 were a few mm in length when the cap was removed eleven days after seeding. Stand counts increased rapidly in the subsequent 10 days (or 21 days after seeding), then reaching a plateau in about 30 days after seeding (Fig. 3A). Thereafter, stand counts steadily declined, especially in treatments 3 and 4, due to seedling mortality. The coefficient of variability in emergence from Harkey silt loam 1 and 2 ranged from 14 to 19%.

Seedling emergence from Bluepoint loamy sand began six or seven days after subirrigation (Fig. 3B), several days later under surface irrigation. Seedling emergence from Harkey silt loam 3 was also similar to that from the loamy sand (the data are not shown). Stand counts increased rapidly in the next 10 days (or 17 days after seeding). Thereafter, stand counts remained essentially unchanged.

Final emergence counts made 20 to 30 days after seeding declined with increasing salinity of irrigation water, except for the case of surface-irrigated loamy sand (Fig. 4). The final emergence from subirrigated cases ranged from 50 to near 80% at the lowest salinity of irrigation water, and 30 to 60% at the highest salinity. The major difference in emergence was associated with soil types or the initial soil salinity. The ANOVA has shown that the soil type, including the initial soil salinity, and the salinity treatment (1 through 4 of Table 2) had a highly significant effect on emergence in all cases subirrigated (Table 4). No significant effect of salinity treatment was observed in the surface-irrigated loamy sand. The cultivars tested also had a significant effect on emergence (Case II of Table 4).

Emergence from Harkey silt loam and Bluepoint loamy sand (BP) when subirrigated with the solutions with various Na/Ca or Cl/SO_4 ratios varied (Table 5). However, the ANOVA indicated that the treatments involving specific ions did not cause a significant effect on emergence, including the cases involving the gypsum application (Case III of Table 4). Therefore, no mean separation is indicated in Table 5.

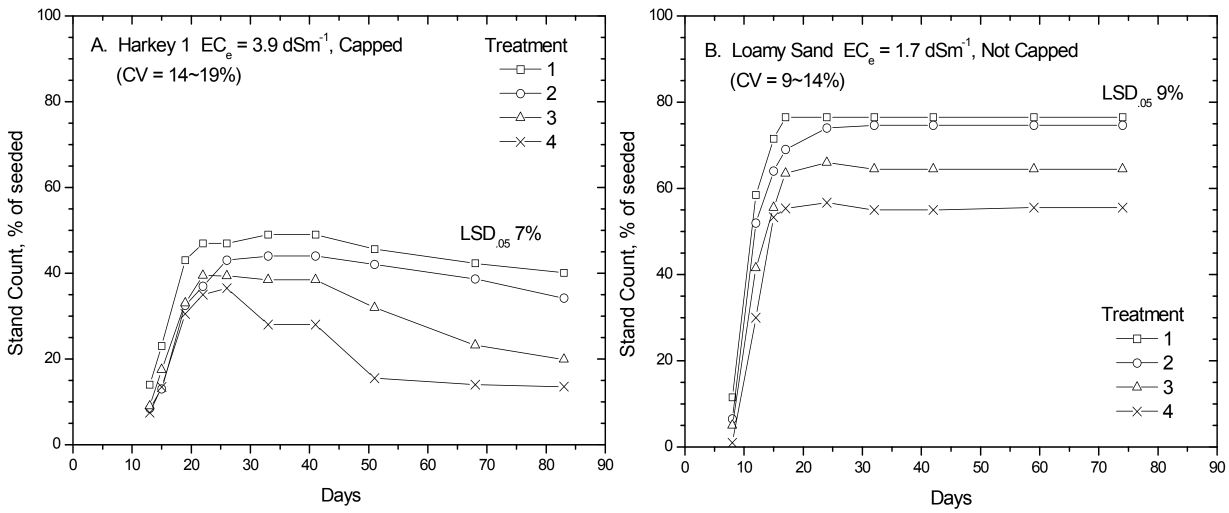

Fig. 3. Stand counts of onion cultivar BR-1 in subirrigated Harkey silt loam 1, and subirrigated Bluepoint loamy sand. For explanation of the treatment, refer to Table 2.

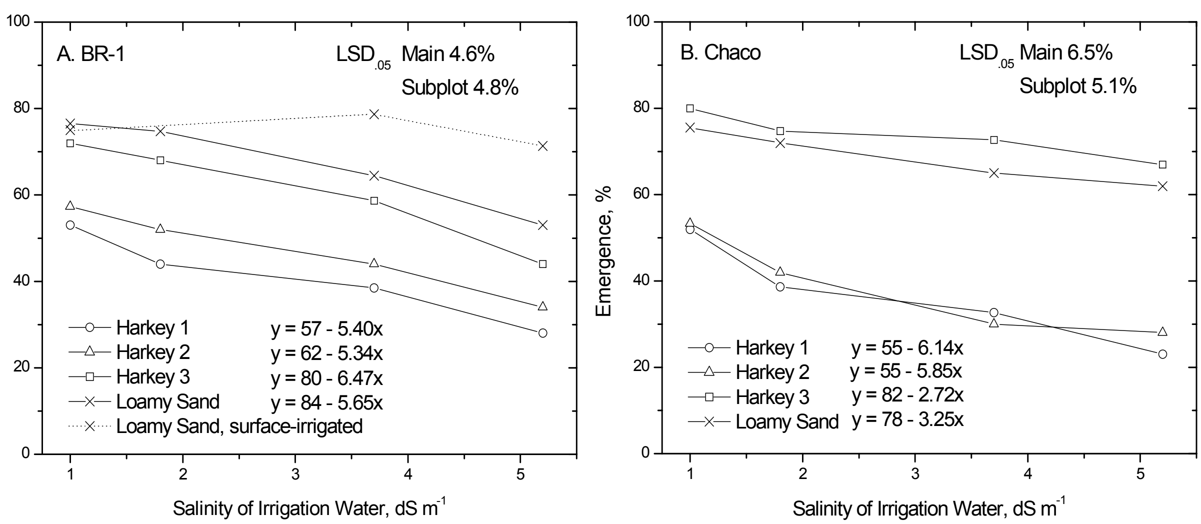

Fig. 4. Seedling emergence of two onion cultivars; BR – 1 (A), and Chaco (B) from four soils subirrigated with saline solutions. The dotted line in Fig. 4A is from surface-irrigated loamy sand.

Table 4. Analysis of variance (ANOVA) using a split plot layout; Emergence.

	Observed F Main	Observed F Sub	$LSD_{0.05}$ Main	$LSD_{0.05}$ Sub
			------ % -------	
I. Main (Soil Type), Sub (Water Salinity)				
BR-1	72**	41**	4.6	4.8
Chaco	87**	22**	6.5	5.1
II. Main (Cultivar), Sub (Water Salinity)				
Harkey 1	29*	26*	2.3	6.7
2	15*	12*	2.8	4.2
3	213**	46*	2.8	3.8
Loamy Sand	7	16*	5.6	8.6
III. Main (Soil Types), Sub (Specific Ions)				
Na/Ca				
BR-1	52**	3.9	2.7	5.4
Chaco	54**	2.0	7.7	4.5
Cl/SO_4				
BR-1	19*	2.2	13	14
Chaco	58**	0.3	9.8	8.3
Gypsum Added				
BR-1	63**	2.0	7.0	10.8
Chaco	61**	0.4	7.5	8.1

[1] - The required F values for the main and subplot shown are at a 5% level.

Table 5. Seedling emergence from subirrigated Harkey silt loam (HK1, HK2, HK3), Bluepoint loamy sand (BP), and surface-irrigated loamy sand.

	Trt	BR-1		Chaco		Trt	BR-1		Chaco	
	No.	HK 1	BP	HK 1	BP	No.	HK 2	HK 3	HK 2	HK 3
		-------------	%	-------------			-------------	%	-------------	
Na/Ca										
1:3	6[1]	47	60	27	74	6[1]	49	62	44	76
1:1	3	39	65	33	65	2	52	68	42	75
3:1	5	35	60	32	62	5	40	65	35	78
Cl/SO_4										
1:3	8	32	-	27	-	8	40	61	50	71
1:1	3	38	65	33	65	2	52	67	43	75
3:1	7	30	-	34	-	7	44	58	50	61
Na/CM Cl/SO_4										
1:1 1:1	2	44	75	39	76	2	52	68	42	75
1:3 1:3	9	31	-	26	-	9	39	68	39	66

[1] - Treatment numbers shown in Table 2.

Seedling Mortality: Seedling morality first appeared about 2 weeks after emergence, and continued for several months in Harkey silt loam 1 (Fig. 3). Morality was minimal in loamy sand, especially when surface-irrigated. Mortality rates, computed as the percentage of seedlings emerged, instead of the number of seeds sown, increased with increasing salinity of irrigation water (Fig. 5). Seedling mortality of the highest salt treatment in Harkey 1 appears to be lower than that from the adjacent treatment, but this observation had no statistical significance.

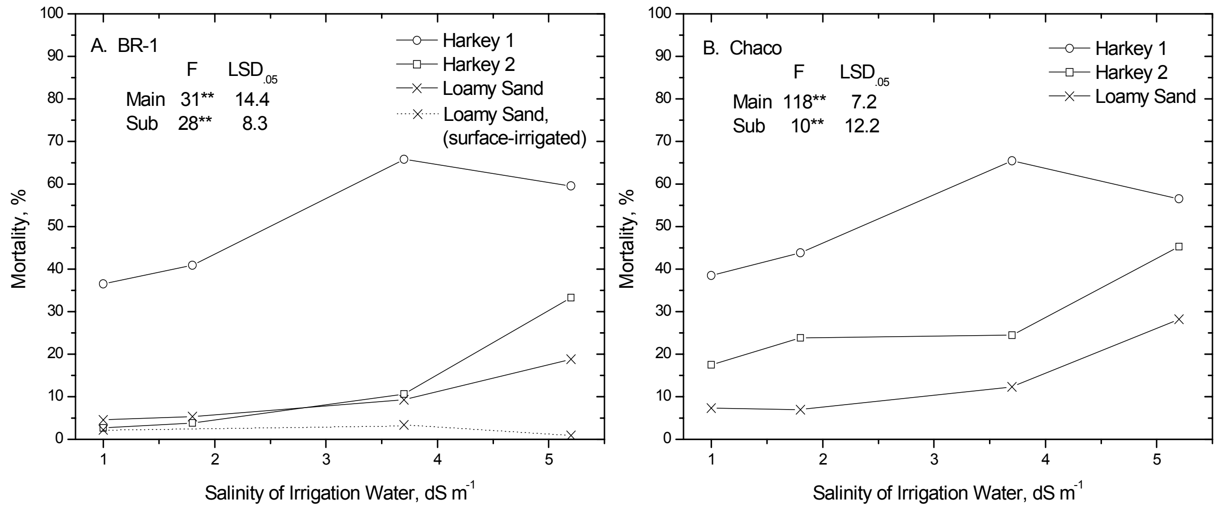

Fig. 5. Seedling mortality of BR-1 (A) and Chaco (B) in three soils subirrigated with saline solutions, and BR-1 surface-irrigated (dashed line, A).

Seedling Growth: At the conclusion of the experiment extending 4 ½ months after seeding, onion seedlings have grown on the average 35 cm tall under treatment 1, and 25 cm tall in treatment 4. Top dry weight per pots reduced significantly with the saline treatments (Fig. 6). The rate of top dry matter reduction ranged from 0.5 to 1.3 g/pot in 'BR-1', and in 'Chaco' 0.4 to 1.6 g/pot per unit increase in salinity of irrigation water (Fig. 6). The rate of the growth reduction was greater in 'Chaco'as indicated by the regression equation shown in the figure.

Seedling weights per pot decreased significantly with increasing Na to Ca + Mg ratio in onions grown in Bluepoint loamy sand, but not in Harkey silt loam subirrigated with saline solutions having salinity of 40 me L^{-1}(Table 6). This was, however, not a case in Harkey loam 2 subirrigated at 20 me L^{-1}(Table 6). The growth was affected by the Cl to SO_4 ratio and by the application of gypsum in Harkey silt loam 1, but not Harkey silt loam 2.

The reduction in top dry weight per pot can be a result of the decrease in seedling emergence or survival. The results presented in Fig. 7, however, indicate that dry weight per

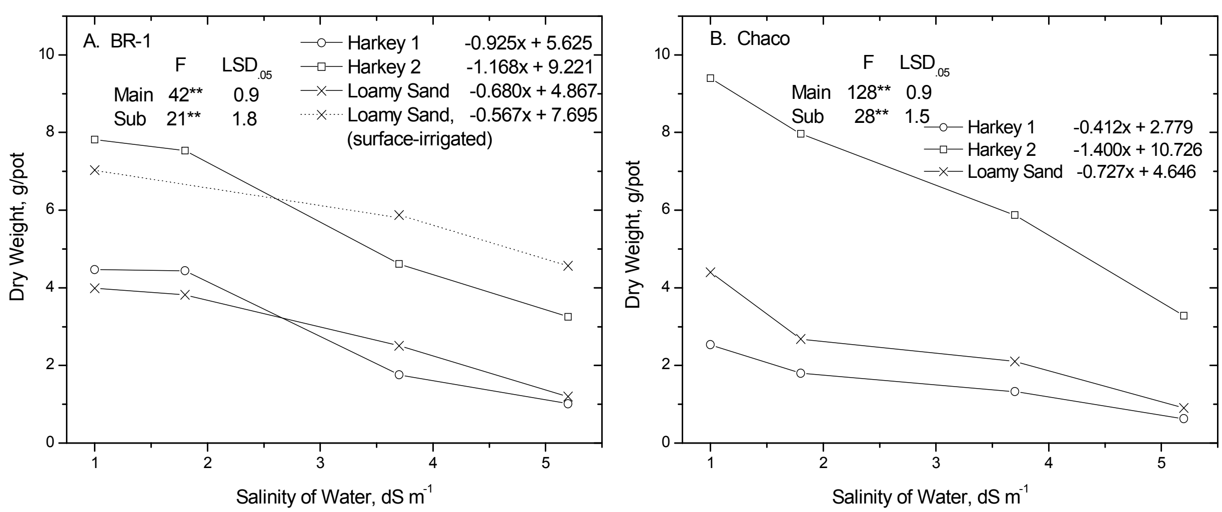

Fig. 6. Dry top weight per pot of two onion cultivars; BR-1 and Chaco from three subirrigated soils and surface-irrigated loamy sand (dotted line).

seedling has also decreased with increasing salinity. The rate of dry matter reduction per plant ranged from 0.17 g/dS m^{-1} in Bluepoint loamy sand to as large as 0.3 g/dS m^{-1} in Harkey silt loam 2.

The dry top weight of onions grown in Bluepoint loamy sand was substantially lower than that from Harkey 2 soil (Fig. 6), even though seedling emergence was similar to that from Harkey 2 soil (Fig. 4). Recall that the initial soil salinity of the loamy sand (1.2 dS m^{-1}) was lower than that of Harkey 2 soil (2.2 dS m^{-1}). However, we used the second seedling method on Harkey 1 and 2 soil but not on Bluepoint silt loam. It is likely that soil salinity of Harkey 2 soil was actually lower than that of the loamy sand after decapping. Additionally, salinity of soil solution in the loamy sand would have been higher than in Harkey 2 soil, because of low water retention capacity (Table 1). This is especially true when subirrigated. It is also possible that soil nutrient levels of the loamy sand, especially micronutrients, such as Zn, were lower than those of Harkey silt loam, and may have affected seedling growth.

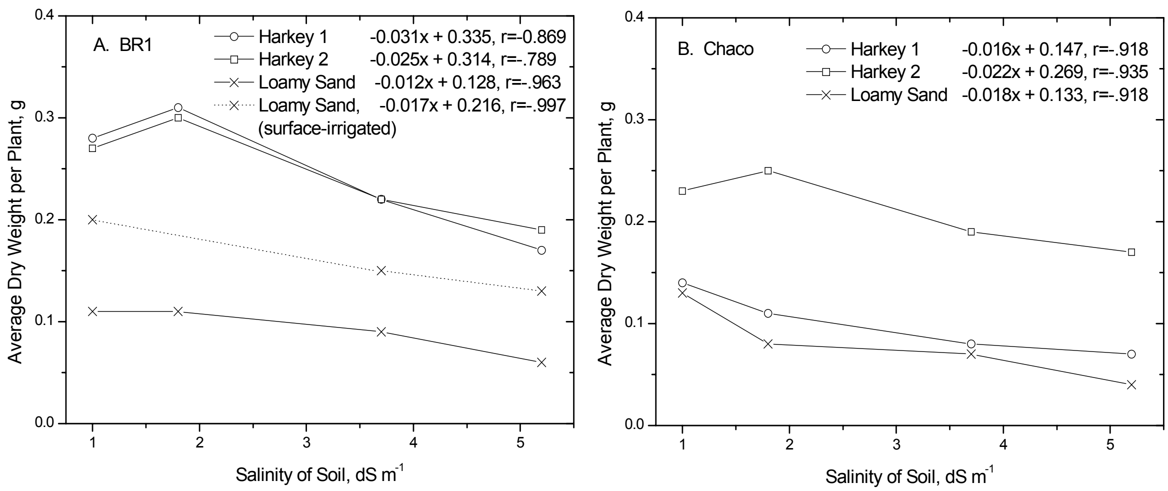

Fig. 7. Dry top weight per seedling of two onion cultivars; BR-1 and Chaco from three subirrigated soils and surface-irrigated loamy sand (dotted line).

Table 6. Analysis of variance (ANOVA) using a split plot layout; Seedling growth.

	Observed F		$LSD_{.05}$			Observed F		$LSD_{.05}$	
			Main	Sub				Main	Sub
	Main	Sub	------- % -------			Main	Sub	------- % -------	
I. Main (Soil Types), Sub (Water Salinity)					II. Main (Cultivars), Sub (Ion Composition)				
BR-1	42**	21**	0.89	1.80	Na/Ca at Cl:SO4 = 1:1				
Chaco	28**	28**	0.93	1.52	Harkey 1	0.5	2.0	0.5	0.77
					Harkey 2	2.7	0.9	3.23	2.13
					Bluepoint	0.4	4.3	0.47	1.26
					Cl/SO_4 at Na: (Ca+Mg) = 1:1				
					Harkey 1	14.0	20**	0.35	0.52
					Harkey 2	1.0	1.4	3.08	3.43
					Gypsum addition to Solution 2				
					Harkey 1	33**	10.7*	1.0	1.28
					Harkey 2	3.5	4.4	2.2	2.67

Table 7. Plant top dry weight of onions (BR-1 and Chaco) in Harkey silt loam (HK1), and Bluepoint loamy sand (BP) subirrigated at salinity of 40 ml L^{-1}, and in Harkey 2 (HK2) subirrigated at 20 ml L^{-1}

	Trt No.	HK1 BR-1	HK1 Chaco	Bluepoint BR-1	Bluepoint Chaco	Trt No.	HK2 BR-1	HK2 Chaco
		g/pot					g/pot	
Na (Ca+Mg)								
1:3	6	1.6	1.7	3.0a	3.4a	6	7.2	8.0
1:1	3	1.7	1.3	2.5ab	2.4ab	2	7.5	7.9
3:1	5	1.9	1.8	1.9b	1.8b	5	5.6	8.2
Cl/SO_4 at Na: Ca+Mg = 1:1								
1:3	8	2.3a	1.8a	-	-	8	6.8	8.1
1:1	3	1.7b	1.3b	-	-	2	7.5	7.9
3:1	7	1.0c	1.0c	-	-	7	5.8	6.3
Na/CM Cl/SO_4								
1:1 1:1	2	4.4a	1.84a	-	-	2	7.5	8.0
1:3 1:3	9	1.2b	1.1a	-	-	9	5.4	7.0

[1]-Apply to Harkey (low salt)

Dry root weight of onions was found to be linearly related to dry shoot weights (Fig. 8). The data came from subirrigated loamy sand, and the numbers in the figure correspond to the solution number in Table 2. The root weight of 'Chaco' was nearly twice that of 'BR-1,' mainly because of earlier bulb development.

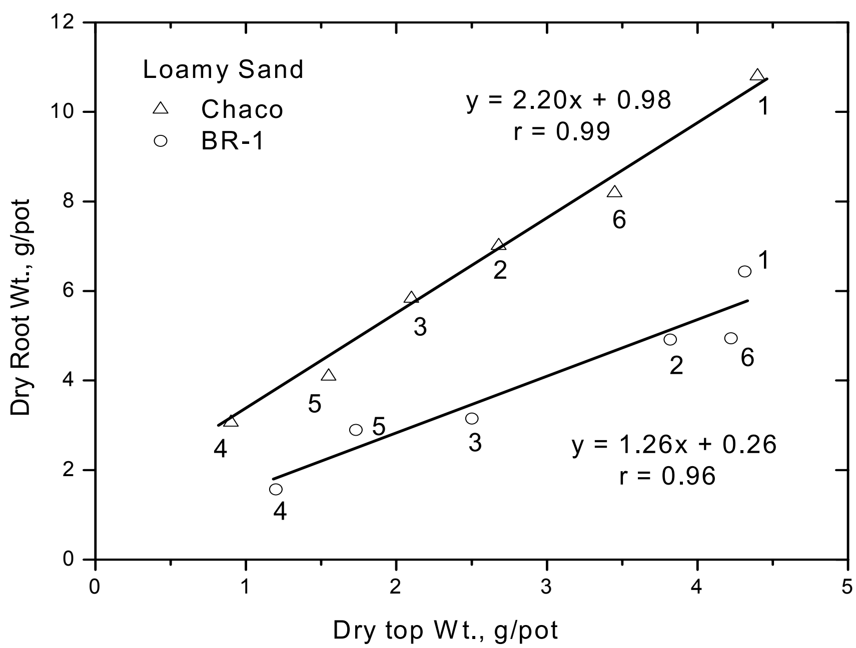

Fig. 8. The relationship between the dry top weight and the dry root weight of two onion cultivars: BR-1 and Chaco grown in subirrigated loamy sand.

Tissue Ion Concentration: The concentration of Na and Cl measured in the top dry matter of onions grown in Harkey silt loam 1 increased with increasing salinity of the irrigation solutions (Fig. 9). The concentration of Ca, however, changed little or decreased somewhat with increasing salinity. There was a significant difference in the Na concentration between 'BR-1' and 'Chaco' (Case I of Table 8). The ion concentration data from Bluepoint loamy sand were similar, except for Cl which was significantly less in Bluepoint loamy sand which had lower initial soil Cl content. Irrigation with the solutions having increasing Na to Ca + Mg ratios resulted in a significant increase in the Na concentration in the top dry matter, while Ca concentration remained unchanged or slightly decreased both in 'BR-1' and 'Chaco' (Tables 9). Increasing the Na to Ca + Mg ratio in irrigation water also resulted in a slight increase in leaf Cl concentration (Table 9), although the Cl concentration of irrigating water was identical (Table 2). Increasing Cl to SO_4 ratios resulted in a significant increase in tissue Cl concentration (Table 8 and 9).

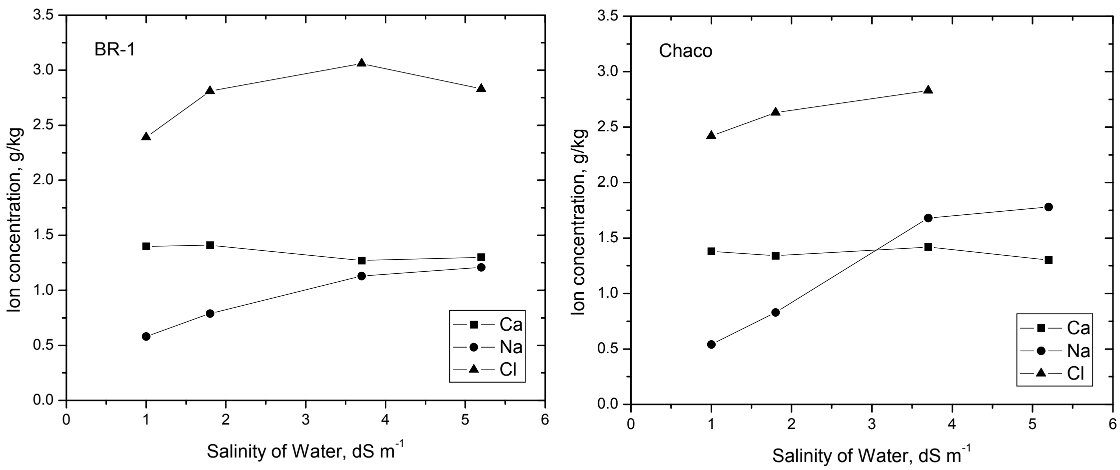

Fig. 9. Ion contents of the top dry matter: subirrigated Harkey silt loam 1 as related to salinity of irrigation water. (Some Cl data are missing due to insufficient samples).

Table 8. Analysis of variance (ANOVA) using a split plot layout; Ion concentration.

		Observed F		$LSD_{.05}$ Main	$LSD_{.05}$ Sub		Observed F		$LSD_{.05}$ Main	$LSD_{.05}$ Sub
		Main	Sub	------ % -------			Main	Sub	------ % -------	
I. Main (Cultivar), Subplot (Water Salinity)						II. Main (Cultivar), Subplot (Specific Ion)				
HK1	Na	82**	98**	0.08	0.2	Na (Ca + Mg)				
	Cl	19**	186**	0.27	0.25	Na	82**	98**	0.08	0.21
						Cl	60**	186**	0.17	0.15
						Cl/SO_4				
						Na	0.8	2.2	0.48	0.41
						Cl	16.7	363**	0.28	0.24
						Gypsum application				
						Ca	0.1	16*	0.30	0.23
						Na	3.8	38*	0.08	0.10
						Cl	1.0	7.4	0.42	0.49

Table 9. Sodium (Na) and Chloride (Cl) concentrations of top dry matter as affected by ionic ratios of irrigation solutions in Harkey silt loam 1 (HK1) and Bluepoint loamy sand (BP).

	Sodium (Na)				Chloride (Cl)			
	Trt	HK1		BP	Trt	HK1		BP
	No.	BR-1	Chaco	BR-1	No.	BR-1	Chaco	BR-1
Na/(Ca + Mg)		------------- % -------------				------------- % -------------		
1:3	6	1.6a	0.95a	0.59a	6	2.6a	2.4a	2.0
1:1	3	1.1b	1.3b	1.5b	3	3.0b	2.6ab	2.1
3:1	5	1.7a	1.6c	3.3c	5	3.1b	2.8b	2.3
Cl/SO4								
1:3	8	1.1	1.0	-	8	2.5	2.1	-
1:1	3	1.1	1.3	-	3	3.0	2.8	-
3:1	7	1.1	1.2	-	7	3.5	3.3	-
Na/Cl Cl/SO4								
1:1 1:1	2	0.7a	0.83a	-	2	2.8	2.6	-
1:1 1:3	9	0.6b	0.58b	-	9	2.3	2.4	-

1/ The numbers in columns followed by the same letter are not statistically different

The ion concentrations in the roots were highly correlated with that of the top dry matter (Fig. 10). The roots retained more Ca and, to a lesser extent, Na than did the top. The concentration of Cl ions in the top was higher than that in the roots, until the Cl concentrations in the irrigation water decreased to appropriately 10 me L^{-1} (Fig. 10).

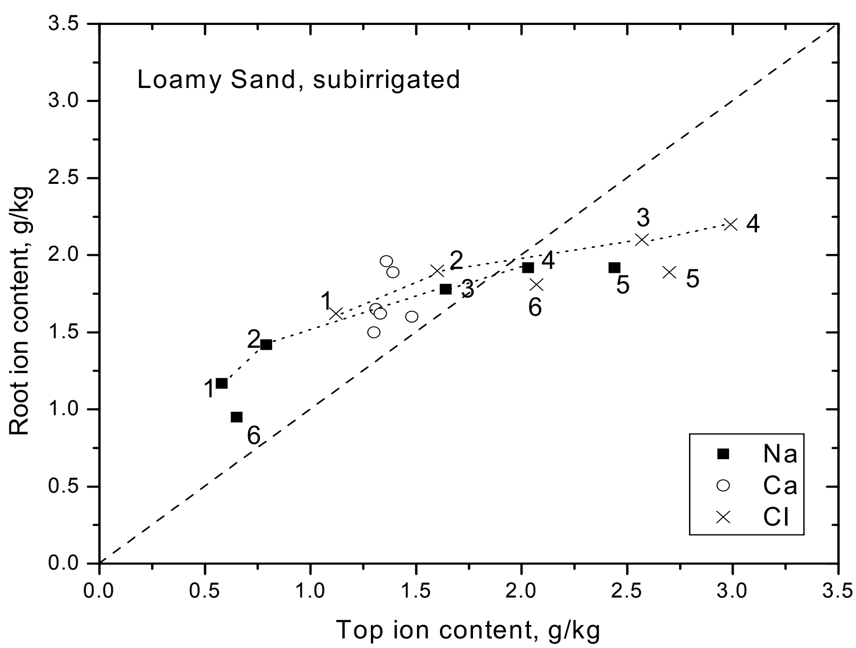

Fig. 10. The relationship between the top ion concentration and the root ion concentration in BR-1 grown in Bluepoint loamy sand.

DISCUSSION

The median monthly flow of the River entering El Paso was previously estimated to be 11.7 Mm^3/mo (9500 acre-ft/mo) during October and November (Riley et al., 2005). Salinity of the incoming streamflow at 5 and 10 Mm^3/mo was estimated to be 2.5 and 2.0 dS m^{-1} or 1850 and 1500 mg L^{-1}, respectively (Miyamoto, 2008). The Na to Ca + Mg, and the Cl to SO_4 ratios in chemical equivalent unit were also estimated at 1.8 and 0.77 at 5 Mm^3/mo, and 1.6 and 0.78 at 10 Mm^3/mo (Miyamoto, 2008). The increase in salinity of the irrigation water was estimated to be about 16% when the concentrate from the nanofiltration process of 10 MGD is to be discharged to the streamflow of 5 Mm^3/mo. The Na to Ca + Mg and the Cl to SO_4 ratios are projected to shift to 1.6 and 0.63, respectively (Miyamoto, 2008). The question raised was if any of these changes may affect onion production, an important industry for the El Paso Valley.

The data obtained in this study indicate that crop establishment and growth of onions are influenced by various soil-related factors and management practices, besides saline water quality. In other words, the impact of concentrate discharge into irrigation water on onion production can not be assessed unless soil-related factors and management practices are specified for each of the crop development stages.

Potential Impacts on Seedling Emergence and Mortality: If onions are to be grown in loamy sand under sprinkler irrigation, the impact of the projected changes in salinity on emergence is likely to be minimal, if any (e.g., Fig, 4 and Table 5), although seedling mortality could increase somewhat when salinity of irrigation water exceeds about 3 dS m^{-1} (Fig. 5). Recall that salinity of the streamflow at 5 Mm^3/mo was estimated to be 2.5 dS m^{-1}. This can increase to 2.9 dS m^{-1} when the 16% increase is incorporated. This level of increase appears not to cause any significant reductions in seedling emergence or survival in loamy sand or possibly sandy soils irrigated with sprinklers, which help leach salts from the seeding zone.

The reality of onion production in the El Paso Valley involves furrow-irrigation of alluvial soils, most of which has soil textures finer than Harkey silt loam used for the present study (Miyamoto, 2000). Even if growers are to use potable sprinklers for crop establishment, onion seedlings might experience difficulties of emerging through soil crust as observed in the surface-irrigated Harkey silt loam during the preliminary experiment. If furrow methods are used, soluble salts will be pushed towards the soil surface, and the salts accumulated at the ridge have to be removed during the bed reshaping process. Even such a procedure is implemented, the initial salinity of the soil is likely to affect soil salinity of the seed zone (Fig. 1), consequently seedling emergence (Fig. 2, and 3; Table 5) as well as seedling survival (Fig. 5). Since seedling emergence appears to decrease almost linearly with increasing salinity of irrigation water (e.g. Fig 4), an increase in salinity associated with the addition of the concentrate needs to be viewed as negative.

The changes in Na/(Ca + Mg) or Cl/SO_4 ratios do not seem to have significant impacts on seedling emergence (Table 5). In fact, there was a tendency to reduce seedling emergence when Ca and SO_4 ions were added to Solution 2 at a rate of 20 me L^{-1}. This result is against the notion that gypsum application usually helps improve crop production in saline areas. Onion crops seem to be among the exception because of its low resistance to salinity. The disposal of nanofiltration concentrate to irrigation water is unlikely to be beneficial for seedling emergence, even when the concentrate contains only Ca and SO_4 ions, but not Na or Cl.

One practical way to increase seedling emergence and survival is to have low initial soil salinity as much as possible (Fig. 4). Under the prevailing cropping pattern involving cotton, it is not easy to have low soil salinity. Cotton is salt-tolerant crop and tolerates easily soil salinity of 3.9 dS m^{-1}, the highest soil salinity of the soil samples we collected. For onion production, however, the threshold soil salinity for emergence appears to be less than 2.2 dS m^{-1}, and preferably as low as 1.2 dS m^{-1}. Therefore, it would be advisable to leach the salts prior to planting onion crop. Alternatively, wheat or other small grain crops can be planted without crop beds so as to achieve salt leaching prior to onion crops. Some onion growers indicate that disking of green manure (soybeans) grown in low profile beds seems to help onion crops. This practice may help leaching salts, and possibly reduces evaporation which brings salts onto the crop beds.

Potential Impacts on Seedling Growth: Seedling growth of onions was reduced significantly with increasing salinity of irrigation solutions (Fig 6). Seedling weight of individual plant was also reduced with increasing salinity, especially in cultivar 'Chaco.' The threshold salinity of irrigation water for seedling growth appears to be no more than 1.8 dS m^{-1} in 'BR-1,' and somewhat less for 'Chaco.' The present data are in agreement with the earlier studies; onion bulb growth declines when soil salinity exceeds about 1.2 dS m^{-1}(Bernstein and Ayer, 1953), or at salinity of irrigation solution as low as 2.0 dS m^{-1} (Wannamoker and Pike, 1987).

It was hoped at the onset of this study that the reduction in seedling growth caused by salinity can be offset by lowering Cl to SO_4 ratios or even Na to Ca + Mg ratios of irrigation water with a presumption that onions are sensitive to Cl, and possibly to Na. The results shown in Table 6 indicate that dry weights were controlled largely by soil types, but not by the changes in ionic composition. There were two minor exceptions; seedling growth increased with lowering Cl/SO_4 ratios in Harkey silt loam 1; and seedling growth response to Ca and SO_4 addition in Harkey silt loam 1 (Table 6 and 7). In reality, however, the changes in Cl/SO_4 ratio is narrow than the tested range. As far as the gypsum application is concerned, it did not yield a positive result. It should also be noted that under lower salinity of irrigation water used in Harkey silt loam 2, there was no significant impact of lowering Cl to SO_4 ratios on seedling growth.

The tissue analysis data indicate that both Cl and Na have accumulated in the plant top (Fig. 9), and these observations are highly significant in terms of statistical confidence (Table 8). It is a matter of speculation if Cl was toxic to the plants or Na was. The data shown in Fig. 10, however, indicate that Na can be retained somewhat in the root system when the Na concentration in irrigation water is less than about 20 me L^{-1}. The data set also indicates that Cl ions are readily transported to the top to a greater extent than Na. The data shown in Table 8 and 9 also indicate that an increase in Na/(Ca + Mg) ratio in irrigation solutions resulted in increased Cl uptake, even though the Cl concentration was kept at the same level. The reverse did not occur with increasing Cl to SO_4 ratios. It would be reasonable to conclude that Cl tends to accumulate more so than Na in plant tops of onions. However, its adverse effects on growth seem to occur after the osmotic stress reduced seedling growth first.

Some crops develop extensive root systems when subjected to high salinity or the osmotic stress. This response pattern is similar to the case against water stress, and is especially important to onion crops. After all, growers harvest bulbs, but not above-ground biomass. The data shown in Table 3 and Fig. 8 indicate that the observation of above-ground growth is a good indicator of below-ground growth, at least during the seedling stage in sandy soils. Increased osmotic stress does not alter the growth ratio between the top and the roots. However, there seems to be a considerable difference in the top to root ratio between ‘Chaco’ and ‘BR-1’ (Fig.8). This is obviously a reflection of genetic traits. Salt tolerance of onion cultivars grown today is similar to ‘BR-1’ (Miyamoto, 1989), although this may change with future breeding efforts.

One of the methods currently used by onion growers is to seed onions at a higher rate so as to compensate for the reduction in seedling emergence and growth rate. In other words, smaller onions can yield adequately if planted at high density. In reality, this strategy seems to lead to onion sizes which are highly variable depending on salinity status within a given field. Overall yields and uniformity of onion crops are reduced when certain spots or areas are salt-affected. Soil salinity is highly spatially variable within a furrow-irrigated field (Miyamoto and Cruz, 1987). Increasing salinity of irrigation water is unlikely to lower soil salinity and spatial variability, thus limiting onion yields, even under high planting density.

General Comments: This study has shown that onion crop establishment is controlled largely by soil types, including initial soil salinity, management practices, salinity of irrigation water, rather than ionic composition. This finding implies that there would be little difference in impact between NF and RO concentrate, as far as onion crop establishment is concerned. This may also apply to alfalfa of which growth had been reported be a function of salinity, but not ionic composition (Soltanpour et al. 1999). A practical question then became what size of the treatment plant is appropriate for minimizing the salinity impact. This question can not be answered by agronomic consideration alone.

REFERENCES

Bernstein, L. and A.D. Ayers, 1953. Salt tolerance of five varieties of onions. Proc. Amer. Soc. Hort. Sci. 62, 367.

Hills, F.J., Little, T.M., 1972. Statistical Methods in Agricultural Research. Hills, F.J., Little, T.M., University of California.

Maas, E.V., 1990. Crop Salt Tolerance in Agricultural Salinity Assessment and Management. ASCE Manuals & Reports on Engineering Practice No. 71:262-304. K, Tanji (Ed).

Miyamoto, S., 2008. Potential impacts of desalination concentrate on salinity of irrigation water; A case study in the El Paso Valley. Texas Water Resources Institute. Technical Report, 314. College Station, Texas.

Miyamoto, S., 2000. Soil Resources of El Paso: Characteristics, Distribution and Management Guidelines. Texas A&M University, Agrilife Research Center at El Paso.

Miyamoto, S., 1989. Salt effects on germination, emergence, and seedling mortality of onion. Agron. J. 81:202-207.

Miyamoto, S., and I. Cruz. 1987. Spatial variability of soil salinity in furrow-irrigated Torrifluvents. Soil Sci. Soc. Am. J. 51:1019-1025.

Miyamoto, S., G.R. Gobran, and K. Piela, 1985. Salt effects on seedling growth and ion uptake of three pecan rootstock cultivars. Agron. J. 77: 383-388.

Rao, T.S., Page, A.L., and N.T. Coleman, 1968. The influence of ionic strength and ion-pair formation between alkali-earth metals and sulfate on Na-divalent cation exchange equilibria. Soil Sci. Soc. Amer. Proc. 32:639-643.

Riley, R.T., 2005. Treatment of nonirrigation water at the Canal Street Water Treatment Plant. Thesis presented at the University of Texas at El Paso.

Rhoades, J.D. and S. Miyamoto. 1990. Testing soils for salinity and sodicity. In: R.L. Westerman (ed.), "Soil Testing & Plant Analysis, 3rd ed." Soil Sci. Soc. of Am. Madison, WI. Ch. 12, 299-336.

Soltanpour, P.N., Al-Wardy, M.M., Ippolito, J.A., Rodriguez, J.B., Self, J., Gillaume, M., and D. Mathews, 1999. Chloride versus sulfate salinity effects on alfalfa shoot growth and ionic balance. Soil Sci. Soc. Am. J. 63:111-116.

Turner, C.D., Walton, J.C., Bermea, E.A., and M. Quezada, 2002. Salinity and TOC removal using nanofiltration. The University of Texas at El Paso. Water Treatment Technology Program Report No. 46.

U.S. Environmental Protection Agency. 1983. Methods of Chemical Analysis of Water and Wastes (EPS-600/4-79-020). U.S. Gov. Print. Office, Washington, DC.

Wannamaker, M., and L.M. Pike, 1987. Onion responses to various salinity levels. J. Amer. Soc. Hort. Sci. 112(1):49-52.