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Salinity and specific ion effects on onion establishment in relation to disposal of desalting concentrates

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ABSTRACT

Concentrate from nanofiltration (NF) is usually enriched with divalent ions, and low in proportions of monovalent ions. Therefore, its disposal to irrigation water may not be deleterious, especially for growing crops susceptible to specific effects of Na and/or Cl. This possibility was examined in a greenhouse by observing effects of four levels of salinity and ion composition of irrigation solutions on seedling emergence and growth of onions (sensitive to Cl ions) in loamy sand and silt loam. Seedling emergence from surface-irrigated loamy sand was excellent, regardless of the saline solutions used. In subirrigated silt loam, however, seedling emergence was reduced by increasing initial soil salinity and salinity of irrigation solutions, but not by the ion composition. Seedling growth was reduced by increasing Cl to SO_4 ratio only when the Cl concentration of irrigation solutions exceeded a concentration between 10 and 20 me L^{-1}. The Cl effect seems to appear after seedling growth is first reduced by salinity. The addition of Ca and SO_4 to the irrigation solution reduced seedling growth. The disposal of NF concentrates into irrigation water, and associated impacts on establishment of crops sensitive to osmotic stress should be evaluated mainly by considering an increase in salinity, soil types, and cultural practices.

Keywords: Concentrate disposal; Desalting; Irrigation; Nanofiltration; Onion; Salinity

1. Introduction

With increasing desalinization activities, disposal of concentrate from membrane processes is becoming a significant issue [1]. Two types of membrane processes are commonly used; nanofiltration (NF) and reverse osmosis (RO). The membranes used for NF usually reject divalent ions (such as Ca, Mg and SO4), while letting monovalent ions (such as Na and Cl) to pass through. The membranes used for RO reject essentially all ions, and are typically operated at a higher pressure than that for NF processes. Since NF membranes reject divalent ions, concentrates from NF are enriched with divalent ions, and lower in proportion of monovalent ions as compared to RO concentrates. Divalent ions are usually less hazardous than monovalent ions to soils and plants, thus some suggest that NF concentrates can be added to irrigation water with little hazard or even with some benefits as the sodium adsorption ratio (SAR) can decrease [2]. If so, it offers a simple and cost-effective way of disposing NF concentrates.

A recent review of concentrate composition, however, shows that the SAR of NF concentrates is rarely lower than that of the feed water [3]. Some examples are shown in Table 1. In the municipal effluent reported by Chang et al. [4], and the Rio Grande return flow tested by Riley [5], the SAR of the NF concentrate was only slightly lower than that of the feed water, although it was significantly lower than that of RO concentrates. In the situations involving groundwater and the Rio Grande River, the SAR of the concentrate from the NF process was actually greater than that of feed water [2,6]. These

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increases in SAR are caused by the concentration effect, e.g., SAR increases with increasing ionic concentration, even when Na to (Ca+Mg) ratios remains unchanged. These elevated SAR values shift towards the SAR of dilution water when blended [3].

The main change in concentrate quality is a decrease in Cl to SO_4 and Na to (Ca + Mg) ratios, although this also varies with membrane type as well as the ionic composition of feed water [3]. In the examples listed in Table 1, the Na to (Ca + Mg) ratio of NF concentrate from the Rio Grande return flow [5] decreased from 1.47 to 0.65. Likewise, the Cl to SO_4 ratio of the municipal effluent studied by Chang et al. [4] decreased from 2.28 to 0.85. Salinity of irrigation water will inevitably increase upon application of NF concentrates to irrigation water stream. Therefore, disposal of NF concentrates to irrigation water seems to have a merit only if these changes in ionic composition can offset the adverse impact of increasing osmotic stress. We found no literature addressing this topic.

This study was conducted to test the above possibility using onions as a test crop. Onions are susceptible to specific effects of Cl ions [7], and are grown widely using winter irrigation return flow or groundwater with moderate salinity of 750 to 1500 mg L^{-1} in the Rio Grande Basin. According to local growers, crop establishment is a critical phase for growing onions with return flow. Likewise to many other vegetable crops, seedling emergence and growth of onions can be reduced as soluble salts accumulate in crop bed. According to a greenhouse study, onion seed can germinate in saline solutions with an electrical conductivity (EC) as high as 27 dS m^{-1}, but seedling emergence

Table 1
Feed water quality, reported rejection rates, and the estimated concentrate quality at a recovery rate of 80% (Miyamoto, 2008).

	TDS	Na	Ca	Mg	HCO_3	Cl	SO_4	SAR	Na/ Ca + Mg	Cl/SO_4
	mg L^{-1}	me L^{-1}								
Mulford, et al. [6][1]: groundwater, nanofilter, NF 70										
Feed water	483	1.24	5.40	0.63	1.62	1.52	3.87	0.71	0.21	0.39
Rejectiom Rate (%)		(40)	(85)	(90)	(82)	(56)	(99)			
Concentrate	2030	3.2	23.8	3	5.6	4.9	19.2	0.88	0.12	0.26
Chang, et al. [4][1] : Municipal effiuent, Nonomax 50										
Feed water	416	2.40	1.1	2.6	3.10	2.1	0.92	1.76	0.6	2.28
Rejection Rate (%)		(12)	(88)	(89)	(74)	(20)	(97)			
Concentrate	1427	3.55	4.88	12.04	12.12	3.85	4.49	1.22	0.2	0.85
Chang, et al. [4][1] : Municipal effluent, RO membrane, Nanomax 95										
Feed water	416	2.40	1.1	2.6	3.10	2.1	0.92	1.76	0.65	2.28
Rejection Rate (%)		(96)	(98)	(99)	(98)	(98)	(99)			
Riley [13][1] : Riverwater, Nanofilter, E4-2200- DLX by Osmonics										
Feed water	815	7.10	3.18	1.64	(3.62)	4.10	4.20	4.57	1.47	0.98
Rejection Rate (%)		(24)	(89)	(78)	(33)	(6)	(91)	-		
Concentrate	2330	13.9	41.5	6.7	8.4	5	19.5	4.26	0.65	0.26
Turner, et al. [2][1] : Riverwater, Nanofiltration 2540 ESNA Hydranautics										
Feed water	710	5.70	2.32	1.16	(2.57)	3.00	4.79	3.69	1.64	0.63
Rejection Rate (%)		(76)	(92)	(90)	(87)	(63)	(94)			
Concentrate	3110	23	16.8	5.34	11.5	10.5	22.8	6.9	1.4	0.46

TDS and SAR denote the total dissolved salts and the sodium adsorption ratio, respectively.

[1]correspond to the reference number.

Salinity of NF concentrates shown is lower that of RO concentrates at an assumed recovery rate of 80%. This feature can be misleading as the volume of NF concentrates involved is usually greater than that of RO concentrates for producing the same amount of product water after blending (Miyamoto 2008). The effect of ionic composition on plants will be discussed at equal salinity levels between NF and RO concentrates.

under subirrigation can be reduced at irrigation water EC of 4.9 dS m^{-1} in loamy sand initially free of salts [8]. The use of sprinklers can reduce salt accumulation in crop beds, but soil surface crusting can impair seedling emergence of onions which have hooked hypocotyl. The pioneer work of Bernstein and Ayers [9] indicate that growth of onion bulbs may be reduced starting at soil salinity of 1.2 dS m^{-1} (measured in the soil saturation extract and is designated as EC_e), and may result in a 50% reduction in bulb weight at EC_e of 4.1 dS m^{-1}. A more recent study [10] indicate that seedling growth of onions is reduced significantly at EC of culture solutions as low as 2 dS m^{-1} in a sand culture experiment. The solutions used for both experiments contained NaCl and $CaCl_2$, but not SO_4 salts.

This study evaluated the effect of salinity and ionic composition on seedling emergence, growth and ion uptake of two onion cultivars. Following the cultural practices of growing onions in the Southwestern US, 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 used to discuss the potential impacts of concentrate disposal into irrigation water.

2. Materials and Methods

Two commercial onion cultivars were used: NuMex BR-1 (hereafter referred to as 'BR-1') and NuMex Chaco (hereafter referred to as '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', while others observed no difference.

Two soil types were used—Harkey silt loam (calcareous, typic Torrifluvent) and Bluepoint loamy sand (calcareous, Torripsamment). Harkey silt loam, which is sandier than most alluvial soils of the Rio Grande Valley, was collected from the A_p horizon of a field planted with cotton in previous years at two locations. These samples are numbered 1 and 2, respectively (Table 2). In addition, the third soil sample, designated as Harkey silt loam 3, was used after leaching a check-in basin with tap water in order to have a soil sample with low salinity. These samples were air-dried, crushed, and passed through a 4-mm screen. All samples were analyzed for salinity and ionic composition [11]. Soil salinity (EC_e) of these samples ranged from 0.7 to 3.9 dS m^{-1} with the SAR of 0.7 to 6.1 in the saturation extract (Table 2).

Saline solutions used were prepared by adding various salts to deionized water (Table 3). The first four solutions had salinity levels of 10, 20, 30 and 40 me L^{-1} (1.0, 1.8, 3.7, and 5.2. dS m^{-1}), while the Na to (Ca+Mg) or the Cl to SO_4 ratio was maintained at a 1:1 ratio in chemical equivalent unit. 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 or 40 me L^{-1} (Table 3). The high salinity level (40 me L^{-1}) was used for Harkey 1 soil and Bluepoint loamy sand, and the lower salinity (20 me L^{-1}) for Harkey 2 and 3 soils. Solution 9 was prepared by adding $CaSO_4$ at 10 or 20 me L^{-1} to 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 at three weeks after planting.

2.1. Soil column experiment

A soil column experiment was conducted for determining the vertical distribution of soil salinity and moisture upon subirrigation. The soil samples were placed in duplicates in PVC pipes (5.2 cm ID) to a depth of 18 cm at bulk densities of 1.32 kg L^{-1} for silt loam and 1.38 kg L^{-1} for loamy sand. They were subirrigated once with solution 1. Soil samples were taken one week after subirrigation from various soil depths, and were analyzed for soil moisture and salinity of the saturation extract [11].

Table 2
Salinity and ion composition of soil samples used for the experiment.

Soil Type		SWC	EC_e	Na	Ca	Mg	Cl	SO_4	SAR
		kg kg^{1}	dS m^{-1}	----------------------		me L^{-1}	---------------------------------		
Harkey slit Loam (Typic Torrifluvent)									
	1.	0.39	3.9	21.0	17.4	6.0	19.0	24.3	6.1
	2.	0.39	2.2	12.6	8.2	2.7	10.1	12.6	5.4
	3.	0.39	0.6	0.9	2.5	0.9	0.4	4.2	0.7
Blue point Loamy Sand (Torripsament)									
		0.20	1. 2	0.8	8.2	1.8	4.4	2.7	0.4

SWC and ECe are the saturation water content of the saturated soil paste and the electrical conductivity of the saturation extract.

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

Trt[3]	EC	Salinity	Na:CM	Cl:SO_4	SAR	Na	CM[1]	Cl	SO_4
	dS m^{-1}	me L^{-1}				---------------------me L^{-1}			------------------------
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)[2]	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 at 1:1 ratio.
[2]Used in Harkey loam 2 and 3.
[3]Corresponds to treatment number.

2.2. Seedling emergence and growth experiments

Seedling emergence and growth were measured using the three soil samples 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 where water evaporation rates were determined to be spatially equal. For a preliminary experiment, the seed (50 seed per pot) was placed on a smooth soil surface, covered with the soils to a depth of 0.5 cm, and irrigated with solution 1. The pots were then subirrigated overnight by placing them in a shallow pan of solution 1. Seedlings emerged well from the loamy sand, but not from Harkey 1 and 2 soils. In the second attempt, we placed a layer of fiberglass screen over the seeded pots, and an additional 2 cm layer of the soil was placed over it. The pots were subirrigated as above, and the top 2 cm layer of the soil was removed by lifting the fiberglass screen after sub-irrigation, but prior to emergence. This seeding method, hereafter referred to as the second method, may represent removal of salt crusts formed at the ridge of crop bed under furrow irrigation.

The formal evaluation of salt effects on seedling emergence and growth was conducted in four replicates during December 2006 to March 2007 for a period of 4 months, using Harkey silt loam 1 and 2, and the loamy sand. The temperature of the greenhouse was set based on local climatic data at 26 to 16°C during the first month, 16 to 7°C for the next two months, and 29 to 18°C for the final month. Harkey 3 soil was later added to the emergence experiment which extended for 40 days starting in January of 2007 in a separate greenhouse with the same sequence of the temperature regimes. No additional measurement was taken from Harkey 3 soil beyond the 40-day period.

The pots were subirrigated weekly for the first month, every 10 to 14 days for the next two months, and 7 to 10 days during the last month by placing the pots in a shallow pan of prepared solutions. In addition, the loamy sand seeded with 'BR-1' was surface-irrigated approximately at the same intervals as the subirrigated cases at a leaching fraction of 30%. No surface-irrigation was used for the silt loam as the preliminary test indicated difficulties of seedling emergence. The total number of irrigation amounted to 13 times during the test period, and the evapotranspiration loss during the test period was estimated to be 23 to 28 cm in silt loam and 20 to 26 cm in loamy sand, based on the measured weight losses of the potted soils one day after and prior to each irrigation.

Seedlings emerged were counted for the next 20 to 35 days. The number of seedlings which died was also recorded. Seedlings were grown until the end of March, and were cut 1 cm above the soil level, and dry weights measured. Soil samples were collected with a small core sampler at 1 to 3 cm intervals just prior to clipping harvest, and were analyzed for soil salinity. This data set will be referred to as the ending soil salinity. The roots (or below the ground surface portion) of 'BR-1' and 'Chaco' were collected after clipping by washing loamy sand out. By this time, seedlings of 'Chaco' just began to show bulb formation, while 'BR-1' was not. They were dried at 60ºC and weighed.

The plant tops from Harkey silt loam 1 and the loamy sand were washed with distilled water and dried. 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), and Cl with an ion chromatograph [12]. 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 replicated four times.

2.3. Statistical analysis

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 (ANOVA), a split plot design [13] was used for evaluating the main and subplot effects on seedling emergence, growth, and ion uptake.

3. Results

3.1. Soil column experiment

Soil salinity (EC_e) 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) ranged from 3 to 5% at the top 1 cm, and 5 to 8% at deeper depths. Soil salinity at the top 1 cm increased many fold upon subirrigation (Fig. 2). Soil salinity at a depth of 1 to 3 cm was approximately equal to or slightly higher than the initial soil salinity of the soil columns, except for Harkey silt loam 1 (Fig. 1). Soil moisture contents measured one week after the first subirrigation were relatively uniform with the CV of 3 to 6% (Fig. 1).

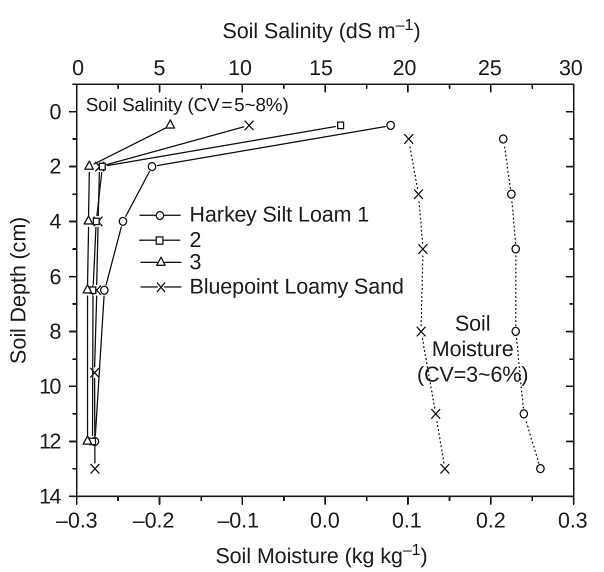

Fig. 1. Soil salinity and soil moisture distribution one week after subirrigation with solution 1: soil column experiment.

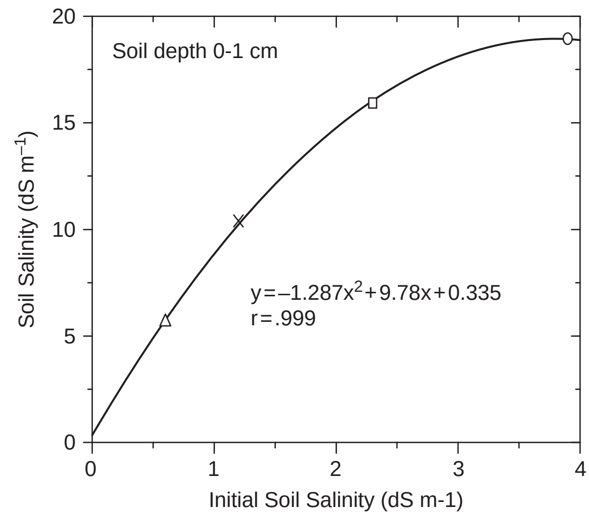

Fig. 2. Soil salinity and soil moisture distribution one week after subirrigation with solution 1: soil column experiment.

3.2. Seedling emergence

Only a few seedlings emerged from Harkey silt loam 1 and 2 when surface-irrigated with solution 1, presumably because of soil crusting (the preliminary experiment). The preliminary experiment also indicated low seedling emergence (<20%) from Harkey silt loam 1 and 2 when seeded at a depth of 0.5 cm, then subirrigated. Many hypocotyls were salt-burned. Seedling emergence has improved when the second seeding method involving the removal of the salt crusted layer was employed (Fig. 3a). Seedlings from subirrigated Harkey silt loam 1 and 2 were a few mm in length when the salted soil layer was removed ten days after seeding. Stand counts increased rapidly in the subsequent 10 days, then reaching a plateau. Thereafter, the stand counts steadily declined, especially in treatments 3 and 4 in Harkey 1 soil, due to seedling mortality.

Seedling emergence from subirrigated loamy sand (Fig. 3b) began seven days after subirrigation. Stand counts increased rapidly in the next 10 days, and then remained essentially unchanged. Seedling emergence from the surface-irrigated loamy sand was delayed by one day, presumably because of lower soil temperature associated with the surface application of water.

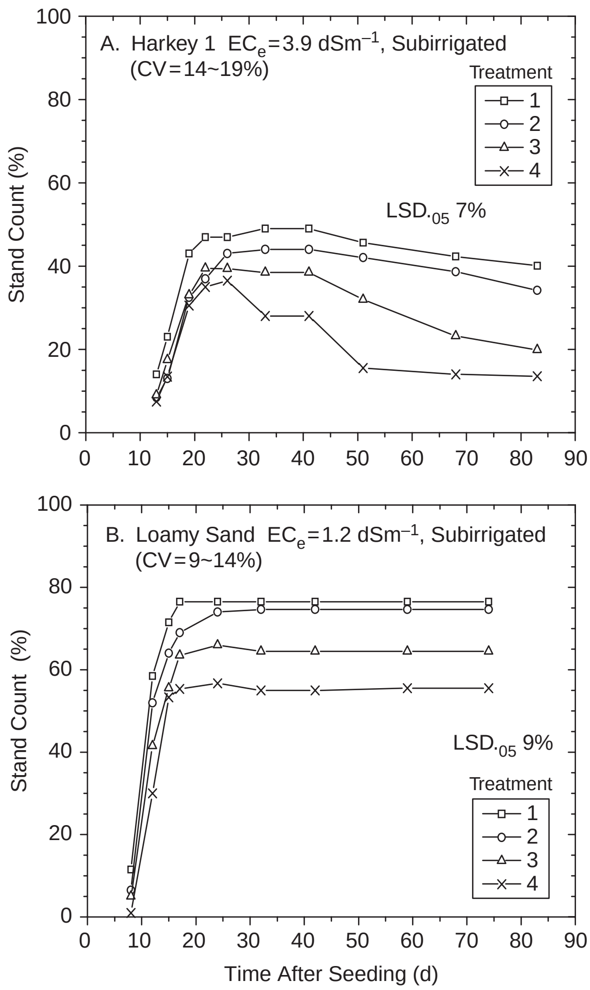

Fig. 3. Stand counts of onion cultivar BR-1 in subirrigated Harkey silt loam 1 (3a), and subirrigated Bluepoint loamy sand (3b). For explanation of the treatments, refer to Table 3.

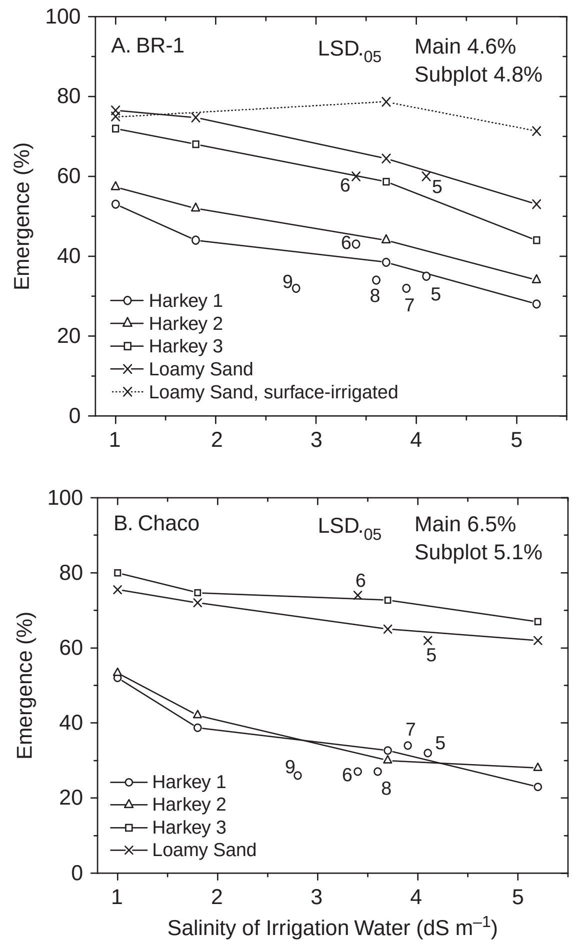

Fig. 4. Seedling emergence of two onion cultivars; BR – 1 (4a), and Chaco (4b) from four soils subirrigated with saline solutions. The dotted line in Fig. 4a is from surface-irrigated loamy sand. Numbers represent treatments shown in Table 3.

Thereafter, emergence counts increased rapidly, as observed under subirrigation.

Final emergence counts made 20 to 30 days after seeding decreased with increasing salinity of the solutions (Fig. 4). However, emergence from surface-irrigated loamy sand was not significantly affected by increasing salinity of irrigation solutions, as exemplified by the data for cultivar B-1 (Fig. 4a). The main difference in emergence was associated with soil types or the initial soil salinity. The ANOVA has shown that the soil type, including the initial difference in soil salinity, and the salinity treatment had a highly significant effect on emergence (Table 4).

Emergence from the silt loam and the loamy sand when subirrigated with the solutions with various Na to (Ca + Mg) or Cl to SO_4 ratios was similar at the equal salinity of the irrigation solutions as shown in Fig. 4. Note that the data points from treatments 1 through 4 with the ionic ratio of 1:1 are connected by the solid lines. The data from the solutions having the different ratios are shown by the numbers in Fig. 4, which coincide with the solution identification numbers of Table 3. The ANOVA revealed that these treatments involving various ionic ratios had no statistically significant effect on emergence (Case III, Table 4).

Seedling mortality in Harkey silt loam 1 first appeared 2 weeks after emergence, and continued (Fig. 3a). Mortality was minimal to zero in loamy sand (Fig. 3b). Seedling mortality in other soils was less than 10% in 'BR-1' and less than 20% in 'Chaco'.

3.3. Seedling growth

At the conclusion of the experiment, seedlings have grown on the average 35 cm tall under treatment 1, and 25 cm tall in treatment 4. We also observed leaf tipburn

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

	Observed F		$LSD_{0.05}$	
	Main	Sub	Main	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	113**	46*	2.8	3.8
Loamy Sand	7	16*	5.6	8.6
III. Main (Cultivar), Sub (Ion Composition)				
Na/(Ca+Mq) ratio				
HK1	18*	0.8	6.8	11.7
HK2	9	2.7	7.3	8.0
HK3	10	0.8	9.4	6.2
CI/SO_4 ratio				
HK1	0.3	0.7	11.5	13.8
HK2	0.2	1.5	2.3	8.0
HK3	2.1	2.4	10.7	13.3
Gyp sum addition to Solution 2				
HK1	3.8	2.9	7.5	9.4
HK2	13.4*	4.5	4.5	11.8
HK3	0.9	1.0	7.5	14.6

*Singnificant at 1 and 5% levels, and are referred to as highly significant respectively repeatedly.

Table 5
Analysis of variance (ANOVA) using a split plot layout; top dryweight.

	Observed F		$LSD_{.05}$	
			Main	Sub
	Main	Sub	-------- g/pot ---------	
I. Main (Soil Types), Sub (Water Salinity)				
BR-1	42**	21**	0.89	1.80
Chaco	128**	28**	0.93	1.52
II. Main (Cultivars), Sub (Ion Composition)				
Na/(Ca+Mg) at Cl: SO_4=1.1				
Harkey 1	0.5	2.0	0.5	0.77
Harkey 2	2.7	0.9	3.23	2.13
Bluepoint	0.4	14.3*	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
Gyp sum addition to solution 2				
Harkey 1	33**	10.7*	1.0	1.28
Harkey 2	3.5	4.4	2.2	2.67

*Significant at 1 and 5% levels, and are referred to as highly significant and significant respectively repeatedly.

(as long as 1 cm in length), especially those which were grown in the loamy sand with solutions 3 and 4 and others with comparable Cl concentrations. Dry weight of the above-ground (top) biomass per pot decreased

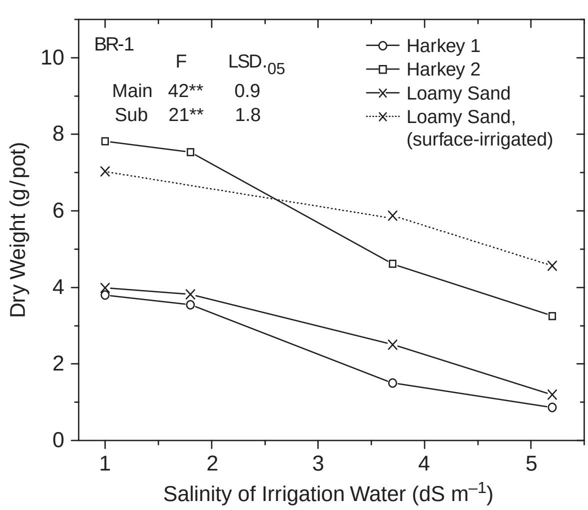

Fig. 5. Dry top weight per pot of onion cultivar; BR-1 from three subirrigated soils and surface-irrigated loamy sand (dotted line).

with increasing salinity of irrigation solutions (Fig. 5). The results for 'Chaco' were similar, thus are not shown. The ANOVA has shown that the soil types, including the initial soil salinity levels, as well as the salinity of irrigation solutions had a highly significant effect on growth of both cultivars (Case I of Table 5). The reduction in seedling growth under subirrigated conditions occurred at salinity of irrigation water around 2.0 dS m^{-1} (Fig. 5).

Increasing Na to (Ca+Mg) ratios had a significant effect on seedling growth only in the loamy sand (Case II of Table 5). The Cl to SO_4 ratio as well as an addition of Ca and SO_4 to solution 2 also had a significant effect on growth in Harkey 1 soil, but not in Harkey 2 soil (Case II, Table 5). Recall that Harkey 1 soil and the loamy sand were irrigated at 40 me L^{-1} solutions, and Harkey 2 soil at 20 me L^{-1}.

Top dry matter decreased consistently with increasing Cl to SO_4 ratios in Harkey 1 soil (Table 6). There was the same trend in Harkey 2 soil, but with no statistical significance. The addition of Ca and SO_4 reduced top dry matter in Harkey 1 soil. The dry matter also decreased significantly with increasing Na to (Ca+Mg) ratio in the loamy sand, but not in Harkey loam. There are no data for treatments 7 through 9 for the loamy sand, as they were excluded from the beginning.

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. 6, however, indicate

Table 6
Top dry weight of onions (BR-1 and Chaco) in Harkey slit loam and Blue point loamy sand subirrigated.

		Trt No.	Top dry wt. (g/pot)	
			BR-1	Chaco
Harkey 1 (irrigated at 40 me L^{-1})				
Na: (Ca + Mg): No significant Difference				
Cl : SO_4 at Na : Ca+Mg = 1:1				
1:3		8	2.3a	1.8a
1.1		3	1.7b	1.3b
3.1		7	1.0c	1.0c
Cl SO_4, Na : (Ca + Mg)				
1.1	1.1	2	4.4a	1.84a
1:3	1:3	9	1.2b	1.1a
Harkey 2 (irrigated at 20 me L^{-1})				
Na: (Ca+Mg): No significant Difference				
Cl: SO_4 at Na: Ca + Mg + 1.1				
1:3		8	6.8	8.1
1:1		2	7.5	7.9
3:1		7	5.8	6.3
Na: (Ca + Mg) Cl: SO_4				
1:1	1:1	2	7.5	8.0
1:3	1:3	9	5.4	7.0
Bluepoint Loam Sand (40 me L^{-1})				
Na: (Ca + Mg)				
1:3		6	3.0	3.4a
1:1		3	2.5ab	2.4ab
3:1		5	1.9	1.8b

The numbers followed by the same letter are not statistically different at a 5% level.

that dry weight per seedling has also decreased with increasing salinity. The seedlings grown in the loamy sand were smaller, because of the high plant density. The dry weight of roots was found to be linearly related

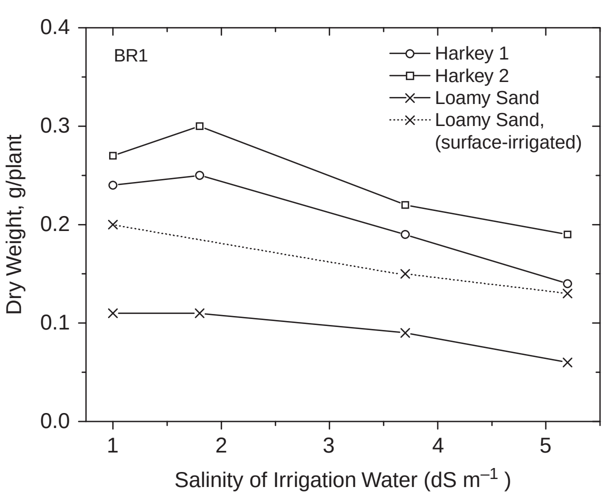

Fig. 6. Dry top weight per seedling of BR-1 in three subirrigated soils and surface-irrigated loamy sand (dotted line).

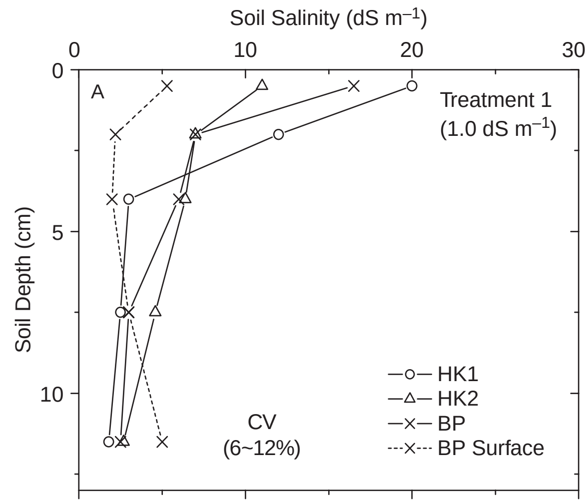

Fig. 7. Soil salinity distribution after subirrigation of Harkey soil (HK) and Bluepoint loamy sand (BP) for 4 months with Solution 1.

to dry shoot weights with the *r* value of 0.96 and 0.98 for 'BR-1' and 'Chaco,' respectively.

3.4. Ending soil salinity

Soil salinity measured at the termination of the experiment is shown in Fig. 7 for treatment 1. Soil salinity from treatments 2, 3 and 4 was greater, but the pattern of distribution was similar (data are not shown). The highest soil salinity towards the surface was found in subirrigated Harkey 1 soil (HK1), reaching EC_e of 20 dS m^{-1}, followed by subirrigated Bluepoint loamy sand (BP) and subirrigated Harkey 2 soil (HK2). The surface-irrigated loamy sand had the lowest soil salinity (the dotted line Fig. 7).

3.5. Tissue ion concentrations

The concentration of Ca, Na and Cl measured in the top dry matter grown in subirrigated Harkey silt loam 1 is shown in Fig. 8. The data points from treatment 1 through 4 are connected with the solid lines, and the data from the remaining treatments are designated by the treatment number shown in Table 3. (The Cl data for treatment 4 are not available because of insufficient quantity of the samples). The Ca concentration of top dry matter essentially remained constant, whereas that of Na and Cl increased almost linearly with increasing the concentration of respective ions in the irrigation solutions (Fig. 8). However, there was one case where the Na concentration of the top dry matter from treatment 4 was notably lower than the value which would be expected from the linear extrapolation. This data set came from the plants irrigated with the highest salinity (solution 4) and was severely salt-stressed.

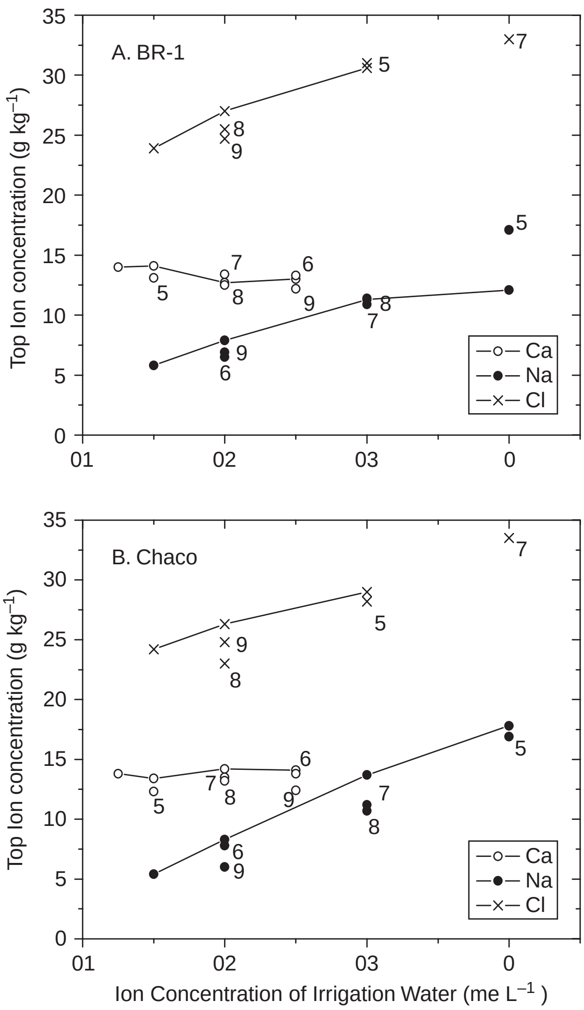

Fig. 8. Ion contents of the top dry matter: subirrigated Harkey silt loam 1 as related to ionic concentration of irrigation water. Numbers represent treatments shown in Table 3.

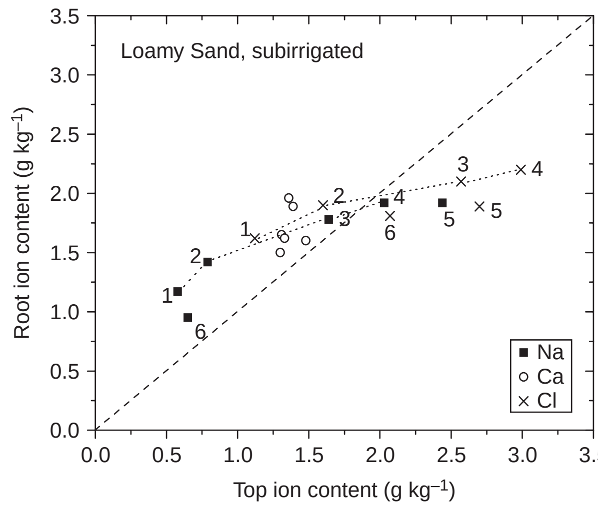

Fig. 9. The relationship between the top ion concentration and the root ion concentration in BR-1 grown in Bluepoint loamy sand. Numbers represent treatments shown in Table 3.

In all other causes, the Na and Cl concentrations of plant tops increased with increasing respective ion concentrations in irrigation solutions, irrespective of ionic compositions.

The ion concentrations in the roots are plotted against those of the top dry matter in Fig. 9. The roots retained more Ca and, to a lesser extent, Na than did the top. The concentration of Cl in the root was higher than that in the top, until the Cl concentrations in irrigation water reached between 10 and 20 me L^{-1}. Thereafter, Cl was readily transported to the top and accumulated. This cross-over concentration in the irrigation water coincides with or somewhat greater than the threshold concentration for Cl proposed by Maas [7] above which Cl toxicity supposedly come into play. The concentration of Na in the top exceeded that of the root when the Na concentration in the irrigation solutions was closer to 30 me L^{-1}.

4. Discussion

Disposal of concentrates into ditches and canal is practiced commonly in nonsaline areas [14]. However, in saline areas of the west, it can be problematic. Typically, irrigation districts do not accept highly saline concentrates from RO processes, but are uncertain about NF concentrates. Since NF concentrates are enriched with divalent ions, some suggest that its application to irrigation stream would not be deleterious, or can be even beneficial, as low SAR improves soil structure [15]. However, as discussed in the introduction, the SAR of NF concentrates is not substantially lower than that of the feed water, although it is lower than that of RO concentrates [2,4,5,14,16]. In addition, the formation of sulfate ion pairs with divalent cations further reduces the replacement of exchangeable Na from the cation exchange sites [17]. Of course, there are exceptions, e.g., application of NF concentrate from gypsic water, such as studied by Mulford et al. [6], to sodic irrigation water can be beneficial. However, such situations are not prevalent in saline areas of the Southwest. We then hypothesized that disposal of NF concentrate to irrigation water may have a merit only if reduced Na or Cl concentrations can offset the inevitable increase in salinity and osmotic stress.

Onions were used in this study, not only because they are a major winter cash crop in the Rio Grande Valley, but also because they are known to be susceptible to specific effects of Cl ions. Maas [7], for example, placed onions as being Cl sensitive with a Cl limit of 10 me L^{-1} in irrigation water, although no specific work was cited to validate this limit. This study has shown that the Cl limit of irrigation water happens to coincide with the concentration of Cl in solution 2 (10 me L^{-1}) above which the Cl concentration in plant tops begins to exceed that in the roots (Fig. 9). The analysis of plant top also has shown that the Cl concentration of plant top increased almost linearly with increasing Cl concentrations in irrigation solutions (Fig. 8). These data support the idea that Cl ions can accumulate in plant top of onions. The leaf tip burn we observed when irrigated with solutions 3, 4 and others with comparable or higher Cl is probably a symptom of Cl toxicity caused by the Cl accumulation in the plant top.

Sodium ions usually affect plant growth by inducing Ca or other nutrient deficiency, such as K [7,18]. In the present experiment, tissue Ca concentrations were nearly independent of Na to (Ca+Mg) ratios (Fig. 8), thus Ca deficiency can be ruled out. Tissue Na concentrations were much lower than Cl concentrations (Fig. 8), and Na ions were retained in the roots more so than Cl ions (Fig. 9). In addition, we observed no statistically significant reduction in growth except in the loamy sand when Na/(Ca+Mg) ratios were increased (Tables 5 and 6). This data set may indicate that Na is probably not as deleterious as Cl ions for growth of onions.

The real issue is seedling growth response to Cl at an equal osmotic stress which is approximately proportional to the equivalent concentration of dissolved salts. Increasing Cl to SO_4 ratios at an equal salinity resulted in a significant reduction in seedling growth in Harkey 1 soil (Tables 5 and 6). This observation supports our original hypothesis that a reduction in Cl to SO_4 ratio could reduce the deleterious effect on growth. However, no significant effect of Cl to SO_4 ratio was observed in Harkey 2 soil (Tables 5 and 6). In the case of treatment 9 (where Ca and SO_4 were added to solution 2), seedling growth was actually reduced, even though the Cl to SO_4 ratio decreased. The corresponding EC of these solutions increased from 1.8 to 2.8 dS m^{-1} upon the addition of Ca and SO_4 (Table 3).

These observations seem to be consistent with an alternative hypothesis that seedling growth was first reduced by osmotic stress, and then the effect of Cl became apparent when the Cl concentration in irrigation was elevated from 20 to 30 me L^{-1}. Note that Harkey 1 soil was irrigated at the Cl concentration of 30 me L^{-1} in solution 7, and Harkey 2 at 15 me L^{-1} for treatment 7, and 5 me L^{-1} for treatment 8. In Harkey 2 soil, specific effects of ionic composition were statistically absent at a 5% level. However, there was a tendency of reduced seedling growth of 'Chaco' with increasing Cl to SO_4 ratio, which could have signaled the onset of Cl effect. This osmosis hypothesis may also explain why the increasing in Na to (Ca+Mg) ratio caused a significant reduction of seedling growth in the loamy sand (Table 5). The salinity of the treatments increased from 1.7 to 2.1 dS m^{-1} (Table 3). The loamy sand had the soil water retention capacity only about half of the capacity of Harkey soil (Fig. 1). Therefore, salinity of the soil solution upon water depletion would have been higher than that of Harkey soil, although EC_e of subirrigated cases were similar (Fig. 7). The reduction in seedling growth has probably occurred due to the accentuated osmotic stress.

The reduction in seedling growth under subirrigated conditions occurred at salinity of irrigation water around 2 dS m^{-1} (Fig. 5). This finding is in agreement with the work of Wannamaker and Piker [8], reporting a significant reduction in seedling growth when grown with 2.0 dS m^{-1} of a NaCl solution in hydroponic culture. The current finding is also in agreement with an earlier work of Bernstein and Ayers [2], indicating a significant reduction in bulb weight at soil salinity as low (EC_e) of as 1.2 dS m^{-1} in the saturation extract. Since the initial reduction in seedling growth of onions appears to be controlled by osmotic stress, the appraisal of irrigation water quality can be made based on salinity of the irrigation water, rather than the ionic composition, at least from the agronomic perspective. Soltanpour et al. [19] also reported a similar finding with alfalfa (*Medicago sativa*), which has higher Cl threshold, 20 me L^{-1} [7].

Crop establishment is among the most difficult task in field management in saline areas. The effect of ion composition was not evident in seedling emergence (Table 4). Emergence was controlled largely by salinity of irrigation solutions, soil types, and the irrigation methods. Since the majority of onion crops are produced under furrow irrigation, it may be useful to postulate the cause of emergence failures under subirrigation. High soil salinity is known to reduce seed germination and/or increase hypocotyl damage [20]. A previous study with 'BR-1' has shown that seed germination is significantly reduced when salinity of the incubating solution approaches 20 dS m^{-1}, but it does eventually germinate even at 30 dS m^{-1} [8]. Since salinity of the surface 1 cm of Harkey 3 and the loamy sand was 6 and 11 dS m^{-1} (or 12 and 22 dS m^{-1} in soil solution) respectively, the seed placed at 0.5 cm deep might have germinated without difficulty. (Salinity of the soil solution was estimated from EC_e with an assumption that it increases in proportion to the saturation to field capacity ratio). In the case of subirrigated Harkey 1 and 2 soils, less than 20% of the seed planted emerged when seeded at 0.5 cm (the preliminary experiment). Judging from the data shown in Fig. 1, the soil salinity at the seeding depth of 0.5 cm seemed to have been in the range of 16 to 18 dS m^{-1} in the saturation extract (30 and 35 dS m^{-1} in the soil solution). This range of soil salinity is high enough to reduce both seed germination and hypocotyl development [8]. When the second seeding method was used, the seed was placed at 2.5 cm below the soil surface where soil salinity was probably less than 5 dS m^{-1} in the saturation extract (Fig. 1). At this level of soil salinity, essentially all of the seed planted should have germinated in a few days, yet seedling emergence was reduced (Figs. 3 and 4). We suspect that hypocotyl damage has occurred, as reported in some other crops [21], when pushing through the salted surface layer of the soil. Soluble salts in soils move along with the upward capillary flow of water, and accumulate at or near the soil surface under subirrigation, thus forming a thin salted layer.

There are a few methods that can be used to improve crop establishment, and include leaching irrigation prior to bedding, or reshaping of the bed after irrigation to remove the salt-crusted surface layer of the crop bed. However, when salinity of irrigation water exceeds about 20 me L^{-1}, reshaping of crop beds is likely to have a limited value. The use of high seeding rates is another. However, soil salinity distribution in irrigated soils is highly spatially variable [22], and a high seeding rate can lead to small onions in low salt section, as observed in the loamy sand. In the area of high salinity, seedlings may not survive as experienced in Harkey 1 soil (Fig. 3 A). The use of sprinklers can reduce crop establishment difficulties only if the soil type in question does not present crusting problems.

Looking at the overall picture, it is evident that ion composition is a minor factor which may or may not control seedling emergence, mortality and growth. Soil types, especially initial soil salinity and soil crusting, and irrigation methods are likely to dictate seedling establishment. For example, emergence was excellent in loamy sand (>80%) under surface-irrigation, regardless of the quality of irrigation solutions used (Fig. 4a). If onions are to be grown in sandy soils under sprinklers, the impact of irrigation water quality on emergence is likely to be minimal. In Harkey silt loam, however, emergence was poor under surface-irrigation, presumably due to soil crusting. Under subirrigated conditions, emergence from Harkey soil varied with the initial soil salinity, besides salinity of irrigation water (Fig. 4). This finding indicates that soil salinity at the end of the previous cropping can potentially dominate emergence from furrow-irrigated fields rather than quality of water used for irrigation of onions. This means that the impact of salinity on onion establishment can not be predicted without knowing soil types and cultural practices.

There are several other factors which may affect the use of NF, instead of RO processes. One of the factors is higher SAR or Na concentrations in permeate from NF as compared to RO processes, as pointed out by Chang et al. [4]. High SAR under low salinity (<500–1000 mg L^{-1}) can cause adverse effects on urban soils when used for outdoor watering [15]. Likewise, Cl concentrations in permeate from NF processes would be higher than those from RO processes. Elevated levels of Cl in permeate limits the blending of the feed water, because of a potential for Cl concentration of the blend to exceed the drinking water standards. This usually means that a larger quantity of the feed water must be filtered; creating greater quantities of concentrate from NF process, which need to be disposed of [3]. In addition, elevated levels of Cl ions in the permeate can cause foliar damage of landscape plants when used for landscape irrigation. The foliage of salt sensitive plants can be damaged through sprinkler applications of the water containing Cl concentration as low as 150 mg L^{-1} [23] which is usually lower than the Cl limit for public water supply. The consequences of NF process seem to be more complicated than the idea that it can be beneficial because of divalent ion rejection.

5. Conclusion

Application of concentrates from nanofiltration (NF) to irrigation water inevitably increases osmotic stress, which can not be compensated by higher proportions of divalent ions or lower proportions of monovalent ions in production of onions. Disposal of NF concentrates, therefore, should be decided based on salinity hazard, especially in crops sensitive to osmotic stress by considering soil types, and cultural practices, besides the projected increase in salinity of irrigation water.

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