

Article

Growth, Evapotranspiration, and Ion Uptake Characteristics of Alfalfa and Triticale Irrigated with Brackish Groundwater and Desalination Concentrate

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Abstract: Persistent drought, low snowfall, and low rainfall have reduced availability of fresh water for irrigating agricultural crops in many arid and semi-arid regions of the world. Brackish groundwater (electrical conductivity; EC > 3 dSm⁻¹) is increasingly used for irrigation in New Mexico. This study investigates the effect of ion uptake from brackish groundwater and concentrate irrigation on the performance of two forage species, alfalfa (*Medicago sativa*) and triticale (*×Triticosecale*), in sand soils in greenhouse conditions. Two simultaneous experiments were run for 90 days using tap water (control; 0.7 dSm⁻¹), brackish groundwater (BGW; 4 dSm⁻¹), reverse osmosis concentrate (RO; 8 dSm⁻¹, Ca²⁺ dominant), and BGW plus sodium chloride (BGW + NaCl; 8 dSm⁻¹, Na⁺ dominant). BGW + NaCl irrigation significantly reduced the evapotranspiration (ET) of both the species. Deep percolation (DP) increased significantly with RO and BGW + NaCl irrigation in alfalfa but only with BGW + NaCl irrigation in triticale. Alfalfa plant growth decreased with increasing salinity, while triticale plants followed an opposite trend. ET continued to decrease with increasing salinity for both species. Na⁺ dominant (BGW + NaCl) irrigation produced robust growth and early flowering and ear head formation in triticale. Na⁺ ion concentration in shoots was above 0.66%, which led to reduced alfalfa growth, while more than 1.22% did not decrease triticale growth or biomass. Increased Ca²⁺ sequestration in alfalfa played a crucial role in reducing Na⁺ ion toxicity. Species performance primarily confirmed that alfalfa is moderately salt-tolerant while triticale is confirmed to be a halophyte producing abundant growth and biomass with higher Na⁺ uptake. Triticale proved to be a promising species for reuse of RO concentrate for agriculture in marginal lands.

Keywords: brackish groundwater (BGW); reverse osmosis (RO); evapotranspiration (ET); biomass; ion concentration

1. Introduction

Water is the primary basis of survival for all forms of life on the earth. With increasing global population, pressure on available water resources from industries and urbanization has grown. A combination of various factors, such as low rainfall and snowfall, recurring droughts, and increasing temperatures, has led to concerns about declining groundwater levels, reduced volumes of groundwater storage, reduced river flows, and increased soil salinity [1]. About 7–10% of earth's land surface (1000 million ha) is affected by soil salinity [2], of which sodium-affected soils are even more widespread [3].

The availability of fresh water is becoming scarce in arid and semi-arid regions of the world. Under these circumstances, brackish water, which is variably saline, is used to supplement irrigation shortfalls. In New Mexico, a semi-arid state in the southwestern USA, about 75% of the aquifers are brackish with salinity higher than 3 dSm^{-1} [4,5]. In these regions, brackish groundwater (BGW) is used for irrigating agricultural crops, which can potentially reduce crop productivity. BGW is commonly used for many purposes, including as a coolant in power generation plants, in aquaculture, in oil and gas industry, and for growing algae as biofuel [6,7]. Yordanov et al. [8] suggested the use of drainage water, seawater, and recycled water for crop production as a part of a solution to water scarcity, while Babcock et al. [9] utilized treated saline wastewater effluent as a source of irrigation to cultivate salt-tolerant species.

One way to utilize BGW is to desalinate it first using, for example, a reverse osmosis (RO) system, which separates out fresh water and the highly saline concentrate. Fresh water can be used for domestic purposes and RO concentrate could be utilized for irrigating certain salt-tolerant species. If properly done, this might be an effective way to recycle RO concentrate without the associated high costs of disposal and concerns about environmental pollution.

Previous studies have reported RO concentrate reuse for growing salt-tolerant species such as *Triticosecale*, *Atriplex canescens*, *Hordeum vulgare*, *Lepidium alyssoides*, *Distichlis stricta*, and *Panicum virgatum* [10]. There are certain species that have a natural ability to germinate, grow, and survive under high salt concentrations [11] and can be grown for various purposes [12], including as a salt substitute in animal fodder. It is also reported that saline conditions can stimulate growth in some halophytes [13–15]. Alfalfa is reported to be moderately salt tolerant but highly varies with the varieties, and triticale is reported to be a halophyte. According to Shukla [16], as salinity increases, the plant growth, biomass, crop cover, and evapotranspiration (ET) decreases in many plants. Khan and Glenn [17], in their study on two barley varieties, irrigated with three salinity treatments (0, 150, and 250 mol m^{-3} of NaCl), and showed that biomass and grain yields are reduced by 2.4 to 3.1% with every 1 dSm^{-1} increase in soil saturated paste extract (EC_e), up to 11.8 dSm^{-1} in the root zone. A 50% yield reduction of biomass and grain yield occurred between 17 and 21 dSm^{-1} . Li et al. [18] reported that salinity did not influence the normal growth of adaptive plants; rather, plants were able to adjust to salt stress by changing their root morphology, especially in the sand soils and desert environment where saline groundwater was the sole source of irrigation for plants. In a study by Malek et al. [19], irrigation with saline wastewater from an electrical power plant increased ET and yield of alfalfa. Flores et al. [10], in a study on triticale, reported higher ET and no decrease in biomass with increasing salinity up to 8 dSm^{-1} . Ozturk et al. [20] showed similar results for triticale in their study, where ET increased and no differences were observed in biomass with increasing salinity.

Salehi and Arzani [21] studied the effect of high salinity (electrical conductivity; $\text{EC} = 16 \text{ dSm}^{-1}$) on 18 lines of triticale and reported the least grain loss where the $\text{Ca}^{2+}/\text{Na}^{+}$ ratio was identified as a supporting factor for the salt tolerance mechanism. The $\text{Ca}^{2+}/\text{Na}^{+}$ ratio is important to maintain constant Ca^{2+} activity or a stable $\text{Ca}^{2+}/\text{Na}^{+}$ ratio because it balances out the effects of Na^{+} addition. According to Cachorro et al. [22], high Ca^{2+} concentration could decrease the Na^{+} toxicity.

Earlier studies have shown tolerance in alfalfa and triticale when irrigated with wastewater. Triticale is confirmed to be a salt-tolerant species, showing no differences in the biomass increase with increasing salinity even up to 10 dSm^{-1} [20]. We chose to work with these two forage species, but with different salinity treatments of Ca^{2+} and Na^{+} dominant concentrates, keeping the highest salinity EC at 8 dSm^{-1} . For this study, alfalfa and triticale were selected because of their wider acceptability as forage crops in the United States. These species also displayed 100% total germination and emergence when irrigated with BGW and RO up to 8 dSm^{-1} in our preliminary results. Alfalfa is a high-quality, high-nutritive-value leguminous crop, rated as moderately salt-tolerant with a salinity threshold of 2 dSm^{-1} . In the United States, alfalfa is among the top three field crops, cultivated in 26 states and contributing to more than US\$ 10 billion per year to the farm economy, primarily as an animal feed [23].

Alfalfa is known for its relative tolerance to salinity, capacity to tolerate extreme temperatures (hot days and cold nights), high nutritional value, high minerals, and palatability to livestock [24,25].

Triticale is a newly cultivated crop—mainly for forage and pasture—with over 404,686 ha in the USA [26]. It is used as feed grain because it is a good source of protein and vitamin B [27]. It is highly adaptable to a wide range of soils and climatic conditions and produces high biomass [28,29]. Some studies have reported triticale as a moderate halophyte with a salinity threshold of 6.1 dSm^{-1} [30]. It is also reported to be drought-tolerant [31–33] and could be a potential forage crop on degraded rangelands and other areas on desert margins.

Our current research utilizes BGW and two concentrates (Ca^{2+} and Na^{+} dominant, respectively) to irrigate two forage crops, alfalfa (*Medicago sativa*), a moderately salt-tolerant species which highly varies among varieties, and triticale (\times *Triticosecale*), a halophyte. We tested the hypothesis that irrigation water salinity will not suppress ET and biomass yield for either forage crop. Consequently, there will be no yield reduction, assuming high ion uptake for both species. Specific objectives of this study were to determine the effect of irrigation with BGW and Na^{+} and Ca^{2+} dominant concentrates on soil and plant ionic concentration, and how that will affect the plant growth and biomass production.

High salinity impacts livestock production in arid regions, mainly due to restricted forage production under saline conditions [34]. Our research explores effective ways to continue forage production in degraded rangelands and in desert margins utilizing available BGW and RO concentrate. This could be a way forward for our future irrigation water challenges, allowing us to produce better forage crops and promote livestock.

2. Materials and Methods

Seeds of alfalfa (*Medicago sativa*) and triticale (\times *Triticosecale*) were purchased from Curtis & Curtis Inc. (Clovis, NM, USA) and Helena Chemical Company (Mesquite, NM, USA), respectively. Sand soil (93% sand, 3% silt, 4% clay) was collected from West Mesa, Las Cruces, NM, USA.

The BGW was obtained from the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, NM, USA. The soil was prepared after air drying, grinding, sieving through a 2 mm sieve, and autoclaving at 80°C for 4 h.

Two replicated runs (from 7 October 2017 to 7 January 2018) were conducted in the Fabian Garcia Science Center (FGSC) greenhouse in Las Cruces, NM, USA (32.2805°N and 106.770°W ; elevation 1186 m). For each experimental run, the experimental unit was a pot (20 cm depth and 18 cm diameter) containing either alfalfa or triticale. Four water treatments with salinity EC of 0.7 dSm^{-1} , 4 dSm^{-1} , 8 dSm^{-1} (Ca^{2+} dominant), and 8 dSm^{-1} (Na^{+} dominant) were arranged in a completely randomized design with four replicates. There were (2 species) \times (1 soil type) \times (4 irrigation water treatments) \times (4 replicates) = 32 pots in each run. Randomization was achieved by generating random numbers using Microsoft Excel (2013).

Tap water (0.7 dSm^{-1}) used as control was procured from FGSC in Las Cruces, NM, USA. The BGW (4 dSm^{-1}) and RO (8 dSm^{-1} , Ca^{2+} dominant) were obtained from BGNDRF, and BGW + NaCl (8 dSm^{-1} , Na^{+} dominant) was prepared in the laboratory by adding an appropriate amount of laboratory-grade NaCl (Table 1).

Each pot was filled with 3.94 kg of sand soil after their perforated bottoms were covered with cheesecloth topped with gravel to prevent soil loss and allow free drainage. Soil was poured in increments to allow its uniform distribution within the pot. Pots were irrigated with tap water three to four times to leach out the salts and bring soil $\text{EC} \leq 1 \text{ dSm}^{-1}$. Ten seeds per pot of each species were sown in the top 1–2 cm of the soil, separated by 2 cm. During the initial four weeks, pots with the seedlings were sub-irrigated with control water until the plants established. Fertigation was done with half-strength Hoagland solution [35] until the initiation of two to three leaves.

Saline irrigation treatments were introduced after four weeks of seedling establishment. Both species were irrigated with respective treatments along with fertilizer at different times, depending on when the saturated soil moisture content depleted to approximately 50%. Alfalfa needed to be irrigated

every 9–10 days and triticale every 5–6 days. A total of 10 irrigations in alfalfa and 13 in triticale were carried out during the entire 90-day crop growth period. The higher irrigation frequency and number of irrigations for triticale were attributable to its higher aboveground biomass and evapotranspiration as compared with alfalfa, and as reported in our results.

Table 1. Chemical properties of irrigation water used for the experiment: tap water (control), brackish groundwater (BGW) from BGNDRE, RO concentrate (RO) from BGNDRE, and BGW + NaCl irrigation.

Treatment	Ion Concentration					SAR	EC (dSm ⁻¹)	pH
	meq L ⁻¹		mg L ⁻¹					
	Na ⁺	Ca ⁺	Mg ²⁺	K ⁺	Cl ⁻			
Control (tap water)	2.53	2.59	0.79	5.33	57.2	1.95	0.7	7.3
BGW	15.87	20.4	16.54	6.74	697.7	3.69	4	7.4
RO (Ca ⁺ dominant)	30.09	34.88	30.12	14.0	892.7	5.28	8	7.4
BGW + NaCl (Na ⁺ dominant)	50.11	18.78	15.98	-	-	12.02	8	7.4

EC: electrical conductivity, SAR: sodium absorption ratio.

Leaching fraction (LF) was determined using Equation (1) [36].

$$LF = V_{\text{drain}}/V_{\text{irr}} \quad (1)$$

Evapotranspiration (ET) was determined using water balance Equation (2) [16]:

$$ET = IR + R - \Delta S - RO - DP \quad (2)$$

where IR is the depth of irrigation (cm), R is rainfall (cm; = 0), ΔS is the change in soil water storage between irrigations (cm), RO is runoff (cm; = 0), and DP is the deep percolation (cm; leachate collected from the bottom of the column). The volumes of IR and DP were converted to depths from the known area of the soil cross-section in the pot. Samples of leachates were stored in small vials and their EC and pH were recorded.

The greenhouse meteorological data was recorded every day using a Watchdog 2475 Plant Growth Weather Station and analyzed with SpecWare 9 Pro GH FGSC 2B software (Spectrum Technologies, Inc., Aurora, IL, USA). The daily measurements included air temperature, relative humidity, and photosynthetically active radiation (PAR).

Plant heights were recorded once every month (30, 60, and 90 days) at three different stages of plant growth using an ordinary ruler to measure plant heights as affected by salinity. Active growth phase (60 days) plant height data were used for analysis.

At the conclusion of each run, harvested shoots, roots, and soil were bagged separately. Fresh weights of shoots and roots were recorded, then shoots, roots, and soil were oven-dried at 65 °C for 3 days. The dry weights of roots and shoots were recorded. Dried soils were ground and then sieved through a 2-mm screen, while the dried shoots and roots were ground to pass a 0.42 mm screen.

Subsamples of the ground shoot material were extracted in concentrated nitric acid at 60 °C for 30 min followed by digesting at 120 °C for 90 min with the addition of 30% hydrogen peroxide. In the shoot extracts, Na, Ca, and Mg were determined using inductively coupled plasma atomic emission spectroscopy (ICP-OES), while Cl was determined using flow injection analysis (FIA). Soil subsamples were extracted in ammonium acetate for determination of Na, Ca, and Mg, and in water for determination of Cl. Soil extracts and leachates were analyzed for Na, Ca, Mg, and Cl as previously described for plants.

Statistical Analysis

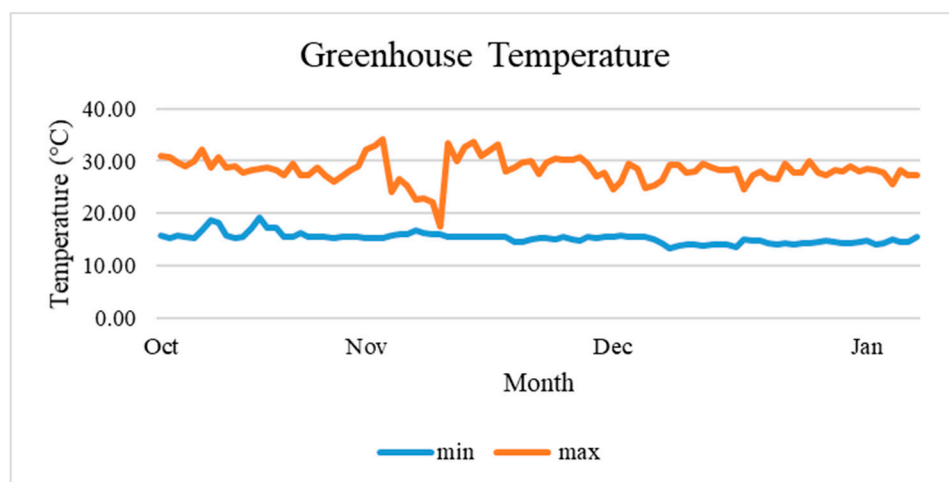
Statistical analysis was performed using SAS version 9.4 (TS1M3) (SAS Institute Inc., Cary, NC, USA) with significance defined at $\alpha \leq 0.05$. Data from both the runs, including ET, DP, LF, plant height,

aboveground biomass (AGB; fresh and dry biomass), and shoot ion concentration parameters, were analyzed using one-way analysis of variance (ANOVA), separately by species. Since no significant differences were obtained for most parameters between the two runs, data for both runs were combined by species for ANOVA. Results were modeled using a general linear model [10].

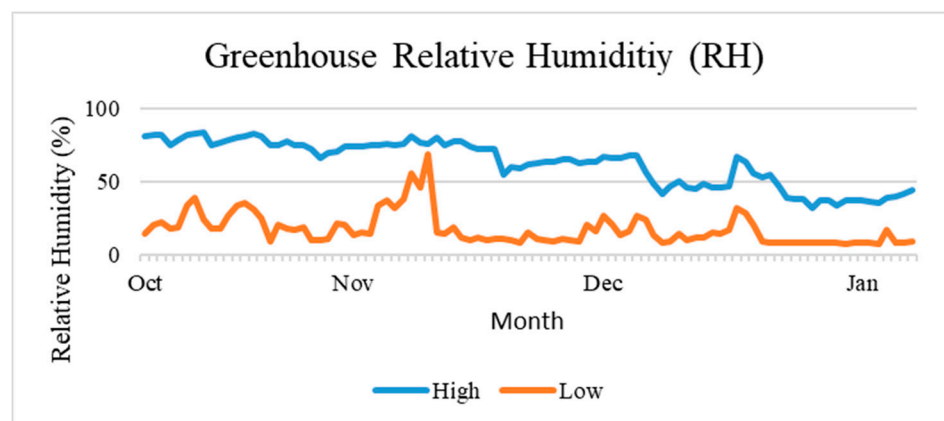
3. Results

3.1. Greenhouse Meteorological Data

The greenhouse temperature ranged between 13.40 and 33.4 °C, and relative humidity between 8 and 84% (Figure 1A,B). The mean daily light integral (DLI) was recorded as 11.6 mol m⁻² day⁻¹ (Figure 1C). On 10 November 2017, a shade was installed inside the greenhouse for five days to prevent direct sunlight, and this dropped the mean DLI to 0.1 mol m⁻² day⁻¹ (Figure 1C).

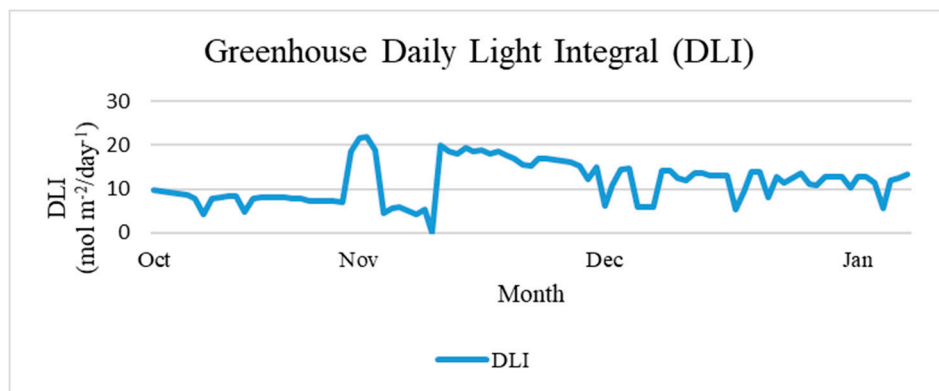


(A) Greenhouse Temperature



(B) Greenhouse Relative Humidity

Figure 1. Cont.



(C) Greenhouse Daily Light Integral (DLI)

Figure 1. Greenhouse data on maximum and minimum temperature (°C), relative humidity (RH; %), and daily light integral (DLI; mol m⁻²/day⁻¹) obtained during plant growth period from 7 October 2017 to 7 January 2018.

3.2. Evapotranspiration and Deep Percolation

For both species, ET for the control treatment was significantly higher than the BGW + NaCl treatment. No significant differences were observed among control, BGW, or RO irrigated treatments (Figure 2A1,B1). For alfalfa, deep percolation (DP) was significantly higher with RO and BGW + NaCl, while for triticale, only BGW + NaCl treatment led to an increase compared to the control (Figure 2A2,B2).

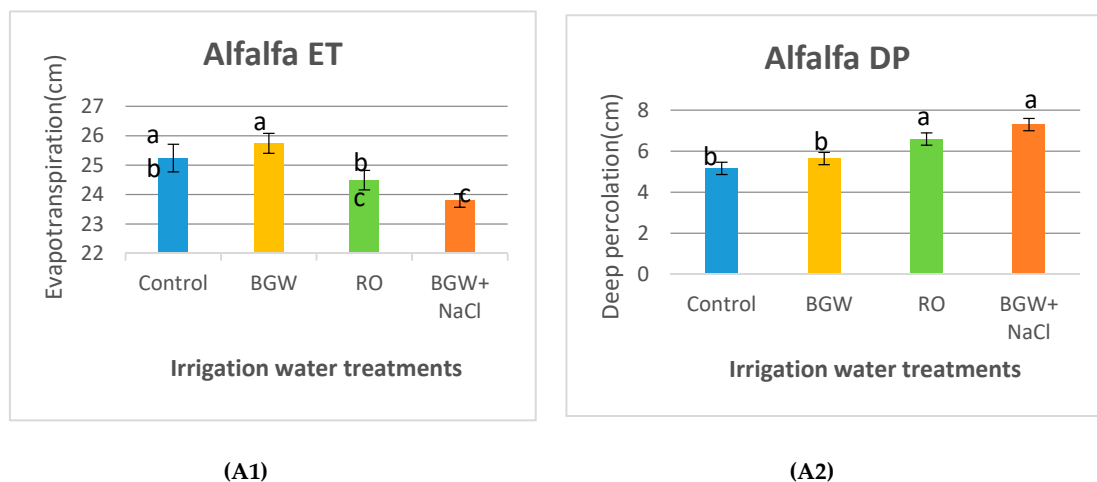


Figure 2. Cont.

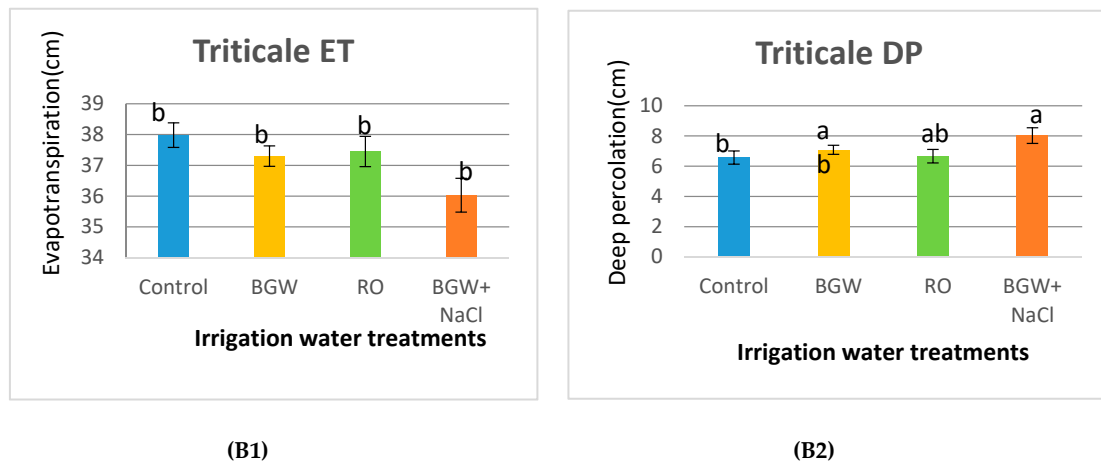


Figure 2. (A1,A2) Total evapotranspiration (ET) and total deep percolation (DP) in alfalfa. (B1,B2) Total evapotranspiration and total deep percolation in triticale. Means within species sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of four replications. The electrical conductivities (ECs) of the saline treatments were control (0.7 dSm^{-1}), BGW (4 dSm^{-1}), RO (8 dSm^{-1}), and BGW + NaCl (8 dSm^{-1}).

3.3. Volumetric Leaching Fractions

For both species, the average LF_s ranged between 15% and 24% to prevent salinity buildup in the soil. For alfalfa, as the irrigation water salinity increased, the average LF also increased significantly with RO and BGW + NaCl treatments (Figure 3A). However, for triticale, average LF increased only with Na^+ dominant BGW + NaCl irrigation treatment compared to the control (Figure 3B).

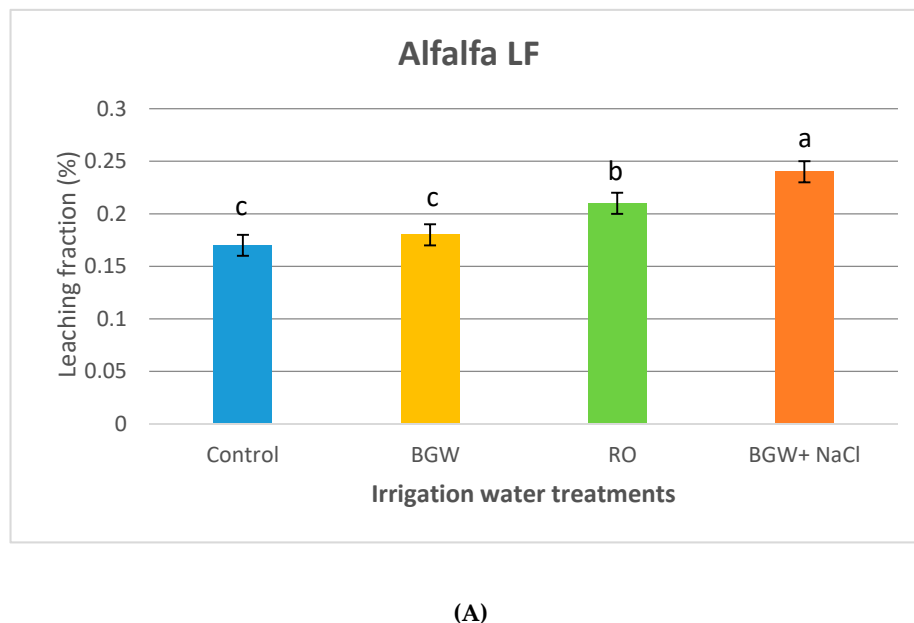
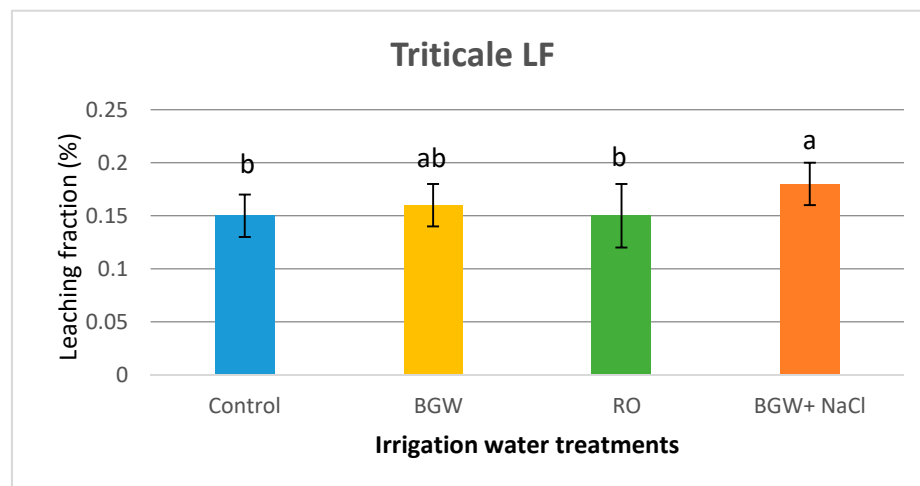


Figure 3. Cont.

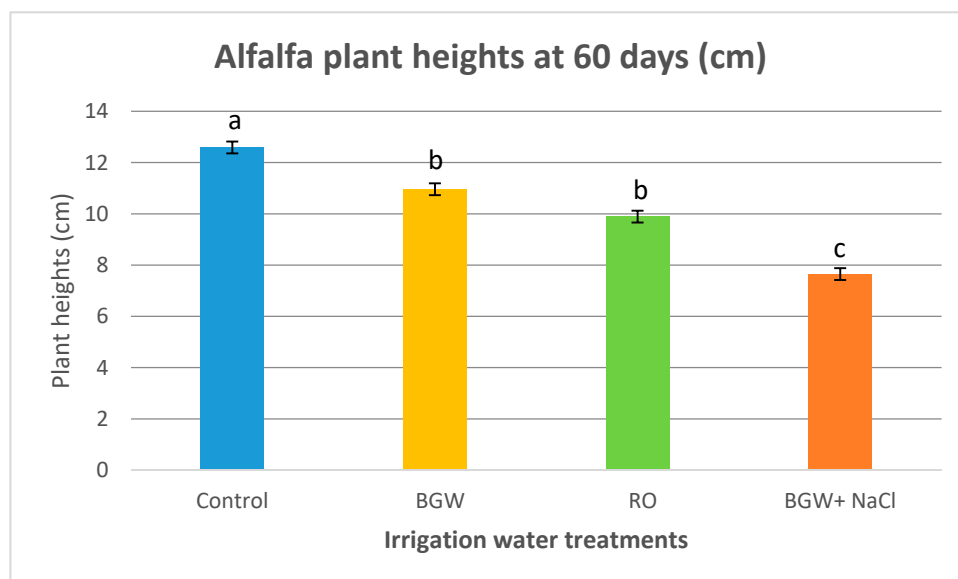


(B)

Figure 3. Leaching fractions (LFs) of alfalfa and triticale calculated with every irrigation in sand soils. Means within species sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of four replications. The ECs of the saline treatments were control (0.7 dSm^{-1}), BGW (4 dSm^{-1}), RO (8 dSm^{-1}), and BGW + NaCl (8 dSm^{-1}).

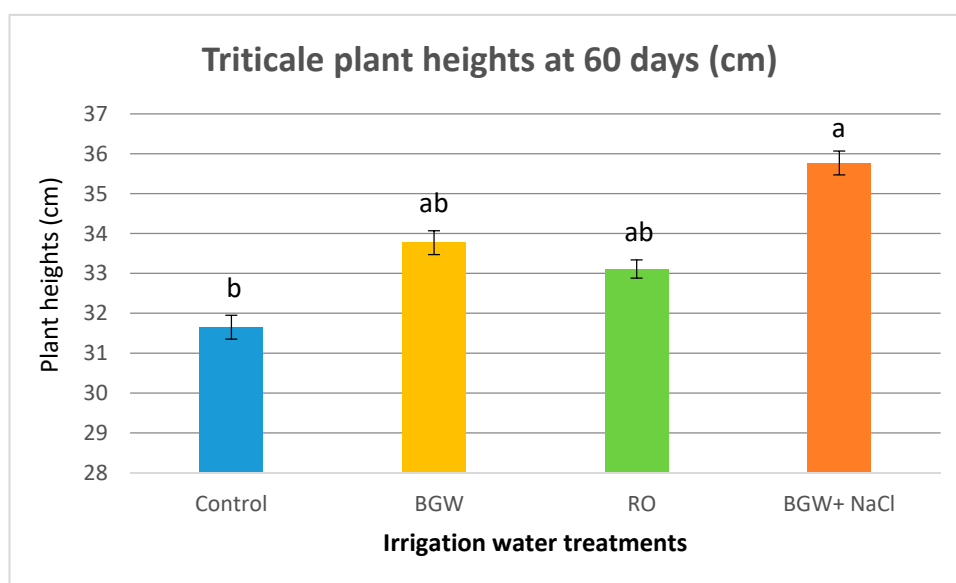
3.4. Plant Heights

Although plant heights were measured three times during the growing season, we are presenting only 60-day plant height data, considering it to be the active growth stage for both species. On day 60, alfalfa plants were progressively smaller with increasing irrigation water salinity, and the smallest plant heights were recorded with BGW + NaCl irrigation treatment (Figure 4A).



(A)

Figure 4. Cont.



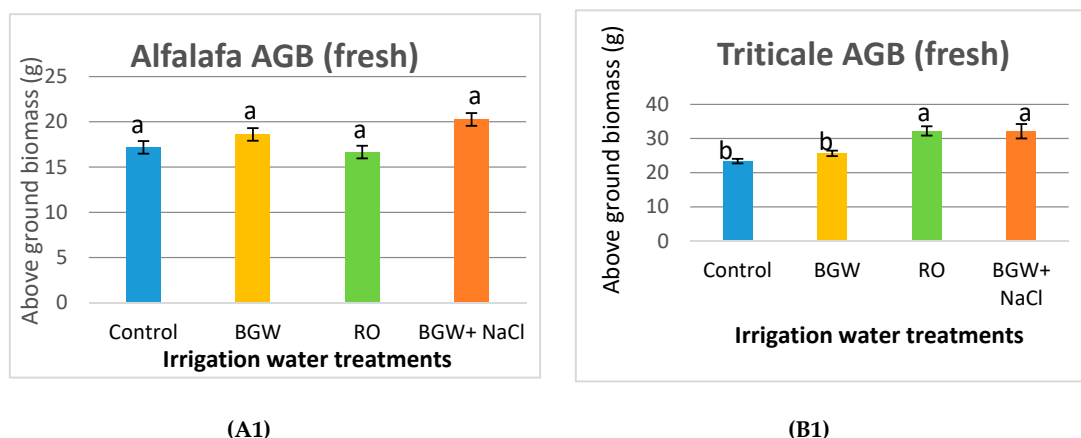
(B)

Figure 4. Plant heights were measured at 30, 60, and 90 days during the entire plant growth period, but the above figure shows the mid-growth stage (at 60 days). Means within species sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of four replications. The ECs of the saline treatments were control (0.7 dSm^{-1}), BGW (4 dSm^{-1}), RO (8 dSm^{-1}), and BGW + NaCl (8 dSm^{-1}).

In contrast, triticale plant heights were unaltered by BGW and RO irrigation treatments, and slightly increased with BGW + NaCl irrigation (Figure 4B). Visually, triticale at the highest salinity, with Na^+ dominant BGW + NaCl irrigation treatment, displayed tall and sturdy plant growth with bright green leaves (Figure 4B).

3.5. Fresh and Dry Aboveground Biomass

AGB (fresh and dry) included all biomass (woody and herbaceous) and contained stems, foliage, leaves, and ear heads. Fresh AGB did not differ significantly among the irrigation water treatments in alfalfa (Figure 5A1). In triticale, however, fresh AGB increased with increasing salinity in both RO and BGW + NaCl irrigation water treatments by approximately 9 g when compared to the control (Figure 5B1).



(A1)

(B1)

Figure 5. Cont.

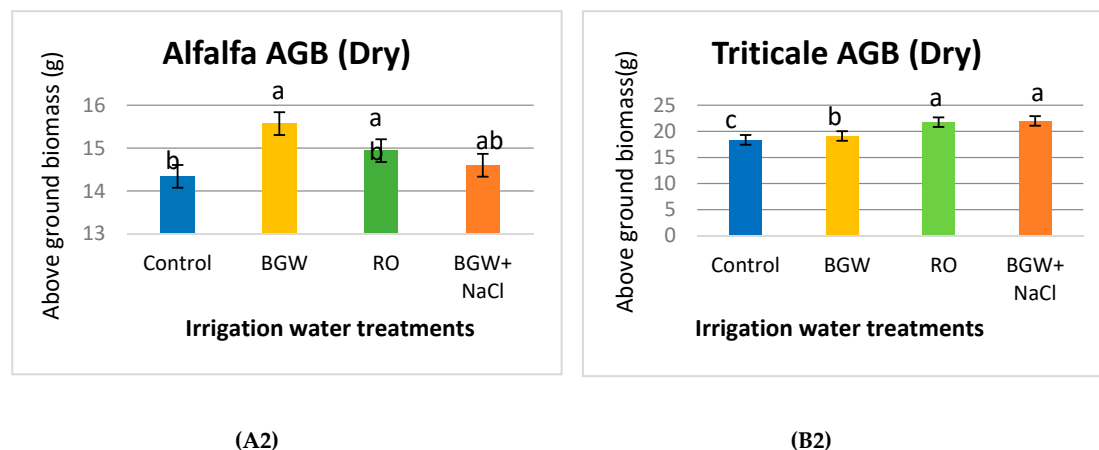


Figure 5. (A1,A2) Aboveground biomass (AGB), fresh and dry, in alfalfa and (B1,B2) triticale after conclusion of two runs. Means within species sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of four replications. The ECs of the saline treatments were control (0.7 dSm^{-1}), BGW (4 dSm^{-1}), RO (8 dSm^{-1}), and BGW + NaCl (8 dSm^{-1}).

Irrigating with BGW produced a significant increase in dry AGB ($15.57 \pm 0.48 \text{ g}$) in alfalfa compared to the control ($14.34 \pm 0.44 \text{ g}$) (Figure 5A2). For triticale, dry AGB increased with increasing salinity, with the highest dry AGB recorded at the highest salinities of RO and BGW + NaCl irrigation (Figure 5B2).

3.6. Shoot Ion Concentration

Alfalfa and triticale shoot Na^+ ion concentration increased with increasing irrigation water salinity, and shoot Na^+ ions increased with the Na^+ dominant BGW + NaCl irrigation (Table 2). Alfalfa shoot Ca^{2+} concentration increased with RO and BGW + NaCl irrigation, while triticale shoot Ca^{2+} increased with BGW and BGW + NaCl. For both species, all saline treatments increased shoot Mg^{2+} ion concentration, but shoot Cl^- increased only with RO and BGW + NaCl irrigation. Highest shoot Cl^- ion concentrations were recorded for BGW + NaCl irrigation in both the species, with 2.6% and 3.7%, respectively.

3.7. Soil Ion Concentrations

For both alfalfa and triticale, soil Na^+ and Mg^{2+} increased, but soil Ca^{2+} concentrations decreased with increasing irrigation water salinity (Table 3). Again in both species, Na^+ concentration increased almost 10–11 times with BGW + NaCl irrigation compared to control. Increasing salinity had no effect on the soil Cl^- concentrations in alfalfa, but resulted in only a marginal increase in triticale.

3.8. Leachate Ion Concentrations

In leachates from alfalfa pots, Na^+ and Cl^- concentrations increased with increasing salinity, particularly with BGW + NaCl irrigation treatment that had much higher proportions of Na^+ and Cl^- (Table 4). For the same pots, Ca^{2+} concentration reached a maximum with BGW + NaCl treatment and not in the Ca^{2+} dominant RO treatment, whereas leachate Mg^{2+} concentration was highest with the latter. In leachate from triticale pots, Na^+ and Cl^- were highest with BGW irrigation and then decreased, while Ca^{2+} and Mg^{2+} ions continued increasing with increasing salinity up to BGW + NaCl irrigation.

Table 2. Effect of irrigation water treatment on shoot ion concentrations (stems + leaves) of alfalfa and (stems + leaves + ear heads) of triticale at the conclusion of two runs conducted in sand soil. Means within columns sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of four replications. The ECs of the saline treatments were as follows: control (0.7 dSm⁻¹), BGW (4 dSm⁻¹), RO (8 dSm⁻¹), and BGW + NaCl (8 dSm⁻¹).

Shoot Ion Concentrations (% of Dry Wt)								
Salinity	Alfalfa (%)				Triticale (%)			
	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻
Control	0.08 \pm 0.009(d)	0.53 \pm 0.06(c)	0.20 \pm 0.05(c)	0.42 \pm 0.03(c)	0.1 \pm 0.01(c)	0.58 \pm 0.01(c)	0.23 \pm 0.00(c)	1.75 \pm 0.03(c)
BGW	0.58 \pm 0.003(c)	0.81 \pm 0.03(b)	0.60 \pm 0.04(b)	0.17 \pm 0.10(d)	0.36 \pm 0.03(c)	0.67 \pm 0.009(b)	0.49 \pm 0.01(b)	2.16 \pm 0.05(cb)
RO	0.66 \pm 0.02(b)	1.85 \pm 0.04(a)	0.86 \pm 0.04(a)	1.39 \pm 0.05(b)	0.62 \pm 0.10 (b)	0.57 \pm 0.02(c)	0.59 \pm 0.14(a)	2.32 \pm 0.19(b)
BGW + NaCl	1.06 \pm 0.03(a)	1.81 \pm 0.05(a)	0.64 \pm 0.02(b)	2.60 \pm 0.10(a)	1.22 \pm 0.03(a)	0.82 \pm 0.03(a)	0.55 \pm 0.03(ab)	3.66 \pm 0.19(a)

Table 3. Effect of irrigation water salinity on soil ion concentrations of alfalfa and *×Triticosecale* after conclusion of two runs conducted in sand soil. Means within columns sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of three replications. The ECs of the saline treatments were as follows: control (0.7 dSm⁻¹), BGW (4 dSm⁻¹), RO (8 dSm⁻¹), and BGW + NaCl (8 dSm⁻¹).

Soil Ion Concentrations (meq L ⁻¹)					Soil Ion Concentrations (meq L ⁻¹)			
Salinity	Alfalfa				Triticale			
	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻ (%)	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻ (%)
Control	1.17 \pm 0.03(d)	90.80 \pm 0.72(a)	5.57 \pm 0.58(c)	0.02 \pm 0.00(a)	1.67 \pm 0.15(d)	89.43 \pm 0.72(a)	6.33 \pm 0.43(b)	0.02 \pm 0.00(c)
BGW	3.53 \pm 0.19(c)	82.90 \pm 0.78(b)	11.83 \pm 0.59(b)	0.02 \pm 0.02(a)	3.90 \pm 0.20(c)	81.2 \pm 0.61(b)	12.97 \pm 0.46(a)	0.03 \pm 0.03(b)
RO	6.57 \pm 0.30(b)	76.47 \pm 1.07(c)	15.23 \pm 0.80(b)	0.02 \pm 0.02(a)	5.67 \pm 0.32(b)	80.50 \pm 0.60(b)	12.57 \pm 0.26(a)	0.04 \pm 0.02(b)
BGW + NaCl	9.43 \pm 0.49(a)	75.87 \pm 0.62(c)	12.90 \pm 0.12(a)	0.05 \pm 0.02(a)	11.43 \pm 0.96(a)	73.90 \pm 1.99(c)	12.83 \pm 0.90(b)	0.11 \pm 0.05(a)

Table 4. Effect of irrigation water salinity on the presence of ions in the leachate of alfalfa and triticale after the conclusion of two runs conducted in sand soils. Means within species sharing the same letter are not significant at $\alpha \leq 0.05$. Each observation is the mean \pm SEs of three replications. The ECs of the saline treatments were control (0.7 dSm⁻¹), BGW (4 dSm⁻¹), RO (8 dSm⁻¹), and BGW + NaCl (8 dSm⁻¹).

Leachate Ion Concentrations (mg)								
Salinity	Alfalfa				Triticale			
	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻
Control	299.61 \pm 61.18(d)	100.01 \pm 43.30(c)	26.45 \pm 5.39(c)	249.67 \pm 84.77(c)	507.29 \pm 83.29(d)	243.80 \pm 27.32(c)	39.86 \pm 5.75 (c)	511.33 \pm 101.58(c)
BGW	2726.09 \pm 457.40(c)	1033.37 \pm 107.68(b)	891.18 \pm 79.67(b)	4745.00 \pm 505.00(b)	2337.67 \pm 219.59(c)	967.92 \pm 10.66(b)	953.32 \pm 96.7(b)	4030.00 \pm 290.00(b)
RO	4737.43 \pm 265.93(b)	974.50 \pm 19.58(b)	1683.1 \pm 132.94(a)	5470 \pm 166.43(b)	—	—	—	—
BGW + NaCl	6251.06 \pm 592.806(a)	1264.76 \pm 119.78(a)	963.937 \pm 86.57(b)	7696.67 \pm 522.632(a)	10248.03 \pm 1047.79(a)	1054.14 \pm 38.56(a)	2115.44 \pm 273.13(b)	10000.00 \pm 0.00(a)

Note: RO leachate samples of triticale were not analyzed because there were no differences at different treatments.

The mass balance for Na^+ and Ca^{2+} ions was determined from the total ions applied through irrigation water, ions removed through deep percolation, ion uptake by plants into their shoots, and the ions deposited into the soil (Table 5). We reported higher mass balance errors for Ca^{2+} because the soils in New Mexico have high amounts of Ca^{2+} in the soil. In general, it was observed that the mass errors increased as the salinity of irrigation water increased. We could not analyze the total salts accumulated in the roots and other precipitates in the leachate for mass balance.

Table 5. Mass balance for Na^+ and Ca^{2+} ions in the irrigation water (control with $\text{EC} < 0.7 \text{ dSm}^{-1}$), BGW (4 dSm^{-1}), RO (8 dSm^{-1}), and BGW + NaCl (8 dSm^{-1}). Na, sodium; Ca, calcium.

Salinity	Total Salt Applied (mg)		Total Salt in Leachate (mg)		Total Salt in Shoots (mg)		Total Salt in Soil (mg)	
	Na^+	Ca^{2+}	Na^+	Ca^{2+}	Na	Ca^{2+}	Na^+	Ca^{2+}
Alfalfa								
Control	465.5	414.4	299.6	100.0	11.5	7.6	85.7	5785.8
BGW	2920.1	3264.0	2726.1	1033.4	90.3	12.6	258.7	5282.4
RO	5536.6	5580.8	4737.4	974.5	98.6	276.4	481.4	4872.7
BGW + NaCl	9220.2	3004.8	6251.1	1264.8	154.8	264.3	691.0	4834.4
Triticale								
Control	605.18	538.72	507.29	243.80	18.36	107.77	122.37	5698.48
BGW	3796.10	4243.20	2337.67	967.92	68.76	27.97	285.78	5174.06
RO	7197.53	7255.04	0.00	0.00	134.91	124.03	415.49	5129.46
BGW + NaCl	11986.31	3906.24	10248.03	1054.14	268.28	180.32	837.57	4708.91

4. Discussion

4.1. Water Balance Parameters

Our results showed a species-dependent significant ET reduction for both species with BGW + NaCl irrigation as observed by Katerji et al. [37]. Studies have reported to maintain LFs above 15% when irrigating plants with water above 0.7 dSm^{-1} [38]. LFs increased at higher salinities in both species, with BGW and BGW + NaCl irrigation in alfalfa and with BGW + NaCl irrigation in triticale. Khan and Glenn [17] reported higher variability in LFs of triticale species. Flores et al. [10] reported that triticale had the lowest LF of all the halophytes, but produced some of the highest dry biomass, which is similar to our findings and seems to suggest that triticale has a mechanism to combat “physiological drought” caused by salinity stress [39].

4.2. Plant Heights and Biomass

The majority of the time, an increase in salinity corresponds to a decrease in plant growth and results in lower biomass, crop cover, and ET from the plants [40]. In our study, alfalfa plants grew less with increasing irrigation water salinity, whereas triticale plants grew more with increasing irrigation water salinity, with increased plant height and higher shoot biomass, which qualifies it as a halophyte. Some salt-tolerant species display mild toxicity symptoms, while halophytes generally benefit and grow [41]. In our study, triticale showed increased growth and maturity at the highest salinity with BGW + NaCl. In triticale, fresh and dry biomass increased two- to seven-fold with BGW, RO, and BGW + NaCl irrigation. This indicated the high salt-tolerant behavior of triticale. These results demonstrate that triticale is a true halophyte and not a moderate halophyte as reported in literature. Similar to our results for triticale, barley (*Hordeum vulgare*) irrigated with saline water was reported to reach reproductive maturity sooner, display early flowering and ear head formation, and produce more biomass [37]. In contrast, Khan and Glenn [17] reported a decrease in biomass of barley. Our results concur with those of Shalaby et al. [42] where triticale displayed increased shoot biomass when irrigated with Ca^{2+} and NaCl dominant irrigation water. This is because halophytes possess a range of

highly efficient and complementary morphological, physiological, and anatomical characteristics to combat and benefit from a saline environment [3,15,39]. Ozturk et al. [20] in their study on triticale irrigated with non-sodic Ca^{2+} and Mg^{2+} dominant irrigation water with an EC up to 10 dSm^{-1} , did not show any reduction in biomass, and our results report no decrease in biomass with 8 dSm^{-1} Na^+ dominant irrigation water.

4.3. Shoot Ion Content

The most common salts that inhibit plant growth are Na^+ and Cl^- because of their high solubility as well as various ionic interactions between Na^+ and Ca^{2+} or formation of complex carbonates [43]. Glycophytes try to restrict ion movement from roots to shoots, whereas halophytes tend to take up Na^+ ions [44,45]. In this study, we found higher Na^+ accumulation in shoots of triticale (1.22 ± 0.03 %) than alfalfa (1.06 ± 0.03 %) at the highest salinity with BGW + NaCl irrigation. Our data showed that Na^+ above 0.66% in alfalfa led to plant growth suppression, while in triticale no growth decline was seen with shoot Na^+ ions up to 1.22% (Table 2). This could be explained as: Na^+ ions are sequestered in the leaf vacuoles; the ion exchangers and the H^+ pumps located on the tonoplast help to generate electrochemical difference of H^+ , contributing to the membrane potential. This could help with the channel transport activity and keep the water regulated in the cytoplasm for maintaining metabolism and plant growth [46]. Moreover, halophytes have the ability to use inorganic ions such as Na^+ and Cl^- without spending energy (adenosine triphosphate [ATP]) along the electrochemical gradient for osmotic adjustment under saline conditions. All these confirm that triticale is a halophyte.

Halophytes have good NaCl regulation mechanisms with ion-gated channels [47]. They can accumulate NaCl in vacuoles to maintain a low ion concentration in the cytoplasm and good metabolism. We also recorded a slightly higher accumulation of Na^+ in alfalfa shoots at the highest salinity, indicating some salt tolerance for the alfalfa.

Reduced plant growth and functioning in glycophytes was reported when Na^+ was present in excess in the plant system and Ca^{2+} and K^+ were excluded [48]. In this study, alfalfa displayed reduced plant growth when the highest Na^+ concentration was present in its shoots.

Calcium is an important ion because it can defend the plant against high sodium by managing the selection of sodium over potassium, and its absence causes immediate loss of function within the plant [49]. Calcium helps plants exclude Na^+ by lowering cell permeability to Na^+ and by enhancing the activity of Na^+ transporters in the cell membrane [46]. Our results showed increased Ca^{2+} in shoots with RO and BGW + NaCl irrigation only in alfalfa. It can be concluded that triticale has the potential to utilize Na^+ ions for its growth and produce significantly higher fresh and dry biomass at higher salinity with BGW + NaCl, whereas higher Ca^{2+} likely helped lower Na^+ ion toxicity in alfalfa.

Magnesium is an important element because it activates enzymes and is important for RNA and DNA formation. Mg^{2+} ions remained low with increasing irrigation water salinity, but increased slightly with irrigation in both the species. According to Epstein and Bloom [49], a slight increase of Mg^{2+} ions is not particularly detrimental to the plant.

Chloride is an essential micronutrient for growth and development because it helps produce oxygen in the photosynthetic process [49]. However, it could be toxic to plants at high concentrations. Cl^- could be very damaging to plants because, like Na^+ , it accumulates in the shoots and inhibits photosynthesis [50,51]. Our results showed increased Cl^- ions in shoots of both species that reached 2.6% to 3.7% in alfalfa and triticale, respectively. It did inhibit plant growth and dry biomass production in alfalfa at the highest saline irrigation, but triticale remained unaffected despite increasing chloride ions.

4.4. Soil and Leachate Ion Content

In our study, Na^+ ion concentrations found in the BGW + NaCl irrigated soil were 10–11 times higher than in the control. The sodium absorption ratio (SAR) for BGW + NaCl irrigated soil was 12.02, which is very close to being sodic, with a high Na^+ ion concentration of 50.11 meq L^{-1} . An increase in

soil SAR can cause a decrease in soil hydraulic conductivity [52]. Na^+ , Cl^- , and Ca^{2+} leached with the increasing salinity in all pots, and accumulation in the shoot was also observed, resulting in lower Ca^{2+} concentration in the soil. Triticale was able to utilize Na^+ to increase its biomass at the highest salinity, while alfalfa seemed to utilize Ca^{2+} in its shoots to counter Na^+ and Cl^- salinity toxicity. However, it appears that alfalfa could not maintain a $\text{Ca}^{2+}/\text{Na}^+$ ratio, and alfalfa biomass therefore declined. Soil Cl^- concentrations were also low, but some uptake took place, and that could have also contributed to the low alfalfa biomass yield. Not much of the Mg^{2+} ions showed up in the shoot biomass, but they did leach through all pots.

5. Conclusions

This study examined the effects of utilizing BGW and RO concentrates as irrigation sources on the performance of two important and extensively cultivated forage species. Utilizing BGW and RO concentrates as irrigation water for long periods can build up salts in the soil, for which a higher LF needs to be maintained. Moreover, these species have a limited potential for uptake of beneficial ions such as Na^+ or Ca^{2+} . A higher LF helps to leach out all the accumulated salts from soil and groundwater. Based on our results, alfalfa was more inclined towards being a salt-tolerant species when irrigated with Na^+ dominant irrigation water, while triticale displayed good growth and increased biomass production despite high salinity. The unique characteristics of alfalfa to utilize Ca^{2+} in its shoots to counter Na^+ and Cl^- salinity toxicity makes it a good candidate for irrigating with brackish groundwater and RO concentrates. Triticale established itself to be a halophyte that can utilize Na^+ ions for its growth and biomass production at the highest salinity with BGW + NaCl. The tall, vigorous plants with an early maturity at high salinity are a good fit for cultivation in water-scarce desert regions.

An appropriate land use management plan and irrigation scheduling using BGW and RO concentrates as irrigation water for growing alfalfa and triticale can meet our future forage requirements in degraded rangelands. However, the availability and the economic feasibility of utilizing saline water for agriculture depends on various factors. The amount of RO concentrate that could be made available depends upon the size and the recovery rate of the desalination plant, water source, type of reverse osmosis membranes used for the process, and the desired TDS (total dissolved solids) of the concentrate. In United States, there are 534 desalination plants, and the largest inland desalination plant is located in El Paso, Texas, which can produce 27.5 mgd of fresh water. In general, these desalination plants are not located adjacent to agricultural areas, and RO concentrate needs to be transported to agricultural fields depending upon the distance. Efforts are on to reduce these limitations. Rotating the reuse of brackish groundwater and reusing the saline water to grow forage crops seems to be a promising option in promoting soil and air quality, while additional forage production will go a long way in supporting cattle, managing degraded rangelands, and controlling desertification.

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