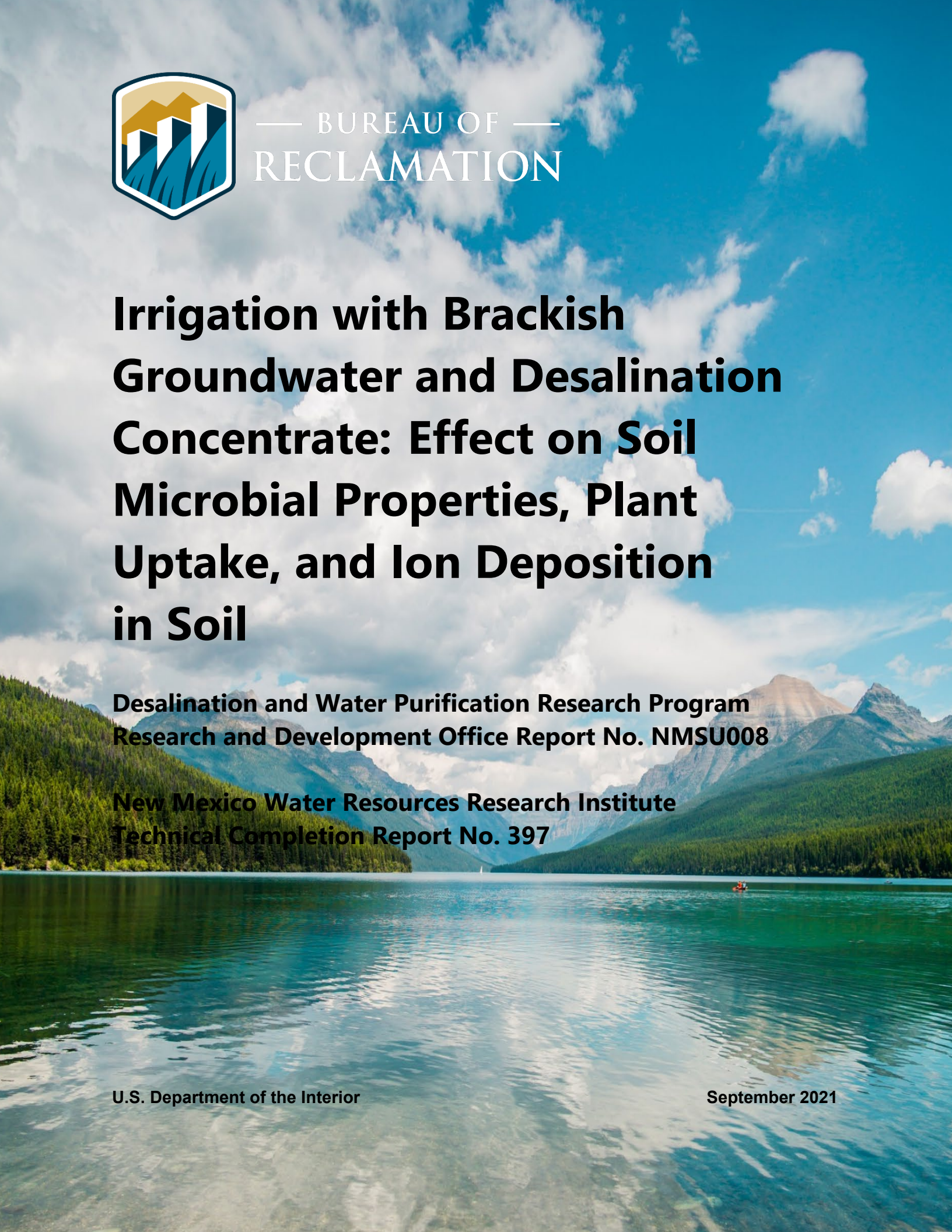

BUREAU OF RECLAMATION

Irrigation with Brackish Groundwater and Desalination Concentrate: Effect on Soil Microbial Properties, Plant Uptake, and Ion Deposition in Soil

Desalination and Water Purification Research Program
Research and Development Office Report No. NMSU008

New Mexico Water Resources Research Institute
Technical Completion Report No. 397

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14. ABSTRACT Surface water for irrigation is getting scarce and brackish groundwater is increasingly used to supplement the shortfall. This project analyzes the impact of irrigation with brackish groundwater and reverse osmosis (RO) concentrate (both from the Brackish Groundwater National Desalination Research Facility (BGNDRF)) on soil physical, chemical, and microbial properties important for maintaining soil health.			
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Prepared for the Bureau of Reclamation Under Agreement No. R16AC00002

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Acknowledgments

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Acronyms and Abbreviations

AFRI	Agriculture and Food Research Initiative (U.S. Department of Agriculture)
AC	*Atriplex canescens*
AL	*Atriplex lentiformis*
BC	Blaney-Criddle
Ca	Calcium
CAP	Coordinated Agricultural Project (U.S. Department of Agriculture)
Cl	Chloride
BSR	Basal soil respiration
BGNDRF	Brackish Groundwater National Desalination Research Facility
EC	Electrical conductivity
ET	Evapotranspiration
ICP	Inductively Coupled Plasma
K	Potassium
Mg	Magnesium
NMSU	New Mexico State University
N	Nitrogen
PI	Principle investigator
RO	Reverse osmosis
Na	Sodium
SAR	Sodium absorption ratio
NaCl	Sodium chloride
H	Shannon diversity index
SWP	Stem water potential
USDA	United States Department of Agriculture
UA	University of Arizona

Measurements

bar	bar
°C	degree Celsius
cm	centimeter
ds/m	deciSiemens per meter
ha	hectare
m	meter
mg C/kg soil	milligram carbon per kilogram soil
mg CO_2-C/kg soil/day	milligram carbon dioxide carbon per kilogram soil per day
mg N/kg soil	milligram nitrogen per kilogram soil
mg/L	milligram per liter
mm	millimeter
mm day^{-1}	millimeter per day
µg p-NP/g soil/h	microgram phosphorous nitrogenphosphate per gram soil per hour

Variables

ET_{0BC}	reference evapotranspiration
k	monthly consumptive use coefficient
p	percentage of total daytime hours for the period (daily or monthly)
Ra	extraterrestrial radiation
T_{mean}	mean of T_{max} and T_{min}
Ta	mean air temperature

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Executive Summary

Severe drought as a result of low precipitation, and high evapotranspiration rates in the southwestern U.S. including New Mexico have stressed variably brackish groundwater for irrigation purposes. Desalination using reverse osmosis (RO) produces both fresh water and highly saline byproduct. RO concentrate, a byproduct of brackish groundwater desalination, can be a source of irrigation water for salt tolerant crops. But in that event, issues related to soil health must be investigated due to the accumulation of salts in the soil. The objectives of this study were to: (i) identify salt deposition patterns due to the drip irrigation method, (ii) measure the plants' ion uptake, changes in plants, and ion concentrations, and (iii) determine the impact of irrigation with brackish groundwater and RO concentrate on the soil microbial community and soil organic carbon.

In this three-year study, brackish groundwater and RO concentrate were Ca dominant and were used to irrigate two halophytic species: *Atriplex canescens* and *Atriplex lentiformis*. This study was conducted in Alamogordo, New Mexico at the Brackish Groundwater National Desalination Research Facility (BGNDRF). The drip irrigated field was divided into two blocks, North and South. The two blocks were planted with mixed *Atriplex canescens* and *Atriplex lentiformis*. Several measurements were taken on soil texture using the hydrometer method, soil water content using the gravimetric method, EC using an EC meter, evapotranspiration (ET) using Blaney-Criddle and Hargreaves models, stem water potential (SWP) using a pressure chamber, as well as plants' ionic uptake, and soil microbial composition. The soil microbial biomass was measured using the fumigation-extraction method. Dissolved organic carbon C and nitrogen N were determined using a Vario-Cube analyzer. Soil, water, and plant samples were collected and sent to AgSource Lab, Nebraska for ion analysis.

No-significant differences were found for ET between the two models. Na and Cl concentrations in soil at a location 90 cm from the west side of the plant trunk were 2844 mg/l at 80% irrigation rates and 5236 mg/l at 60% irrigation rates. Na and Cl at a 60% irrigation rate at 25 cm depth were 1965 mg/l and 5877 mg/l, respectively. A somewhat bell-shaped curve distribution was observed with salt deposition at the edge of the wetting front. The SWP for *Atriplex canescens* was -27 bar. Na and Cl were 5.87 mg/l and 11.1 mg/l, respectively, in *Atriplex canescens* leaf sample. Soil pH was around 8. Soil nitrate produced a nitrogen content of 18.94 mg N/kg for soil at the surface on the north side. Soil ammonia was 0.49 mg N/kg for soil on the north side near the soil at the surface. Soil organic carbon was 3.15% at the soil surface. Microbial biomass was 221 mg C/kg soil at the surface and 140.6 mg C/kg soil at 40 cm soil depth. Glycosaminidase enzyme was 40.62 ug p-NP/g soil/h at 40 cm soil depth. The Shannon microbial diversity index was 3.58 H index at the soil surface and 1.94 H index at 40 cm soil depth. *Atriplex canescens* and *Atriplex lentiformis* showed high performance when irrigated with brackish water and RO concentrate. Future studies should use other *Atriplex* species and explore benefits including their potential as ornamental plants, nitrogen fixation, and other benefits.

1. Introduction

New Mexico and the southwestern U.S. have been under continued and severe drought for the past several years. Continued drought, low rainfall, and high evapotranspiration results in reduced availability of surface water for irrigation, and places increasing pressure on groundwater aquifers that are noncontiguous and saline. High saline water supplies in arid regions are valuable because reverse osmosis (RO) can treat saline groundwater. However, sustainable management of the highly saline concentrate resulting from the RO process is a major environmental problem that limits widespread implementation of inland groundwater desalination in New Mexico and the southwestern U.S. Thus, there is an urgent need to identify solutions for the reuse of RO concentrate, and to design improved irrigation strategies to sustain agriculture in water scarce areas by focusing on food and fodder crops that are tolerant to high saline water.

1.1 Project Background

This project aims to determine the accumulation patterns of various ions in soil that is drip-irrigated with RO concentrate. It quantifies the impact of RO concentrate application on soil microbial properties, ion accumulation, plant ion uptake, and forage quality of *Atriplex canescens* and *Atriplex lentiformis*. The baseline data generated by this proposal are beneficial for research using other nontraditional water sources. It improves the chances of getting additional funding from the Agriculture and Food Research Initiative (AFRI) Coordinated Agricultural Project (CAP), National Science Foundation Track II, and other sources. There is a need to develop a decision support tool for the reuse of different types of nontraditional waters for irrigation to ensure food security as well as for the potential of RO irrigation to mitigate desertification. In addition to data on ion balance, this study provides novel? perspectives on the forage nutritive value of *Atriplex* grown on ground irrigated with RO concentrate.

New Mexico is facing a severe shortage of surface water for irrigation, and the problem is getting worse with continued drought. Since 2010, irrigation water allocation has ranged from 15% to 46% of a year's full allocation. Surface water availability is not likely to improve to full allocation in the near future. Although New Mexico's aquifers have an estimated 20 billion-acre feet of water, it is non-uniformly distributed and about 75% of that water is brackish (Hibbs et al., 1997). Water and salinity stresses are two important abiotic factors that could cause significant plant stress and pose a threat to sustaining agriculture in the region (Adhikari et al., 2012a). There is little information available on the ion deposition patterns resulting from brackish water applied through drip-irrigation systems. Similarly, limited information is available on plant selection, ion uptake, and ion balance for candidate species for cultivation on lands treated with brackish water.

The Brackish Groundwater National Desalination Research Facility (BGNDRF) is located in the Tularosa Basin, Alamogordo, NM. In contrast to coastal desalination facilities that utilize seawater high in sodium and chloride, BGNDRF is an inland desalination facility with

four wells. Sustainable and cost-effective management of concentrate is a major environmental problem that limits widespread implementation of inland groundwater desalination in New Mexico and the southwestern U.S. Interest in land application as a cost-effective treatment system for concentrate has increased, with the focus being on land-applied effluents as a beneficial resource for soil and vegetation rather than as a wastewater "disposal" issue. Sustainable desalination concentrate management will ensure that concentrate accumulation takes place at a depth or location in the soil profile away from the root-zone to avoid vegetation damage and long-term impacts to soil microbial properties or soil health.

Sodium is a large hydrated ion with low charge density that disrupts soil structure and inhibits aggregation. In contrast, calcium has a higher charge density that builds cation bridges and enhances soil aggregation. Thus, given the composition of the groundwater at BGNDRF, evaporating the concentrate may produce a useful agricultural by-product, although our previous work has demonstrated calcite and gypsum formation led to decline in soil hydraulic conductivity (González-Delgado et al., 2011; Adhikari et al., 2012a).

The use of desalinated water and concentrate for growing food and fodder crops is available in Baath and others (2017) who stated that chile pepper, *Capsicum annuum L.*, can be grown with a salinity level of 3 dS/m. Flores and others (2016) illustrated that increases in irrigation salinity increased the dry biomass of *Atriplex canescens* and *Lepidium alyssoides*, respectively. However, questions remain about the applicability of the results on field scales. Such questions include, but are not limited to: where will salt accumulation occur with respect to the drip line (Shukla, 2014), and how will the concentrate application influence the size, activity, and physiological profile of the soil microbial community (Lucero et al., 2011)? In response to these questions, this project aims to produce the knowledge necessary for the development of year-long concentrate disposal strategies that sustainably support salt tolerant food and fodder crops.

Until now, there has been limited technical information on the land application of saline-sodic wastewater to guide land managers in semiarid regions. PI and Co-PIs have published several papers on treated wastewater application to Chihuahuan Desert soil (Babcock et al., 2009; Adhikari et al., 2012b; Picchioni et al., 2012). Research showed that the spatial variability of wastewater irrigation created patches with variable Na concentrations and inverse positional similarity with soil hydraulic conductivity; however, no leaf burns were detected on the native vegetation (Adhikari et al., 2012a; Adhikari et al., 2012c).

Most studies on halophyte germination, growth, and potential as a forage crop utilized laboratory prepared solutions of sodium chloride (NaCl) and other compounds (Soliz et al., 2011; Ghermandi et al., 2013; Ventura et al., 2015; Piovan et al., 2019; Bhatt et al., 2019; Picchioni et al., 2020). Some other studies used brackish groundwater (Panta et al., 2016); however, both brackish groundwater and RO concentrate were used in very limited studies (Flores et al., 2015; 2016; Ozturk et al., 2018). *Atriplex* species have been studied for various

uses including but not limited to food security (Panta et al., 2014; Khan et al., 2015), and their growth potential has been studied in different soils (Flores et al., 2016; Panta et al., 2016). Recently completed greenhouse studies in pots (Tier I) by PI and Co-PIs have demonstrated the potential of the use of Ca-rich concentrate to grow some halophytes. Research has shown that percent germination for all six selected species is unaffected by the salinity of desalination concentrate (Flores et al., 2015). The initial growth experiments showed that the selected six halophyte species grew with no limitation under concentrate irrigation in the sandy soil but some limitations were seen when grown in clay soil (Flores et al., 2016; Flores et al., 2017; Panta et al., 2016). Switchgrass was the only species showing growth limitation in both sand and clay (Flores et al., 2016). A recently completed study at the BGNDRF site (UA and NMSU) determined the growth of *Atriplex* species irrigated with brackish groundwater applications at different rates (80% ETr, 100% ETr, and 120% ETr) (Gallaher et al., 2016).

1.2 Objectives

Our first objective was to identify the salt deposition patterns with respect to the drip line and tree trunk. The second objective was to determine the plant ion uptake, corresponding changes in plants, and ion contents (total applied, accumulated in the soil, plant uptake, and error). Our third objective was to determine the size, activity and physiological profile of the soil microbial community due to irrigation with brackish groundwater and RO concentrate. These three objectives are useful to determine the overall changes to the soil health and are important for designing sustainable concentrate reuse strategies. This project aims to advance science for the sustainable management of concentrate for agriculture.

2. Materials and Methods

2.1 Experimental Site, Irrigation Waters, and Plant Species

The field experimental site is located at BGNDRF, in Alamogordo, New Mexico (32.8832° N, 105.9755° W, elevation 1,322 m), where the PI has an experimental plot (0.4 ha) planted in 2017 with two *Atriplex* varieties. BGNDRF provided the brackish groundwater and RO concentrate. The sodium adsorption ratio (SAR) for all irrigation waters was < 5.9, some cation and anion concentrations are given in Table 1. Plant species selected for this research are *Atriplex canescens* and *Atriplex lentiformis*. These species are native to the southwestern United States and have been identified as potential fodder for cattle. Furthermore, previous greenhouse studies that screened candidate species for cultivation with RO concentrate have indicated that *A. canescens* is especially well suited for growth on salt-contaminated soils (Flores et al. 2016, 2017). *Atriplex* varieties were irrigated with brackish groundwater and RO concentrate at two rates (60% and 80% of reference ET). Irrigation treatments were applied with drip systems (spacing 2x2m) arranged in a completely randomized block design. The dripline was laid north and south. Soil samples were collected at two depths levels (0-25 and 25-50 cm) at three locations (30, 60, and 90 cm from the plant trunk or dripline east and west) in the beginning (base-time) and at the end of the experiment. The reasons for choosing the three locations are that salts move away from the drip line with the advancing wetting front, although differences in

pore spaces and sizes as well as hydraulic conductivities are possible in the 3-D soil volume, salts would continue to move away from dripline in the two directions. Air temperature, wind velocity, humidity and net radiation were recorded. An Excel-based ET calculator was available that was developed for a recently completed study at BGNDRF, similar to the one used in Sammis and others (2012) and Sharma and others (2012). Irrigation volumes (every irrigation) and precipitation volumes were recorded throughout the experiment using an existing weather station on the site.

Table 1. Chemical analysis of the irrigation water.

Irrigation water	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	Cl (mg/l)	K (mg/l)	SAR	EC (dS/m)	pH
Groundwater	17.1	22.5	20	870	4.5	4.5	5	7.4
RO	40	51.8	40.1	1380.4	10.5	5.9	8	7.4

Reference evapotranspiration (ET) was calculated using the Hargreaves and the Blaney-Criddle (BC) equations.

The Hargreaves equation is (Córdova et al., 2015):

$$ET0 = 0.408 \times 0.0023(T\ mean + 17.8)(Tmax - Tmin)^{0.5} Ra \quad (1)$$

where *T mean* is the mean of *Tmax and Tmin*; Ra is extraterrestrial radiation; and the 0.408 coefficient is the conversion factor for MJ m^{-2} day^{-1}) to mm day^{-1}.

The BC equation is (Hafeez et al., 2020):

$$ET0_{BC} = Kp\ (0.46Ta + 8.13) \quad (2)$$

where ET0BC is the reference evapotranspiration (mm) computed by the BC equation, for the period in which p is expressed; Ta is the mean air temperature (°C); p is the percentage of total daytime hours for the period (daily or monthly) out of total daytime hours of the year; and K is the monthly consumptive use coefficient, depending on vegetation type, location, and season.

Soil samples were collected laterally at 10, 30, and 60 cm from drip lines up to 50 cm depths under each water treatment from four different locations during December 2017. These samples were analyzed for water content, electrical conductivity (EC), sodium, magnesium, calcium, and chloride contents at the NMSU Plant and Environmental Sciences labs. This data provided information on depth and distance from the drip line where salt deposition occurred.

Soil samples from four locations under each water treatment were also collected from 0-60 cm depth at an increment of 30 cm and kept in a freezer for soil microbial analysis. The soil microbial biomass was measured using the fumigation-extraction method (Brookes et al. 1985). Dissolved organic carbon C and nitrogen N was determined using a Vario-Cube analyzer (Elementar Americas). Microbial biomass, C, and N were computed as the net flush (fumigated

minus control) of C (or N). C and N mineralization were evaluated by incubation of moist soil samples for 20 days. The rate of CO_2 production during the incubation period was used as a measure of basal soil respiration (BSR). Soil was analyzed for NH_4^+ and NO_3^- concentrations on an Aquakem nutrient analyzer. The net accumulation of mineral N was used to compute the rate of N mineralization. The relative proportion of bacteria and fungi in the soil microflora was determined using the selective inhibition technique (Anderson and Domsch, 1975). Air samples were analyzed for CO_2 using a Varian CP-3800 gas chromatograph (Varian Inc., Palo Alto, CA). The relative contribution of fungal and bacterial biomass to soil respiration was determined using computational approaches described in Anderson and Domsch (1975) and Kaiser and others (1992).

The physiological performance of both *Atriplex* species (four plants per species) were monitored once a year. The photosynthetic rate and stomatal conductance were measured yearly using a portable photosynthetic gas analyzer (LICOR 6400). Stem water potential (SWP) measurements were made on bagged leaves using a Pressure Bomb. The leaf chlorophyll content, an important parameter in determining the photosynthetic rate and a sensitive indicator of plant stress, was determined. Plant samples were used for determining ion uptake for both *Atriplex* species, and sodium, magnesium, calcium, potassium, sulfate, sulfur, and chloride were determined during June and November, separately by species using ICP (inductively coupled plasma) at NMSU. Since *Atriplex* species excrete salt via vesiculated hairs present on the leaf (Belkheiri and Mulas, 2013), we covered some branches inside the canopy in the shaded area to catch the excreted salt. In addition to the ion balance testing, the soil, water, and plant samples were sent to AgSource laboratory, Nebraska for analysis. The ECs and ion composition of irrigation water was monitored. The field was instrumented with sensors to determine soil and weather data.

2.2 Data Analysis

Soil chemistry components (Mg, Ca, Na, SAR, K, N, Cl, and EC) were analyzed as a randomized complete block design RCBD using procedure GLM models (SAS Institute 9.4). Blocks were identified by combinations of field location (north and south), location (distance from plant trunk) (30, 60, and 90 cm, east and west), and two soil depths (0-25 and 25-50 cm) (see Fig. 1). Soil depth, locations (distance from plant trunk), sampling time, and levels of treatments effects on chemistry components were analyzed, separately. Then the block effect was partitioned into field location, distance from plant trunk, soil depth, and field location by distance from plant by soil depth. Field location by distance from plant trunk by soil depth by treatment (60% and 80%) corresponded to the experimental unit. Least squares means were determined for each response variable. Plant chemical components (Mg, Ca, Na, K, N, and Cl) were analyzed using procedure GLM models (SAS Institute 9.4).

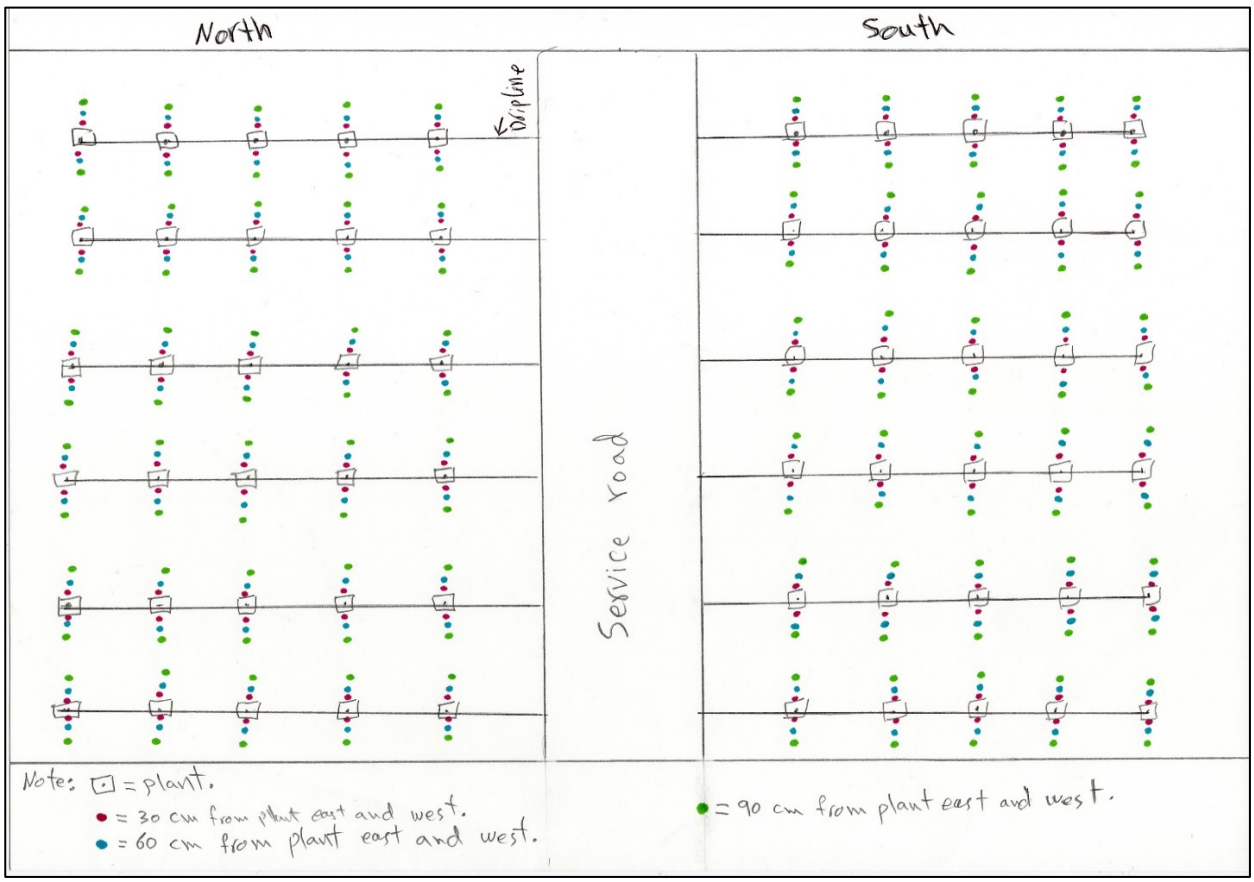

Figure 1. North and south sides of *Atriplex* field, and distance from plant 30, 60, and 90 cm.

2.3 Training Potential

The project employed two graduate students and one undergraduate student. The graduate student is currently working on a PhD degree who collected most samples, and wrote the first draft of the report on the project results. The student will also prepare a paper for submission to a journal. A postdoc completed additional analysis and improved the draft of the report including incorporating comments from reviewers. The undergraduate student was trained as a potential graduate student and ran greenhouse experiments as well as assisted in the soil and plant sampling. This project promoted a strong training program for undergraduate and graduate students of soil and environmental sciences. Proposed methods and results are shared with students of environmental science classes at NMSU (ES 370), and graduate seminars in the Department of Plant and Environmental Science, and for the Water Science and Management program. Research results are shared with growers and stakeholders during field days and annual crop conferences organized by NMSU, Soil Science Society America annual meeting, International Arid lands Consortium, and Win workshop at BGNDRF, Alamogordo.

3. Results

3.1 Reference Evapotranspiration

Reference ET for 2019 is presented below (Fig. 2). The water application for irrigation was 80% and 60% of the BC reference ET during summer months (May to September). Both Hargreaves and Blaney-Criddle equations show similar increase in ET during the summer season which is expected because of the increase in diurnal temperature followed by decreases during fall and winter (Fig. 2).

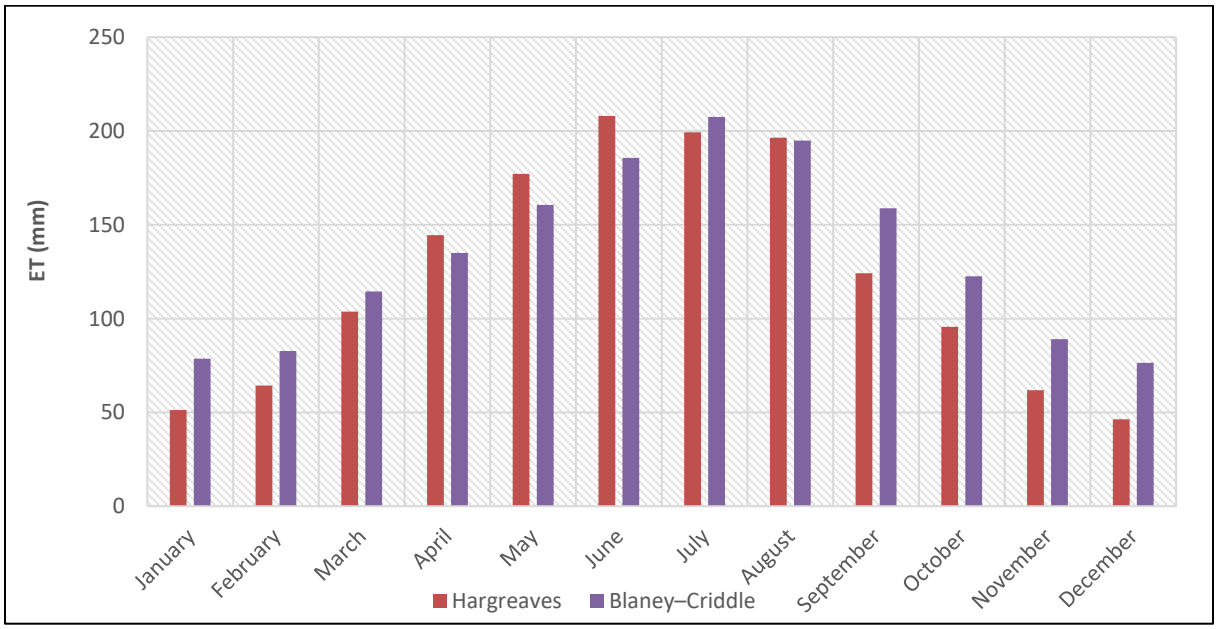

Figure 2. Reference evapotranspiration ET (mm) was calculated using Hargreaves and Blaney-Criddle equations.

3.2 Soil Texture and Chemical Properties Interactions

Soil texture at the experiment site is shown in Table 2. According to the U.S. Department of Agriculture (USDA) classification, the soil texture ranged between loam and clay. At the North Plot, sand ranged from 56.37% to 57.14% and clay from 26.95% to 30.77%, while at the South Plot, sand ranged from 37.28% to 58.46% and clay from 26.50% to 48.54%.

Table 2. Soil texture at two fields (North and South) and two depths (0-25 and 25-50 cm).

Location	Depth	Sand %	Clay %	Silt %	Soil texture
North Plot	0-25	56.37	30.77	12.86	clay-loam
	25-50	57.14	26.95	15.91	loam
South Plot	0-25	58.46	26.50	15.04	sandy-clay-loam
	25-50	37.28	48.54	14.18	clay

Table 3 shows the statistical differences of soil chemical components with respect to the source's effects. Magnesium (Mg) ion concentrations showed differences for sampling time, irrigation rate, location, and irrigation location interaction. Differences on calcium (Ca) ion concentrations can be observed for sampling time, location, soil depth, and irrigation rate location interaction. Sodium (Na) ion concentration was statistically significant for sampling time, irrigation rate, and location from plant trunk. Sampling time and location showed a significant effect on sodium absorption ratio (SAR).

Potassium (K) ion concentration was statistically affected by sampling time, irrigation rate, and location from plant, whereas nitrogen (N) was significantly different for sampling time and location from plant. Sampling time, irrigation rate, location, and irrigation location interaction caused differences in chloride (Cl) concentrations. Electrical conductivity (EC) was significantly affected by both irrigation rate and location from plant trunk.

Table 3. Soil statistical differences of chemical components (Mg, Ca, Na, K, N, Cl, SAR, and EC) with time, irrigation rate, location, depth, irrigation _location, irrigation rate_depth, location_depth, and irrigation_location_depth.

Source	DF	Mg	Ca	Na	SAR	K	N	Cl	EC
		Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Time	1	0.0007*	<.0001*	0.0027*	<.0001*	<.0001*	0.0011*	0.0027*	0.8205
Irrigation Rate	1	<.0001*	0.0725	0.0078*	0.6892	0.0439*	0.081*	<.0001*	0.0134*
Location	5	<.0001*	0.0064*	<.0001*	0.0003*	0.0002*	<.0001*	<.0001*	<.0001*
Depth	1	0.8943	0.0329*	0.9852	0.7281	0.1016	0.3231	0.45	0.9084
Irrigation_Location	5	0.0099*	0.0021*	0.1944	0.2596	0.4929	0.4874	0.018*	0.0671
Irrigation Rate_Depth	1	0.4564	0.6868	0.7297	0.8843	0.8459	0.8292	0.9492	0.7326
Location_Depth	5	0.9526	0.9346	0.8941	0.8734	0.2877	0.431	0.6231	0.6796
Irriga_Location_Depth	5	0.9179	0.9523	0.9315	0.8859	0.9669	0.9745	0.9798	0.9953

Note: Time= beginning and end. Irrigation rate= 60 and 80%. Location= 30, 60, and 90 cm from dripline east and west. Depth= 0-25 and 25-50 cm. DF= degree of freedom. Pr= p value. F= F test value. * = significant differences.

Among ions, Mg, Ca, K, Cl, and SAR, distributions were higher in the first year than the third year; however, Na, N, and EC distribution remained similar for both sampling times (Fig. 3). Mg, Ca, and K, are important for normal plant life and the decrease in those elements would affect the plant growth. Magnesium ion concentration varied from around 400 to 600 mg/l while Ca ion concentration varied from around 1250 to 7500 mg/l. Sodium ion concentration ranged from 1900 to 1600 mg/l whereas SAR ranged from 10 to 18. Potassium ion concentration ranged from 200 to 750 mg/l while N ion concentration ranged from around 220 to 90 mg/l. Chloride ion concentration ranged from 2000 to 3500 mg/l while EC remained around 20 ds/m.

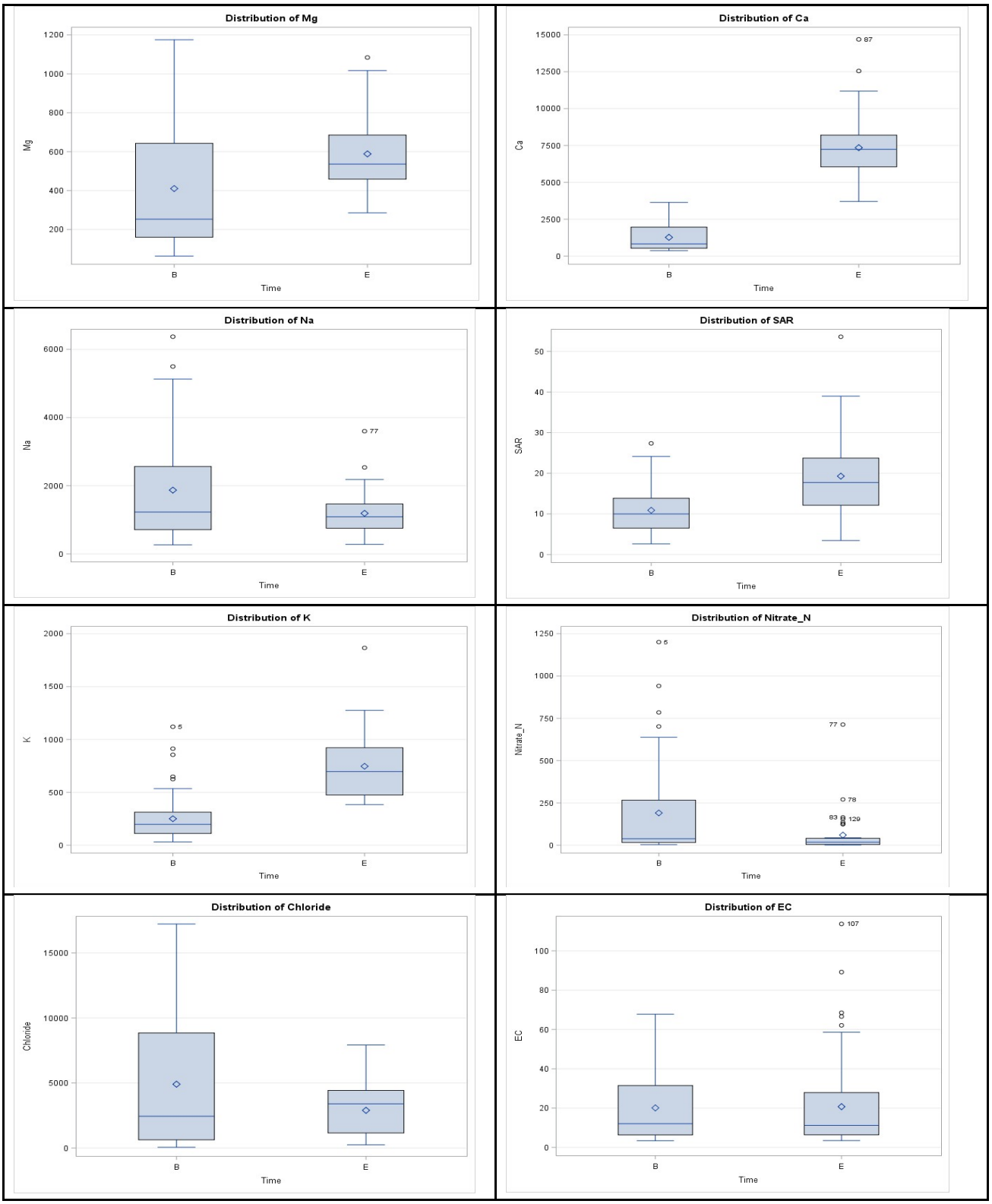

Figure 3. Concentration of ions Mg, Ca, Na, K, NO_3-N, Cl (mg/l), and EC (ds/m) and SAR. Means are distributed by B = baseline sampling in the first year 2017, and E = sampling in the third year (2020).

Soils in plots irrigated at the rate of 60% showed increases in Mg, Ca, Na, SAR, K, Cl, and EC distributions while the nitrogen level remained unchanged for both the 60% and 80% irrigation rates (Fig. 4). Similar trends can be observed in Figure 5, with respect to the location from plant trunk. The dripline was placed north to south and soil samples were collected east to west. Concentrations of Mg, Na, SAR, K, N, and Cl, as well as EC increased with increasing distance from the plant trunk in both east and west directions; however, Ca showed an opposite trend. The increase in concentrations were higher on the east side than the west side for Mg, Na, SAR, N, Cl, and EC (Fig. 5). The reasons could be that salts move away from the drip line, differences in pore spaces and sizes are possible, and salts commutation will change in the two directions However, Mg, Ca, Na, SAR, K, and EC distributions remained similar at both soil depths of 0-25 and 25-50 cm, while the Cl distribution slightly increased at 25-50 cm depth (Fig 6).

After looking through the interactive effects among the four main factors (time, irrigation rate, location of sample, and soil depth), we investigated the effects of each factor on the soil ion concentrations separately to see which factors have greater effects on the concentration of ions overall.

The mean concentrations of Mg, Ca, and K, and SAR increased by the end of the three-year experiment due to the salts deposited to soil from irrigation water compared to the first year when more than 50% of the data values were less than the mean. However, concentrations of Na, N, and Cl decreased by the end of the third year of the experiment compared to the beginning, and the medians were larger than the means (Fig. 3). Figure 4 shows the effect of the irrigation on ion distributions. The mean concentrations of Mg, Na and Cl, and EC increased after applying irrigation at 60% and this could be due to 60% irrigation causing higher concentrate of salts while the mean concentration of K notably decreased. Figure 4 shows the effect of the samples' locations on ion distributions. As can be seen, the mean concentration of all ions at locations 1 and 2 tended to be greater than at other locations. The only ion that was affected by the soil depth was Ca. The distribution of the Ca ions at 0-25 cm was greater than its concentration at 25-50 cm depth (Fig. 6).

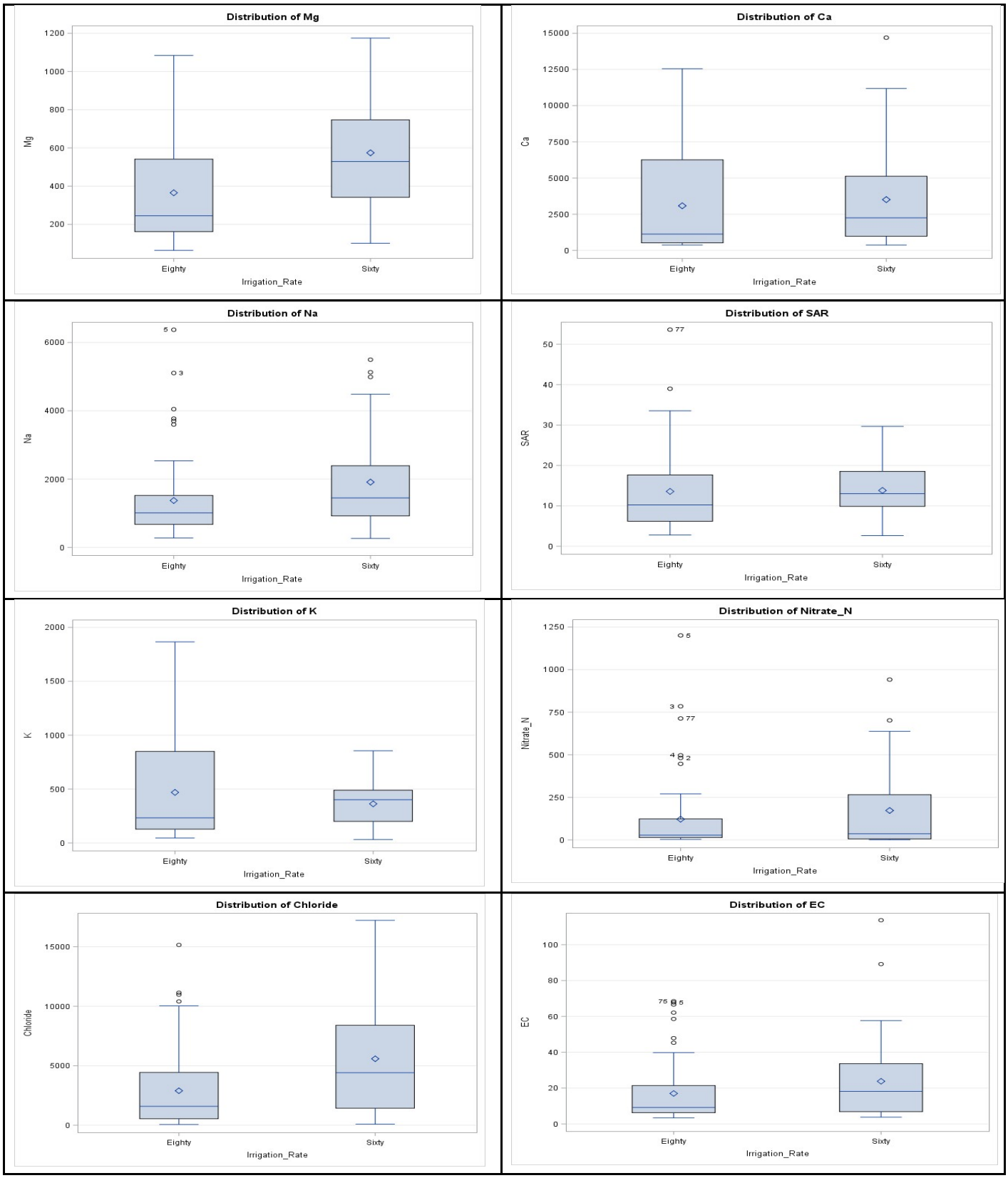

Figure 4. Concentration of ions Mg, Ca, Na, K, NO3-N, Cl (mg/l), and EC (ds/m) and SAR. Means are distributed by irrigation rate. Eighty = 80%, and sixty = 60%.

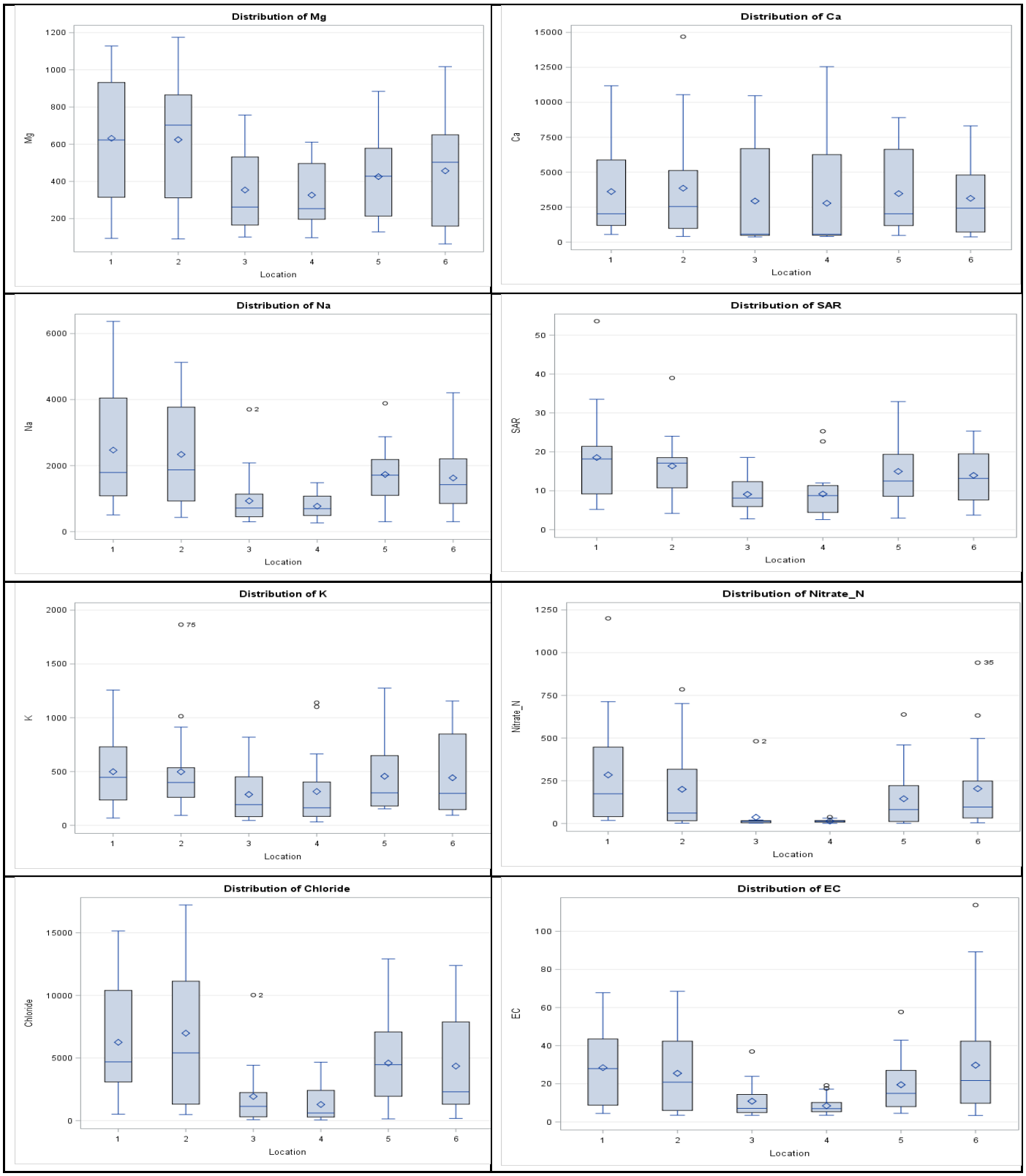

Figure 5. Concentration of ions Mg, Ca, Na, K, NO3-N, Cl (mg/l), and EC (ds/m) and SAR. Means are distributed by location. 1 = 90 cm east, 2 = 60 cm east, 3 = 30 cm east, 4 = 30 cm west, 5 = 60 cm west, and 6 = 90 cm west.

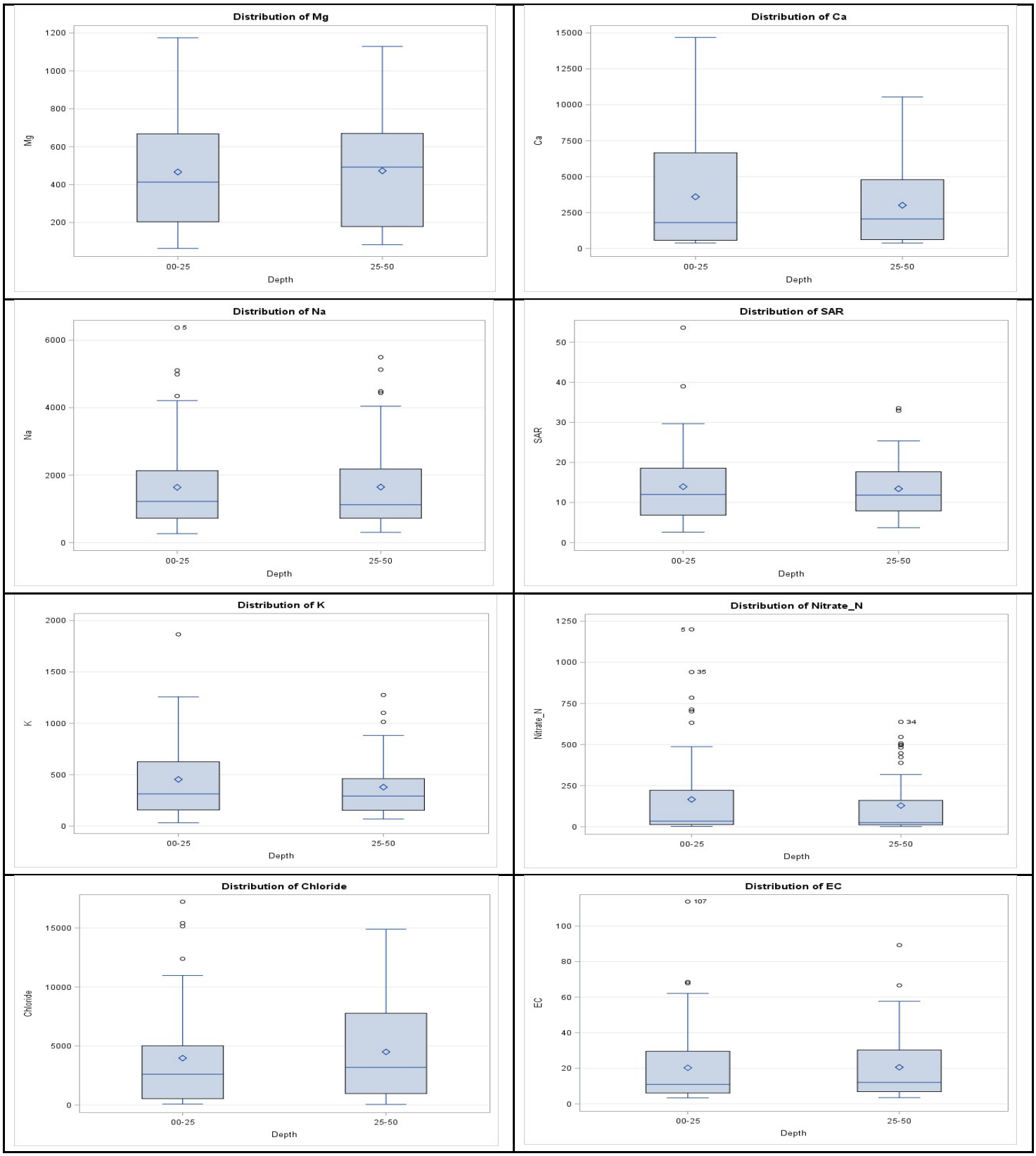

Figure 6. Concentration of ions Mg, Ca, Na, K, NO3-N, Cl (mg/l), and EC (ds/m) and SAR. Means distribution by soil depth (0-25 cm and 25-50 cm).

3.3 Soil Sodium Ion Concentrations

Sodium has adverse effects on soil structure. While sodium enhances soil dispersion, salinity can initially cause soil particles to aggregate, but with increasing zeta potential net dispersion occurs. Also, the forces that bind clay particles together are disrupted when too many large sodium ions come between them. Figures 7 a and b show the effects of the location of plant or dripline (midway between 30E and 30W) and the soil depth on sodium ion concentrations. Increases in the concentration of Na at the depth at 25-50 cm were observed as we move away from 30 cm east to 60 and 90 cm east. Similar observations are true for moving from 30W to 60 and 90 cm west of the plant trunk. However, differences in Na concentrations between 60 cm west of the plant trunk at 25-50 cm depth and 90 cm west were not consistent. Na concentration decreased compared with 0-25 cm depth. Slight increases in Na concentration were found at the depth of 25-50 cm compared with 0-25 cm depth at 90 cm east of plant trunk; however, deceases in Na concentration at 25-50 cm depth at 90 cm east of the plant trunk can be observed when compared with 0-25 cm depth. The figures show that the west side at both soil depths present higher Na concentrations. In general, the trend shows increases in Na concentration as the distance (location) from the trunk increases at both depths.

Table 4 shows the effect of sampling time (first and third year) and irrigation rate (60% and 80%) on sodium concentration. Decreases in Na concentration occurred in the third year; however, missing data for almost half of the samples in the third year would surely affect the data, which was expected to be higher in the third year. An irrigation rate of 60% shows the higher sodium concentration than does the rate of 80%. Decreases in irrigation rate led to increases in Na ion concentration (Table 4).

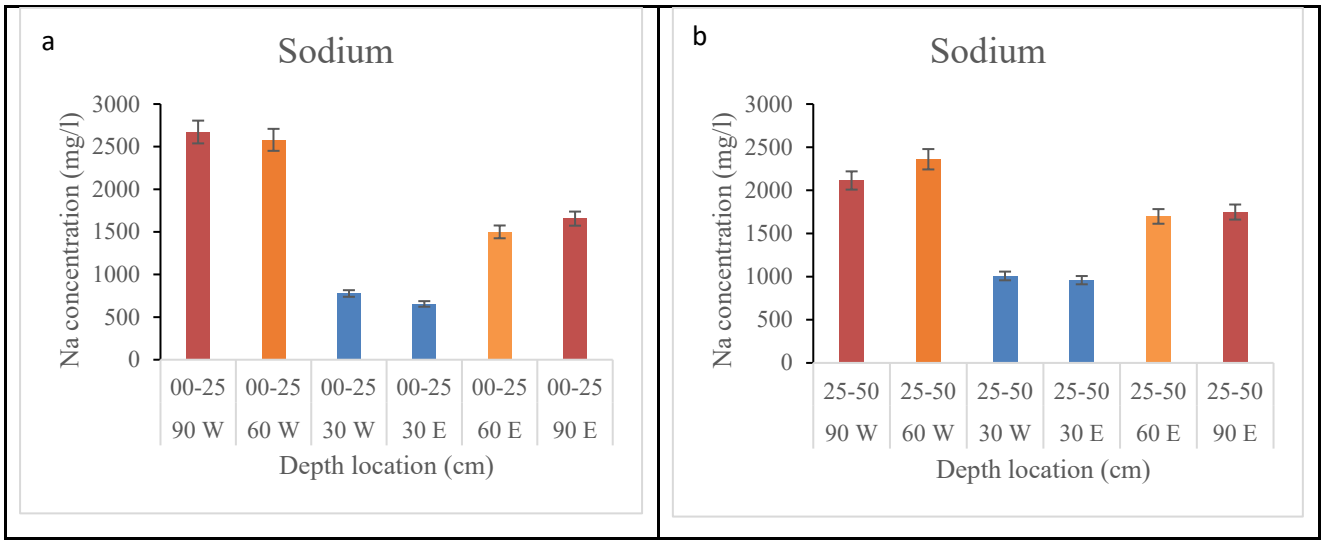

Figure 7 (a, b). Soil sodium ion concentrations (mg/l) mean and standard error at 90, 60, and 30 cm locations west and east from the plant trunk at depths of 0-25 cm and 25-50 cm, respectively.

Table 4. Soil sodium ion concentrations (mg/l) mean with standard deviation in the first year and in the third year and for two irrigation rates (60 and 80%).

Source	Level	Na (mg/l)	
		Mean	Std Dev
Time	First year	1870.86	1520.40 a
	Third year	1189.78	654.46 b
Irrigation rate	80%	1374.46	1248.97 b
	60%	1913.20	1371.79 a

Note: Std Dev lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Irrigation rate and soil depth interaction effect on soil sodium concentration is shown in Table 5. At an irrigation rate of 80%, decreases in Na concentration with increasing soil depth can be observed. At a 60% irrigation rate, Na concentration increased with increasing soil depth.

Table 5. Soil sodium ion concentrations (mg/l) mean and standard deviation for two irrigation rates (60 and 80%) and two soil depths (0-25 and 25-50 cm).

Irrigation rate %	Depth cm	Na (mg/l)	
		Mean	Std Dev
80%	00-25	1419.12	1463.08 a
	25-50	1329.80	1017.39 a
60%	00-25	1860.52	1245.26 a
	25-50	1965.89	1509.82 a

Note: Std Dev lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 6 shows the combination of irrigation rate and location's possible effects on soil Na concentration that could affect the plant growth through root uptake. An irrigation rate of 80% caused increases in Na concentration with increased distance from plant trunk for both directions; however, at 90 cm west, the Na concentration decreased. At a 60% irrigation rate for both 30 and 60 cm distance in both east and west directions, Na concentration increased with increasing distance; however, at a distance of 90 cm in both directions, the concentration decreased.

Table 6. Soil sodium ion concentrations (mg/l) mean and standard deviation for two irrigation rates (60 and 80%) at three locations (30, 60 and 90 cm) east and west from plant trunk.

Irrigation rate	Location	Na (mg/l)	
%	cm	Mean	Std Dev
80%	30E	688.61	314.32 a
80%	60E	869.67	420.99 a
80%	90E	1169.19	508.33 a
80%	30W	1079.15	1031.10 a
80%	60W	2129.12	1365.75 a
80%	90W	2031.84	1987.50 a
60%	30E	901.26	488.56 a
60%	60E	2182.23	1282.69 a
60%	90E	2128.00	1335.33 a
60%	30W	658.97	365.18 a
60%	60W	2896.32	1389.41 a
60%	90W	2844.50	1394.09 a

Note: Std Dev lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 7 shows the effect of irrigation rate, location, and soil depth on Na concentration. At an irrigation rate of 80% at depth of 0-25 cm for both east and west directions, with increasing distance from the plant trunk, increases in soil Na concentration can be observed. This trend was similar for the three distances of 30, 60, and 90 cm east and 30 and 60 cm west; however, at 90 cm west, the concentration decreased. At depth of 0-25 cm with an irrigation rate of 60%, the trend was similar; however, at 90 cm east, the concentration of Na in the soil declined. At a depth of 25-50 cm with a 60% irrigation rate, Na concentration increased with increasing distance from the plant trunk in both east and west directions except at 90 cm west where Na concentration clearly decreased. All these analyses were done to determine how much salt would move away from the rootzone and might not be available for root uptake, which would therefore contribute to good plant health and growth.

Table 7. Soil sodium ion concentrations (mg/l) mean and standard deviation for two irrigation rates (60 and 80%) at three locations (30, 60, and 90 cm) east and west from plant trunk (cm), and two soil depths (0-25 and 25-50 cm).

Irrigation rate	Location	Depth	Na (mg/l)	
%	cm	cm	Mean	Std Dev
80%	30E	00-25	574.27	354.99 a
80%	60E	00-25	733.88	310.71 a
80%	90E	00-25	1308.69	576.58 a
80%	30W	00-25	786.41	479.64 a
80%	60W	00-25	2386.42	1615.56 a
80%	90W	00-25	2396.96	2568.44 a
80%	30E	25-50	802.96	263.92 a
80%	60E	25-50	1005.46	517.53 a
80%	90E	25-50	1029.68	467.52 a
80%	30W	25-50	1371.89	1395.64 a
80%	60W	25-50	1871.81	1192.18 a
80%	90W	25-50	1666.72	1399.16 a
60%	30E	00-25	718.78	319.65 a
60%	60E	00-25	2113.00	806.06 a
60%	90E	00-25	1932.91	682.46 a
60%	30W	00-25	765.20	519.17 a
60%	60W	00-25	2821.86	1550.59 a
60%	90W	00-25	3015.59	1497.76 a
60%	30E	25-50	1083.73	592.99 a
60%	60E	25-50	2251.46	1743.62 a
60%	90E	25-50	2323.08	1857.71 a
60%	30W	25-50	552.73	107.35 a
60%	60W	25-50	2970.77	1444.04 a
60%	90W	25-50	2673.41	1487.78 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.4 Soil Chloride Ion Concentrations

Chloride plays an important role in plants, including aiding in photosynthesis, osmotic adjustment and suppression of plant disease. However, high concentrations of chloride can cause toxicity problems in crops and reduce the yield. Figures 8 a and b show the effects of two soil depths and three locations east and west on soil chloride concentration. The west side at 30 cm from the plant showed increases in chloride concentration at 25-50 cm soil depth compared to 0-25 cm soil depth while at 60 cm distance from plant, chloride concentration decreased at the west side of the plant. At a depth of 25-50 cm, chloride concentration increased on the east rather than the west side at 90 cm distance from the plant. Due to missing data in the third year, chloride concentration was almost half of the concentration in the first year, whereas it was expected to be higher in the third year (Table 8). Chloride concentration was higher with a 60% irrigation rate than at an 80% irrigation rate (Table 8).

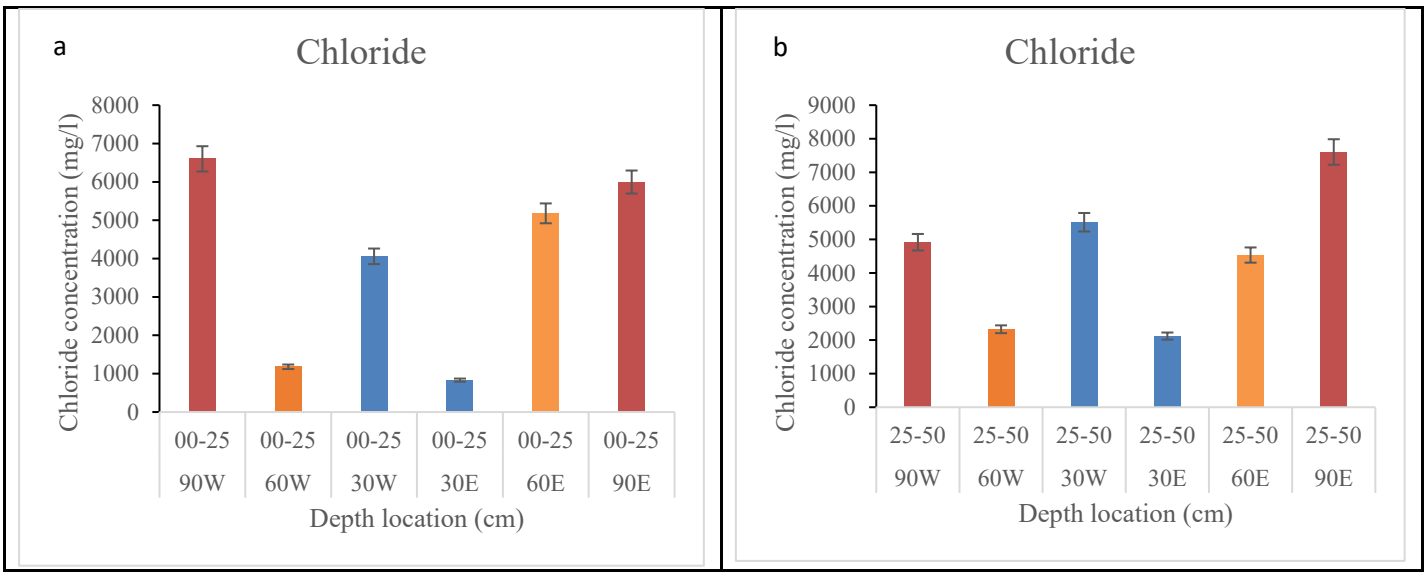

Figure 8 (a, b). Soil chloride ion concentrations (mg/l) at 90, 60, and 30 cm locations west and east from the plant trunk at depths of 0-25 cm and 25-50 cm, respectively.

Table 8. Soil chloride ion concentrations (mg/l) mean and standard deviation in the first year and in the third year for two irrigation rates (60 and 80%).

Source	Level	Chloride (mg/l)	
		Mean	Std Dev
Time	First year	4907.27	4879.23 a
	Third year	2899.47	1901.70 b
Irrigation rate	80%	2892.73	3406.26 b
	60%	5583.27	4562.40 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

At both 0-25 and 25-50 cm soil depths with an irrigation rate of 60%, average chloride concentration was higher than at an 80% irrigation rate (Table 9). At an irrigation rate of 80%, chloride concentration increased with increasing distance from the plant and was the highest concentration observed at 90 cm east from the plant trunk; however, at the 60% irrigation rate, the chloride concentration at 30 cm west from the plant was higher than for 30 cm east (Table 10). The general trend of chloride concentration showed increases with increasing distance from the plant for both east and west sides (Table 10).

Table 9. Soil chloride ion concentrations (mg/l) mean with standard deviation for two irrigation rates (60 and 80%) and two soil depths (0-25 and 25-50 cm).

Irrigation rate	Depth	Chloride (mg/l)	
%	cm	Mean	Std Dev
80%	00-25	2659.27	3464.74 a
	25-50	3126.19	3396.15 a
60%	00-25	5289.35	4802.37 a
	25-50	5877.20	4380.58 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 10. Soil chloride ion concentrations (mg/l) mean and standard deviation for two irrigation rates (60 and 80%) at three locations (30, 60, and 90 cm) east and west from the plant trunk.

Irrigation rate	Location	Chloride (mg/l)	
%	cm	Mean	Std Dev
80%	30E	906.44	755.00 b
80%	30W	1745.39	1843.25 a
80%	60E	2691.45	1440.56 a
80%	60W	2468.39	3204.87 a
80%	90E	5102.29	4065.89 a
80%	90W	3775.43	5061.63 b
60%	30E	1930.77	1417.61 b
60%	30W	7217.28	4862.44 a
60%	60E	6589.05	4124.11 a
60%	60W	855.26	1464.85 b
60%	90E	8923.62	4102.75 a
60%	90W	8236.86	3620.80 b

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 11 shows the interactive effects of irrigation rate, distance from plant, and soil depth on chloride concentration. At a soil depth of 0-25 cm east and west with an 80% irrigation rate, the highest chloride concentration was at 90 cm west of the plant; however, at 25-50 cm soil depth, the highest concentration was at a 60 cm west (Table 11). At 0-25 cm soil depth, east and west of the plant with 60% irrigation rate, the chloride concentration increased with increasing distance from the plant at 90 cm west; however, the highest chloride concentration occurred at 60 cm west from the plant (Table 11).

Table 11. Soil chloride ion concentrations (mg/l), mean and standard deviation for two irrigation rates (60 and 80%) at three locations (30, 60, and 90 cm) east and west from the plant trunk, and for two soil depths (0-25 and 25-50 cm).

Irrigation rate	Location	Depth	Chloride (mg/l)	
%	cm	cm	Mean	Std Dev a
80%	30E	00-25	580.06	475.66 a
80%	60E	00-25	753.10	553.85 a
80%	90E	00-25	3463.83	1646.90 a
80%	30W	00-25	1782.65	1895.76 a
80%	60W	00-25	3970.01	4288.26 a
80%	90W	00-25	4769.79	6027.58 a
80%	30E	25-50	1232.82	905.40 a
80%	60E	25-50	2737.68	2235.00 a
80%	90E	25-50	1919.07	734.17 a
80%	30W	25-50	3154.12	4282.61 a
80%	60W	25-50	6234.57	3949.87 a
80%	90W	25-50	2781.07	4340.71 a
60%	30E	00-25	1032.12	893.13 a
60%	60E	00-25	6703.98	6173.32 a
60%	90E	00-25	6552.32	3369.69 a
60%	30W	00-25	425.76	346.69 a
60%	60W	00-25	8529.41	4743.63 a
60%	90W	00-25	8887.44	3352.58 a
60%	30E	25-50	2829.41	1305.78 a
60%	60E	25-50	7730.58	3798.54 a
60%	90E	25-50	6625.77	5187.54 a
60%	30W	25-50	1284.76	2096.35 a
60%	60W	25-50	9317.82	4044.70 a
60%	90W	25-50	7586.29	4268.73 a

Note: Std Dev in lower case letters correspond to significant differences a = the higher mean. b = the lower mean.

3.5 Stem Water Potential

Stem water potential (SWP) is a sensitive indicator and can clearly show the plant water (and/or salt) stress status. It is affected by several factors such as irrigation, precipitation, wind, temperature, drought, and soil and water salinity. SWP is always negative. Higher SWP indicates more stress occurring in the plant. Plants are stressed and stress further increases with increasing irrigation water salinity. Plant stress as indicated by SWP is variable. As we are growing halophytic species, the values of measured SWP are much lower (-ve value) than those observed for food crops. Still, the plants remain alive. SWP for halophytic species grown in saline soil range between -2.7 bars to -50.7 bars (Ungar, 1977). And according to our results, our plants were moderately stressed (max -36 bar) and the decreasing irrigation rate increased the stress. Table 12 shows the effects of sampling time, irrigation rates, and location. The SWP was higher in the third year than in the first year. As the irrigation rate increased, SWP decreased, while location did not affect it. *Atriplex canescens* showed a lower SWP than *Atriplex lentiformis* (Table 12). Interaction effects of two locations verses two irrigation rates is shown on Table 13. As the irrigation rate decreased (60%), SWP increased for both North and South locations (Table 13).

Table 12. Stem water potential (-bar) mean and standard deviation in the first and third years, irrigation rate (80 and 60%), location (North and South), and plant (*Atriplex C* and *Atriplex L*).

Source	Level	SWP (-bar)	
		Mean	Std Dev
Time	First year	31.21	5.40 a
	Third year	20.75	2.83 b
Irrigation rate	80%	24.77	5.62 a
	60%	27.19	7.87 a
Location	North	25.87	8.82 a
	South	26.08	4.37 a
Plant	AC	27.74	8.05 a
	AL	24.22	5.03 b

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 13. Stem water potential SWP (-bar) mean and standard deviation at two locations (North and South) and two irrigation rates (80 and 60%).

Location	Irrigation rate	SWP (-bar)	
		Mean	Std Dev
North	80%	24.25	8.69 a
	60%	26.69	9.35 a
South	80%	25.03	4.13 a
	60%	28.21	4.60 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

The lower irrigation rate (60%) showed higher SWP in the first year; however, in the third year, the SWP was almost similar for both irrigation rates (Table 14). For both *Atriplex C* and *Atriplex L*, the lower irrigation rate (60%) showed the lowest SWP; however, the differences were not significant (Table 15).

Table 14. Stem water potential SWP (-bar) mean and standard deviation at two times and two irrigation rates (80 and 60%).

Time	Irrigation rate	SWP (-bar)	
		Mean	Std Dev
First year	80%	28.86	4.36 a
	60%	33.55	5.65 a
Third year	80%	20.67	3.19 a
	60%	20.83	2.73 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 15. Stem water potential SWP (-bar) mean and standard deviation for *Atriplex C* and *Atriplex L* under two irrigation rates (80 and 60%).

Plant	Irrigation rate	SWP (-bar)	
		Mean	Std Dev
AC	80%	26.44	6.23 a
	60%	29.05	9.98 a
AL	80%	23.10	4.90 a
	60%	25.34	5.35 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.6 Leaf Ion Concentrations

Leaf ion concentration is important as it can affect the uptake of water, leaf temperature, and photosynthetic rates. Table 16 shows the statistical analysis for leaf ion concentrations. Magnesium was found to vary significantly with the locations and the two *Atriplex* species; however, calcium was statistically different for different locations, plant species, and sampling time (Table 16). Sodium, potassium, and chloride were statistically different between the two *Atriplex* species, and nitrogen was different between locations, sampling time, and irrigation location interaction (Table 16).

Table 16. Statistical differences of leaf chemical components (Mg, Ca, Na, K, N, Cl) with Location, plant, time, irrigation, irrigation_location, irrigation_time, irrigation_plant, and irrigation_location_plant_time.

Source	DF	Mg	Ca	Na	K	N	Cl
		Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Location	1	0.0348*	0.0013*	0.4401	0.2169	0.0008*	0.1920
Plant	1	0.0008*	0.0062*	<.0001*	0.0498*	0.1500	<.0001*
Time	1	0.0802	0.0454*	0.7066	0.8484	0.0089*	0.7182
Irrigation	1	0.6332	0.4066	0.3709	0.6956	0.0575	0.7092
Irrigation_Location	1	0.5178	0.6489	0.9594	0.8900	0.0033*	0.5251
Irrigation_Time	1	0.8530	0.4773	0.6300	0.7329	0.1437	0.7861
Irrigation_Plant	1	0.5817	0.5292	0.5506	0.4653	0.4494	0.9724
Irriga_Location_Plant_time	8	0.2118	0.1485	0.8121	0.1774	0.2843	0.4440

Note: Location = North and South. Plant: *Atriplex lentiformis* and *canescens.* Time: first and third year. Irrigation= 80 and 60%. DF= degree of freedom. Pr= p value. F= F test value. * = significant differences.

Decreases in magnesium, calcium, and sodium distribution with respect to sampling time were observed; however, nitrogen increased while potassium and chloride distribution remained steady (Fig 9). With respect to the irrigation rate, decreases in magnesium and calcium concentrations were found under the 60% irrigation rate; however, sodium and nitrogen concentrations decreased at the 60% irrigation rate (Fig 10). The South location showed increases in magnesium, calcium, and potassium concentrations, while sodium and nitrogen concentrations decreased at the same location (Fig 11). *Atriplex lentiformis* leaf samples showed decreases in magnesium, calcium, sodium, and chloride concentrations whereas potassium and nitrogen concentrations increased (Fig 12).

Figure 9 shows the changes in Mg, Ca, Na, K, N, and Cl ion concentration in the leaf by sampling time. Magnesium ion concentration ranged from 0.9 to 0.79 mg/l while Ca ion concentration ranged from 1.4 to 1.26 mg/l. Na ion concentration ranged from around 3.7 to 3.5

mg/l, whereas K ion concentration ranged from 4.5 to 4.3 mg/l. N ion concentration ranged from 2.1 to 2.4 mg/l, while Cl ion concentration ranged from 7.5 to 7.8 mg/l.

Figure 10 shows the changes in Mg, Ca, Na, K, N, and Cl ion concentrations in the leaf by irrigation rate. Mg ion concentration ranged from 0.9 to 0.8 mg/l, while Ca ion concentration ranged from 1.35 to 1.25 mg/l. Na ion concentration ranged from 3 to 3.8 mg/l, whereas K ion concentration ranged from 4.5 to 4.4 mg/l. N ion concentration ranged from around 2.1 to 2.5 mg/l, while Cl ion concentration ranged from 7.5 to 7.3 mg/l.

Figure 11 shows the changes in Mg, Ca, Na, K, N, and Cl ion concentrations in the leaf for North and South locations, respectively. Mg ion concentration ranged from 7.7 to 9.2 mg/l, while Ca ion concentration ranged from around 1.2 to 1.56 mg/l. Na ion concentration ranged from 3.7 to 3 mg/l whereas K ion concentration ranged from 4.2 to 4.7 mg/l. N ion concentration ranged from 2.52 to 2 mg/l, while Cl ion concentration ranged from 6.5 to 7.5 mg/l.

Figure 12 shows the changes in Mg, Ca, Na, K, N, and Cl ion concentrations in the leaf for *Atriplex canescens* and *Atriplex lentiformis*, respectively. Mg ion concentration ranged from 1 to 0.7 mg/l, while Ca ion concentration ranged from around 1.5 to 1.23 mg/l. Na ion concentrations ranged from 5.9 to 0.9 mg/l whereas K ion concentration ranged from 4.1 to 4.9 mg/l. N ion concentrations ranged from 2.25 to 2.35 mg/l, while Cl ion concentration ranged from 11.5 to 3 mg/l.

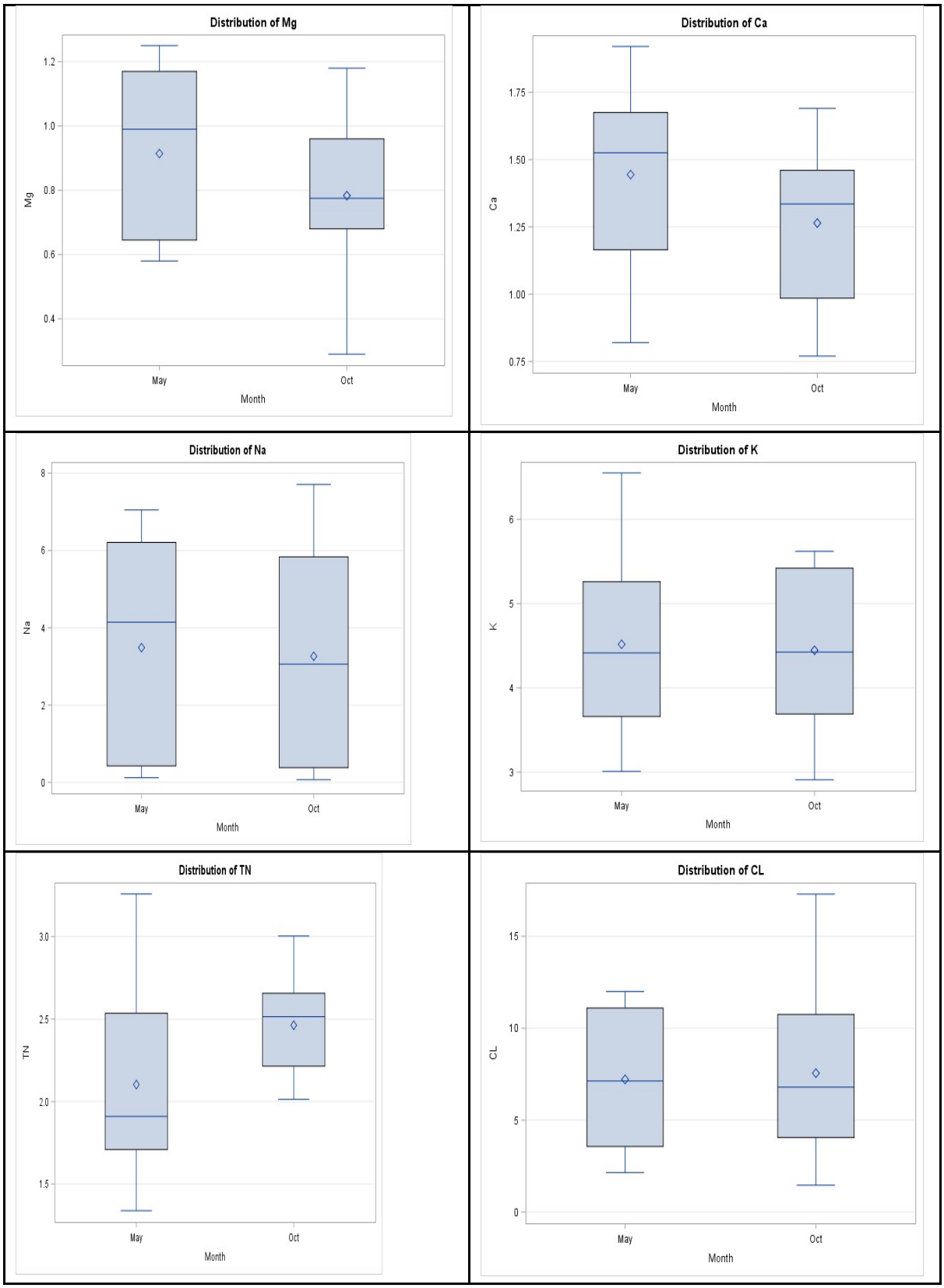

Figure 9. Leaf chemical components Mg, Ca, Na, K, N, and Cl (mg/l) means distribution by time. May = beginning, and October = end of experiment.

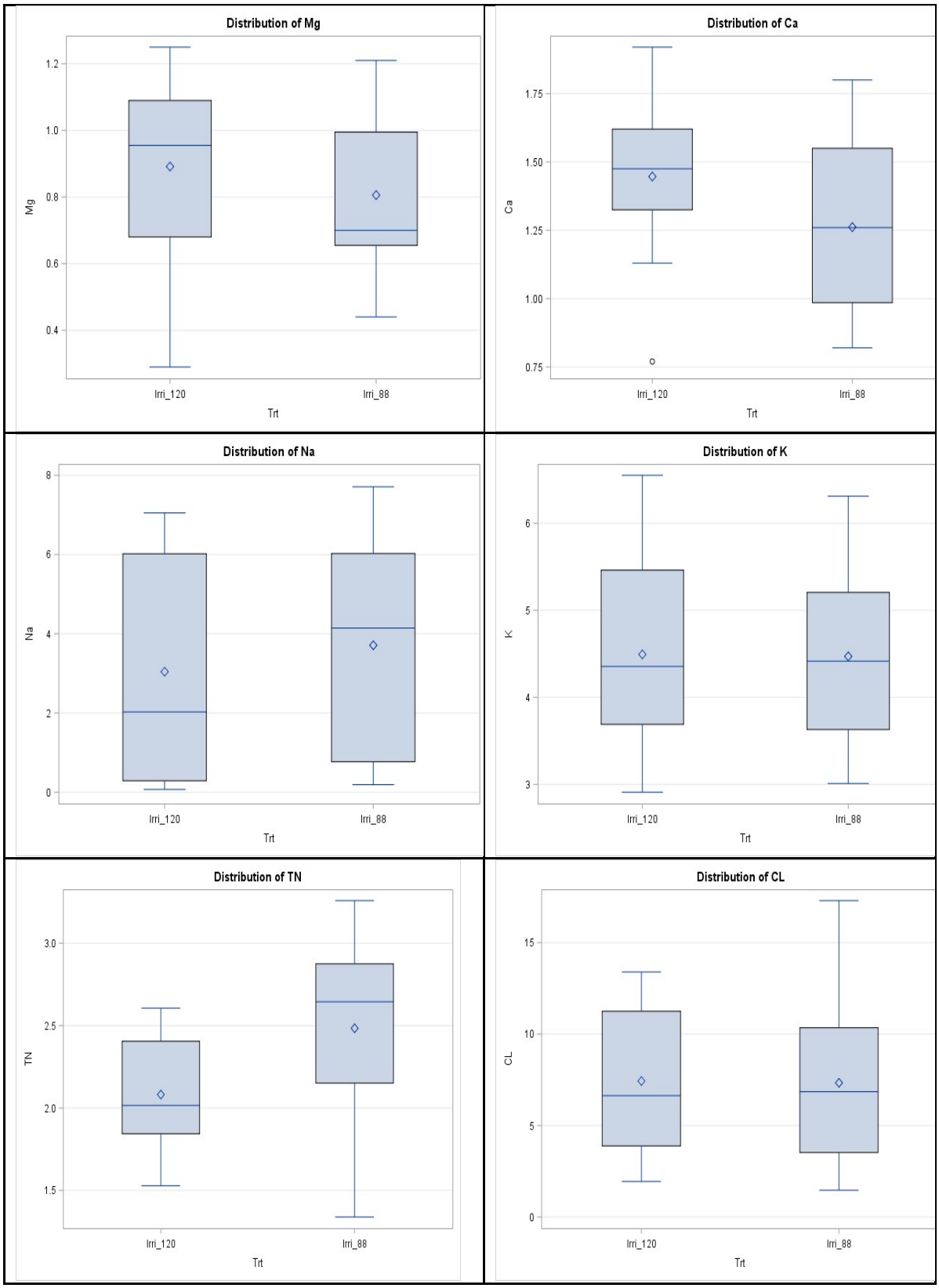

Figure 10. Leaf chemical components Mg, Ca, Na, K, N, and Cl (mg/l) means distribution under two irrigation rates 80 and 60%.

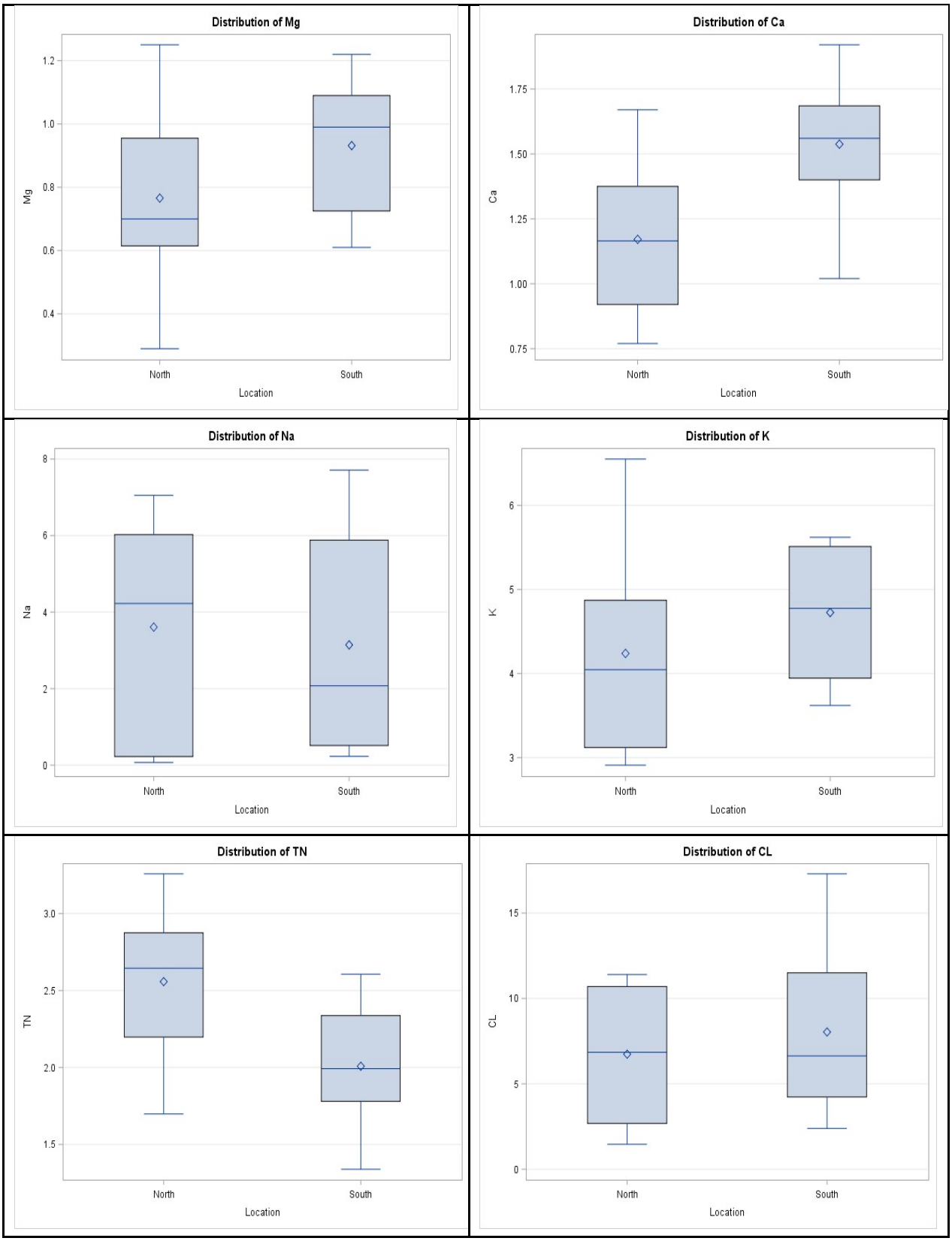

Figure 11. Leaf chemical components Mg, Ca, Na, K, N, and Cl (mg/l) means distribution at two locations, North and South.

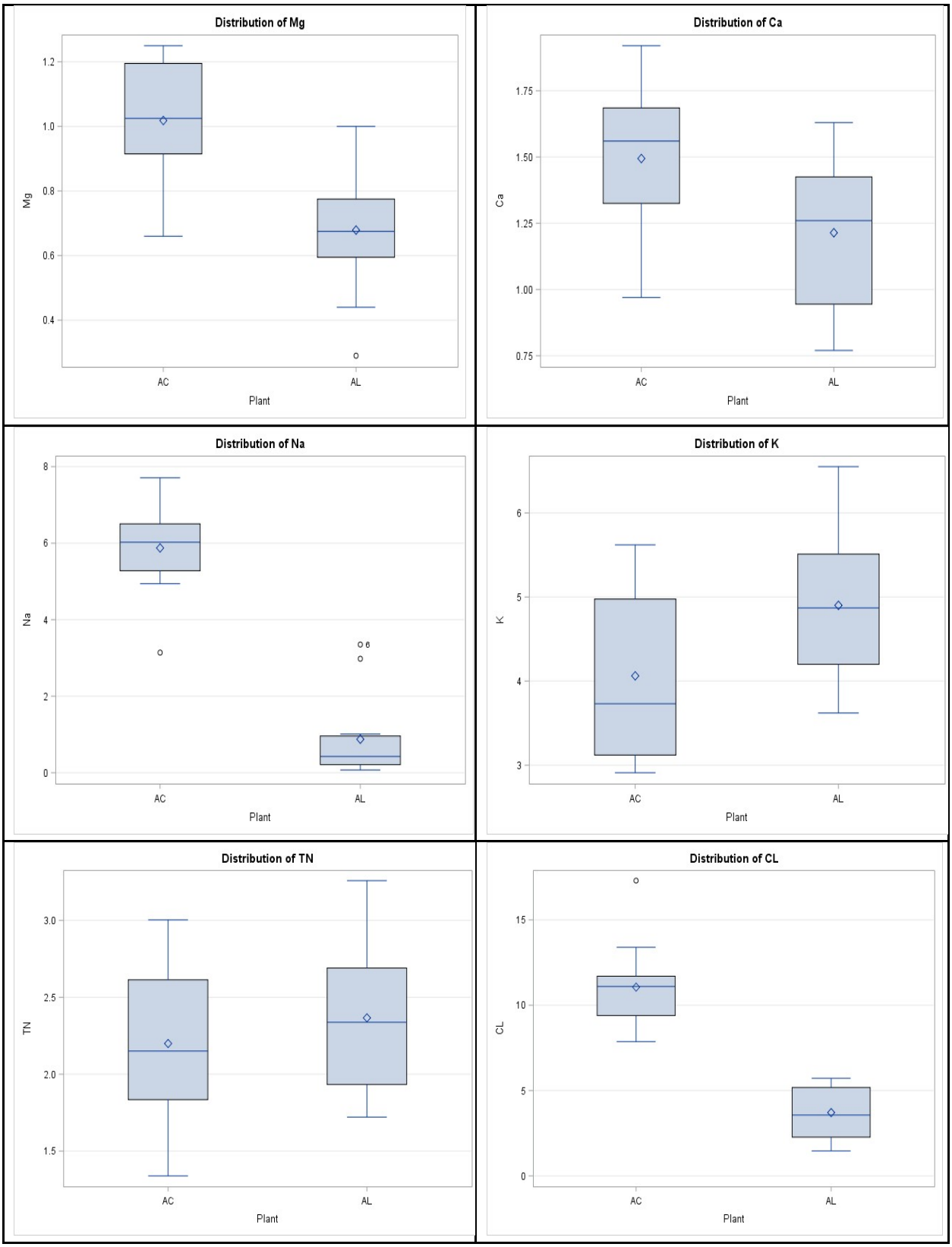

Figure 12. Leaf chemical components Mg, Ca, Na, K, N, and Cl (mg/l) means distribution for *Atriplex C* and *Atriplex L*.

3.7 Leaf Sodium Concentration

Atriplex canescens leaf Na ion concentration was higher than *Atriplex lentiformis* (Table 17). This might be due to more root salty water uptake led to increase Na concentration in *Atriplex canescens*. Considering the interaction between plant species and irrigation rate, *Atriplex canescens* leaf sodium ion concentration was higher at 60% than 80% irrigation rates (Table 18). Sodium concentrated in the lower irrigation rate and *Atriplex canescens* was less tolerated for Na accumulation than *Atriplex lentiformis*.

Table 17. Leaf sodium ion concentration (mg/l) mean and standard deviation at beginning and end of experiment for two *Atriplex* species, two irrigation rates 80 and 60%, and two locations North and South.

Source	Level	Na (mg/l)	
		Mean	Std Dev
Time	Beginning	3.48	2.83 a
	End	3.26	2.85 a
Plant	AC	5.87	1.16 a
	AL	0.87	1.11 b
Irrigation	80%	3.04	2.95 a
	60%	3.70	2.69 a
Location	North	3.60	2.79 a
	South	3.14	2.87 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 18. Leaf sodium ion concentration (mg/l) mean and standard deviation for *Atriplex C* and *Atriplex L* under two irrigation rates 80 and 60%.

Irrigation rate	Plant	Na (mg/l)	
		Mean	Std Dev
80%	AC	5.72	1.38 a
	AL	0.36	0.31 b
60%	AC	6.03	1.00 a
	AL	1.38	1.41 b

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = lower mean.

3.8 Leaf Chloride Ion Concentrations

Table 19 shows leaf chloride concentration for the sampling times, *Atriplex* species, irrigation rates, and locations. At the end of the third year, chloride concentration slightly increased; however, this increase was not statistically significant (Table19). Higher increases in chloride concentration were found for *Atriplex canescens* than *Atriplex lentiformis* (Table 19). *Atriplex lentiformis* has ability to tolerate and reduce the accumulation of Cl in the leaves. Chloride concentration also slightly increased under the 80% irrigation rate and at the north location; however, it was not statistically significant (Table 19). *Atriplex canescens* had significantly higher leaf chloride concentration under both 60% and 80% irrigation rates than *Atriplex lentiformis* (Table 20). This might be due to high selectivity of *Atriplex lentiformis* controlling Cl build up.

Table 19. Leaf chloride ion concentration (mg/l) mean and standard deviation at beginning (May) and end of experiment (October) for two *Atriplex* species, two irrigation rates (80 and 60%), and two locations North and South.

Source	Level	CL (mg/l)	
		Mean	Std Dev
Time	Beginning	7.21	3.91 a
	End	7.55	4.79 a
Plant	AC	11.10	2.56 a
	AL	3.71	1.53 b
Irrigation rate	80%	7.43	4.16 a
	60%	7.33	4.59 a
Location	North	6.73	3.88 a
	South	8.03	4.73 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 20. Leaf chloride ion concentration (mg/l) mean and standard deviation for *Atriplex C* and *Atriplex L* under two irrigation rates (80 and 60%).

Irrigation rate	Plant	CL (mg/l)	
		Mean	Std Dev
80%	AC	11.12	1.82 a
	AL	3.74	1.43 b
60%	AC	10.99	3.33 a
	AL	3.67	1.77 b

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9 Soil Microbial Activities During Year One of the Experiment

3.9.1 Soil pH

Soil pH at two depths and locations is shown in Table 21. No differences were found between the two depths and locations. The location and irrigation rate interaction did not affect soil pH (Table 22). At the soil depth of 0-20 cm under an 80% irrigation rate, soil pH slightly increased; however, this was not significant (Table 23). The measured soil pH is most relevant for the microbial biomass activity.

Table 21. Soil pH mean and standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	pH	
		Mean	Std Dev
Depth (cm)	0-20	8.40	0.22 a
	20-40	8.44	0.27 a
Location	North	8.45	0.34 a
	South	8.40	0.06 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 22. Soil pH mean and standard deviation at two locations under two irrigation rates.

Location	Irrigation rate	pH	
		Mean	Std Dev
North	80%	8.75	0.07 a
	60%	8.15	0.00 a
South	80%	8.44	0.07 a
	60%	8.36	0.02 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 23. Soil pH mean and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

Depth (cm)	Irrigation rate	pH	
		Mean	Std Dev
0-20	80%	8.54	0.21 a
	60%	8.26	0.16 a
20-40	80%	8.64	0.21 a
	60%	8.24	0.13 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.2 Soil Nitrate

Soil nitrate is correlated with the soil content of nitrogen, the most important nutrition element for plants. Soil nitrate concentration was slightly lower at 20-40 cm soil depth and at the South location; however, the differences were not statistically significant (Table 24). For location and depth interaction, nitrate concentration significantly differs from others by the location and depth (Table 25). These results show that the nitrate is concentrated near the soil surface, and this would negatively affect the soil microbial activity near the soil surface than deeper.

Table 24. Soil nitrate (mg N/kg soil) mean with standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	Nitrate (mg N/kg soil)	
		Mean	Std Dev
Depth (cm)	0-20	14.80	5.04 a
	20-40	9.57	4.48 a
Location	North	13.67	7.08 a
	South	10.69	2.77 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 25. Soil nitrate (mg N/kg soil) mean and standard deviation at two locations North and South and two depths (0-20 and 20-40 cm).

Location	Depth (cm)	Nitrate (mg N/kg soil)	
		Mean	Std Dev
North	0-20	18.49	3.62 a
	20-40	8.86	6.68 b
South	0-20	11.11	2.95 a
	20-40	10.28	3.69 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.3 Soil Ammonia

Increasing atmospheric deposition of nitrogen and ammonium reduced microbial activity. Soil ammonia concentration was lower at 20-40 cm depth and at the South location; however, this decrease was not significant (Table 26). At the North side under the 60% irrigation rate, soil ammonia concentration was significantly higher than at the South location (Table 27).

Table 26. Soil ammonia (mg N/kg soil) mean with standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	Ammonia (mg N/kg soil)	
		Mean	Std Dev
Depth (cm)	0-20	0.49	0.47 a
	20-40	0.28	0.07 a
Location	North	0.52	0.46 a
	South	0.25	0.02 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 27. Soil ammonia (mg N/kg soil) mean with standard deviation at two locations North and South under two irrigation rates (80 and 60%).

Location	Irrigation rate	Ammonia (mg N/kg soil)	
		Mean	Std Dev
North	80%	0.25	0.02 b
	60%	0.80	0.50 a
South	80%	0.26	0.00 a
	60%	0.24	0.03 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.4 Soil Organic Carbon

Higher soil organic material induces higher microbial activity. At both soil depths and locations, no differences were observed for soil organic carbon (Table 28). No differences for organic carbon concentrations were found for depths and irrigation rates interaction (Table 29). Our results show that soil organic carbon was greater near the soil surface, and that was reflected in higher microbial activity there.

Table 28. Soil organic carbon (%) mean and standard deviation at two depths (0-20 and 20-40 cm) and two locations North.

Source	Level	Organic carbon (%)	
		Mean	Std Dev
Depth (cm)	0-20	3.15	0.52 a
	20-40	2.96	0.46 a
Location	North	2.77	0.36 a
	South	3.34	0.40 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 29. Soil organic carbon (%) mean and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

Depth (cm)	Irrigation rate	Organic carbon (%)	
		Mean	Std Dev
0-20	80%	2.99	0.82 a
	60%	3.32	0.21 a
20-40	80%	2.87	0.19 a
	60%	3.06	0.76 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.5 Soil Respiration

Soil respiration is also an indication of the level of microbial activity, soil organic matter, plant litter, and decomposition. Low soil respiration rates indicate that there is little or no organic matter, and/or microbial activity. Soil respiration rate was higher at the soil depth of 0-10 cm for 20-40 cm while the rate increased insignificantly at the South location (Table 30). At 0-20 cm depth, soil respiration rate was significantly higher than under the 60% irrigation rate than the 80% rate (Table 31). These results indicated that soil microbial activity is higher at the soil surface than at deeper depths.

Table 30. Soil respiration rate (mg CO_2-C/kg soil/day) means and standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	Respiration (mg CO_2-C/kg soil/day)	
		Mean	Std Dev
Depth (cm)	0-20	7.72	1.71 a
	20-40	5.73	0.60 b
Location	North	6.45	2.07 a
	South	7.00	1.21 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 31. Soil respiration rate (mg CO_2-C/kg soil/day) means and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

Depth (cm)	Irrigation rate	Respiration (mg CO_2-C/kg soil/day)	
		Mean	Std Dev
0-20	80%	6.41	1.23 b
	60%	9.04	0.63 a
20-40	80%	5.36	0.70 a
	60%	6.10	0.24 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.6 Soil Microbial Biomass

Soil microbial biomass was higher at 0-20 cm soil depth than for 20-40 cm depth, with no significant dependence on location (Table 32). Increases in soil microbial biomass at the North location under the 60% irrigation rate was observed (Table 33). Soil microbial biomass was higher at the depth of 0-20 cm for the 60% irrigation rate (Table 34), and a similar increase was found at the same depth at the North location (Table 35). Microbial biomass is highly affected by the presence of soil organic matter or soil carbon. As the organic matter increases, the microbial biomass and activity increase as well as the decomposition. Our results indicated increases in microbial biomass near the soil surface and that could be due to the availability of more organic matter near the surface than at deeper depths.

Table 32. Soil microbial biomass (mg C/kg soil) means and standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	Microbial biomass (mg C/kg soil)	
		Mean	Std Dev
Depth (cm)	0-20	221.50	161.66 a
	20-40	140.60	26.69 b
Location	North	193.30	175.03 a
	South	168.80	13.10 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 33. Soil microbial biomass (mg C/kg soil) means and standard deviation at two locations North and South under two irrigation rates (80 and 60%).

Location	Irrigation rate	Microbial biomass (mg C/kg soil)	
		Mean	Std Dev
North	80%	100.15	25.66 b
	60%	286.45	237.80 a
South	80%	169.85	21.99 a
	60%	167.75	5.30 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 34. Soil microbial biomass (mg C/kg soil) means and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

Depth (cm)	Irrigation rate	Microbial biomass (mg C/kg soil)	
		Mean	Std Dev
0-20	80%	133.70	73.11 b
	60%	309.30	205.48 a
20-40	80%	136.30	25.45 a
	60%	144.90	37.61 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 35. Soil microbial biomass (mg C/kg soil) means and standard deviation at two locations North and South and two depths (0-20 and 20-40 cm)

Location	Depth (cm)	Microbial biomass (mg C/kg soil)	
		Mean	Std Dev
North	0-20	268.30	263.46 a
	20-40	118.30	0.00 b
South	0-20	174.70	15.13 a
	20-40	162.90	12.16 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.7 Glycosaminidase Activity

Measuring glycosaminidase external enzyme activity in the soil is important because of the role that the enzyme plays in the carbon and nitrogen cycling. Organic matter decomposition, especially lignin and chitin, depends on these enzymes. Glycosaminidase activity increases at both soil depths under an 60% irrigation rate. As the irrigation rate decreased, glycosaminidase activity increased (Table 36). At the North location, increases in soil depth led to decreases in glycosaminidase activity; however, at the South side, increases in soil depth led to increases in glycosaminidase activity (Table 37).

Table 36. Glycosaminidase activity (ug p-NP/g soil/h) means and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

Depth (cm)	Irrigation rate	Glycosaminidase activity (ug p-NP/g soil/h)	
		Mean	Std Dev
0-20	80%	19.94	18.61 a
	60%	31.97	23.10 a
20-40	80%	27.26	1.35 b
	60%	40.62	2.05 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 37. Glycosaminidase activity (ug p-NP/g soil/h) means and standard deviation at two locations North and South and two depths (0-20 and 20-40 cm).

Location	Depth (cm)	Glycosaminidase activity (ug p-NP/g soil/h)	
		Mean	Std Dev
North	0-20	40.71	10.74 a
	20-40	33.69	7.74 a
South	0-20	11.20	6.25 b
	20-40	34.19	11.15 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.9.8 Shannon Microbial Diversity Index

The Shannon diversity index (H) is another index that is commonly used to characterize species diversity in a community. The Shannon diversity index accounts for both abundance and evenness of the species present in the soil. Decreases in the H microbial diversity index were accompanied with increasing soil depth; however, the index remained similar at both locations (Table 38). The Shannon microbial diversity index was higher for the 80% irrigation rate at 0-20 cm depth; however, the opposite trend was seen for the 20-40 cm depth (Table 39).

Table 38. Shannon microbial diversity index means with standard deviation at two depths (0-20 and 20-40 cm) and two locations North and South.

Source	Level	Shannon microbial diversity index (H)	
		Mean	Std Dev
Depth (cm)	0-20	3.58	1.38 a
	20-40	1.94	1.69 b
Location	North	2.68	1.99 a
	South	2.83	1.60 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

Table 39. Shannon microbial diversity index means and standard deviation at two depths (0-20 and 20-40 cm) under two irrigation rates (80 and 60%).

		Shannon microbial diversity index (H index)	
Depth (cm)	Irrigation rate	Mean	Std Dev
0-20	80%	4.59	1.08 a
	60%	2.57	0.71 b
20-40	80%	1.06	0.13 a
	60%	2.81	2.35 a

Note: Std Dev in lower letters correspond to significant differences. a = the higher mean, b = the lower mean.

3.10 Soil Microbiology Activities at the End of Year Three

Soil depth was the most effected variable analyzed at the beginning of this study. Therefore, we focused our efforts on the variations of soil microbial properties with depth during the third year of the experiment. Soil pH, organic carbon, and nitrate remained similar for the two depths (Table 40). Increases in soil respiration rate, microbial biomass, and Shannon microbial diversity index were observed with increasing depth (Table 40). This trend is strongly related to soil organic matter, and as the soil organic matter increases, soil respiration, microbial biomass and diversity increase.

Table 40. Mean of soil pH, organic carbon, nitrate, respiration, microbial biomass, and Shannon index with standard deviation at two depths (0-20 and 20-40 cm) at the end of the experiment.

Source	Depth	Mean	Std Dev
pH	00-20	7.94	0.22 a
	20-40	7.96	0.19 a
Organic carbon (%)	00-20	2.74	0.22 a
	20-40	2.82	0.18 a
Nitrate (mg N/kg soil)	00-20	0.15	0.02 a
	20-40	0.16	0.03 a
Soil respiration (mg CO_2-C/kg soil/day)	00-20	3.06	3.26 b
	20-40	23.40	19.94 a
Soil microbial biomass (mg C/kg soil)	00-20	122.95	57.88 b
	20-40	455.55	355.03 a
Shannon index (H)	00-20	3.65	1.77 a
	20-40	5.07	3.40 a

Note: Std Dev in lower case letters correspond to significant differences. a = the higher mean, b = the lower mean.

4. Discussion

Sodium and chloride concentrations were affected by the depth of soil and location from the plant trunk. Soil near the surface and the plant had lower Na and Cl ion concentrations. As the distance from the plant increased, Na and Cl concentrations also increased. This could be due to the irrigation method. Drip irrigation was used to irrigate the plants; therefore, the area nearest to and surrounded by drip irrigation received more water, likely diluting sodium and chloride ion concentrations. These results agree with a study on Chihuahuan Desert soils where the Na concentration decreased with soil depth under sprinkler irrigation (Babcock et al., 2009). Malash and others (2008) also reported that at 15 cm soil depth under drip irrigation, salinity increased with increasing distance from the water source, and that was in complete agreement with our results in the current study.

Salts accumulation during long-term brackish water irrigation has been found the most serious factor causing soil salinization and negatively affected soil properties. Properties affected by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting. Adhikari and others (2012c) and Ozturk and others (2018) reported decreases in soil hydraulic conductivity with increasing soil sodium concentration. In this study, a 60% irrigation rate resulted in Na and Cl ion concentration and increased ion concentrations at a 25-

50 cm soil depth. With both 80% and 60% irrigation rates and in east and west directions, at the depths of 0-25 and 25-50 cm, the ion concentration increased. This could be due to the drip irrigation method that was used because this irrigation method kept the soil near the emitter wetter and the soil got relatively drier as distance from the emitter increased with an attendant decrease in the concentration. Soil Na and Cl ion concentrations as well as SAR increased when irrigated with saline water (Li et al., 2019). Ayers and Westcot (1985) also reported increasing salt concentrations with depth due to plants extracting water and leaving salts in a reduced volume of soil moisture. Huang and others (2011) also reported that the soil water content remained high with increasing irrigation water salinity even though total soil porosity decreased. This was due to the reduced water uptake by plants.

In May (beginning of the measurement time), plants showed higher SWP than toward the end of taking measurements. This could be due to the decrease in plant activity at the end of the growing season. An inverse relationship between soil salt concentration and SWP was observed, and as salt concentration increased under lower irrigation rates, the SWP became more negative. These results agreed with a previous study reporting that with increasing salinity, plants stem water potential decreases (Gorai et al., 2019). Gohar and others (2018) mentioned that as the irrigation water salinity increased, SWP decreased due to the reductions in water availability to the plant. Plant species often differ in their response to salinity stress as measured by their reduced stem (leaf) water potential and osmotic potential (Gorai et al., 2019). *Atriplex L* and *Atriplex C* are a good example of these phenomena in this study. Even though both are halophytes, *Atriplex lentiformis* presented the lower SWP as a mechanism to acclimate to salt stress. Even with different irrigation rates, *Atriplex lentiformis* could lower SWP more than *Atriplex canescens* as observed in the present research. We can conclude that both *Atriplex lentiformis* and *Atriplex canescens* are suitable for irrigation with saline water; however, *Atriplex lentiformis* was more adapted to the increases in soil salinity and this is an advantage for *Atriplex lentiformis* over *Atriplex canescens*.

The differences in leaf sodium and chloride ion concentrations between *Atriplex canescens* and *Atriplex lentiformis* might highlight two different acclimation pathways between the two *Atriplex* species. It has been reported that the tolerance of tissue to accumulated Na+ or Cl−, osmotic stress tolerance, and Na+ or Cl− exclusion are the three adaptation mechanisms of plants to salinity stress (Munns and Tester, 2008). Some plants showed more sensitivity to Cl than Na when the plant growth was more affected by increases in Cl concentration (Tavakkoli et al., 2010). In agreement with our findings, Simpson and others (2018) stated that when irrigating with saline water, *Atriplex lentiformis* presented high growth rates compared with Portulaca L that accumulated high sodium amounts. In this study, *Atriplex lentiformis* accumulated smaller amounts of both Na and Cl concentrations under both irrigation rates than *Atriplex canescens*. This might confirm the ability of *Atriplex lentiformis* to tolerate both Na and Cl accumulation and could be due to a developed mechanism that *Atriplex lentiformis* built to tolerate the deposition of these ions. Ventura and others (2015) emphasized that even with halophytes, the accumulation of salts in plants reduces the nutritional value for animal feed. This is what happened in our study with *Atriplex canescens*, where increased concentration of Na and Cl in

the leaf were observed. This suggested that *Atriplex lentiformis* could be a viable option for animal feed since the nutrition value may not be impacted.

Our results indicated that soil nitrate accumulated more beneath the soil surface to 20 cm depth than for deeper depths. These results contrasted with those reported by Heuermann and others (2019) who found nitrate depletion in upper layers and accumulation into the deeper soil layers. The deeper rooting plants were more efficient at gaining nitrogen (N) than the shallow-rooted varieties, possibly because the N in the form of nitrates is highly soluble and is subject to leaching into the deeper soil layers (Thorup-Kristensen, 2006). These differences reported in various studies could be due to the differences in soil texture and the irrigation water volumes. Soil irrigated with saline water has been reported to increase the emission of ammonia near the soil surface due to the inhibition in nitrate oxidation (Li et al., 2020a; Li et al., 2020b; Zhu et al., 2020). This was in line with our results where soil ammonia was found to be higher at 0-20 cm than at 20-40 cm. Irrigation water salinity of 8 ds/m significantly decreased ammonia concentration as a result of ammonia volatilization with increasing water salinity (Zhou et al., 2016).

In saline soils, organic carbon was negatively affected by increases in soil salinity; however, halophytes plants were found to reduce the loss of soil organic carbon (Yuan et al., 2020). This agrees with our study that found *Atriplex* species helped to manage soil carbon content with no changes in organic carbon by soil depth, irrigation rates, and or locations. In a previous study, soil organic carbon was found to be higher near the soil surface (0-10 cm) than at 30 cm in saline coastal soil (Zhang et al., 2020). These differences between our results and Zhang and others (2020) study were likely due to the fact that the latter study examined a costal soil, which is much different from ours.

At soil depths of 20-40 cm, respiration decreased with decreases in soil microbial biomass. This was similar to the results of a previous study for which microbial biomass was reported to decrease at soil depths of 30 cm due to irrigation with saline water of 7.1 ds/m salinity (Egamberdieva et al., 2010). Wong and others (2008) reported increases in soil microbial biomass with increasing salinity to 10 ds/m, while Muhammad and others (2008) and Tripathi and others (2006) found soil respiration and the soil microbial biomass to be negatively correlated with salinity as more substrate carbon is mineralized for cell maintenance. These reported differences could be due to the variations in soil texture, organic matter content, and the dominant microbial species. The use of RO concentrate to irrigate the two *Atriplex* species in our study showed that the microbial activity increased near the soil surface demonstrating the suitability of RO to irrigate *Atriplex* species without causing negative effects on the soil microbial biomass.

Extracellular enzyme glycosaminidase was clearly affected by the increases in soil depth under the 60% irrigation rate. This could be due to the greater increases in the salt concentration for the 60% irrigation rate than for the 80% irrigation rate. Higher irrigation rates seemed to have

diluted the salt concentrations. Our results supported Otgonsuren and others (2016), who reported that the exposure to salt significantly increased the activity of the extracellular enzymes β-glucosidase, N-acetyl-glycosaminidase and leucine-amino-peptidase on the surface of root tips. Reyes-Pérez and others (2019) concluded that increases in NaCl concentration increased the n-acetyl-β-glycosaminidase enzyme activity. In the current study, because of irrigating *Atriplex* species with RO, glycosaminidase enzyme increased indicating that more decomposition of the organic matter took place, so that consequently more nutrients are available.

Increases in the respiration, and soil microbial biomass with increases in soil depth was observed during the third year of the experiment. A similar study reported significant negative correlation between Shannon diversity index versus soil salinity and depth (Li and Wu, 2018). Our result agreed with this study because we also observed the decrease in Shannon index with increase in depth in the first year. The decrease in Shannon index can be attributed to the lack of nutrients with increasing depth as well as to the increase in salt concentration under an irrigation rate of 60%. In contrast, Chen and others (2017) stated that soil bacterial richness and diversity (Shannon index value) increased with irrigation salinity. These contrasting results illustrate that differences in the distribution of soil organic carbon, pH, total aggregate porosity are some of the important factors controlling the soil microbial diversity, and the respiration (Yang et al., 2019). The advantages of irrigating *Atriplex* species can be clearly observed through the increases in microbial biomass and respiration and how that could reflect on the availability of more nutrients to plants; however, the decreases in Shannon diversity index means there was an absence of some microbial species, and that might negatively affect the organic matter decomposition process.

5. Conclusion

In this study, we studied two drip irrigated *Atriplex* fields irrigated with brackish groundwater and RO concentrate located at the BGNDRF in Alamogordo, New Mexico. The reference ET was around 200 mm during the summer season. Soil depth and distance from dripline were found to be the most effective variables with regard to the distribution and accumulation of sodium and chloride ions. Sodium and chloride were lower near the dripline for both near soil surface and at deeper depths, and higher at 90 cm distance from the dripline. The amount of sodium and chloride were lower in the plant leaf due to this reduction in the sodium and chloride concentration near the dripline.

As halophytic species, *Atriplex canescens* and *Atriplex lentiformis* differed in their response to salt tolerance. *Atriplex lentiformis* was more tolerant to sodium and chloride accumulation than *Atriplex canescens*. Generally, the smaller the irrigation rate, the higher the ion concentration in the leaves. We did observe salt deposition on leaves primarily due to the excretion of excess salts through the plant's leaves. Some other possible explanations could be that the halophytic plants develop a mechanism to control the flow of salty water by controlling

the root water uptake. However, we did observe leaves dying and dropping off due to abiotic stress of water and salt. These mechanisms provide an advantage for growing halophytic species on saline soil or soil irrigated with RO concentrate.

Soil nitrate and ammonia also varied with depth and both were decreased by depth. *Atriplex canescens* and *Atriplex lentiformis* to some extent maintained organic carbon stability in the soil. Soil microbial biomass and respiration were negatively affected by saline irrigation at deeper depths. Microbial diversity and the Shannon index showed reductions with soil depth under saline irrigation. This study emphasized the ability of salt tolerant plants *Atriplex canescens* and *Atriplex lentiformis* to be grown in soils irrigated with RO concentrate.

6. References

Adhikari, P., Shukla, M.K., and Mexal, J.G., 2012a. Spatial variability of soil properties in an arid ecosystem irrigated with treated municipal and industrial wastewater. *Soil Sci*. 177:7:458–469.

Adhikari, P., Shukla, M.K., and Mexal, J., 2012b. Spatial variability of infiltration rate and soil chemical properties of desert soils: implications for management of irrigation using treated wastewater. *Trans of the ASABE*. 55:5:1711–1721.

Adhikari, P., Shukla, M.K., and Mexal, J.G., 2012c. Spatial variability of hydraulic conductivity and sodium content of desert soils: Implications for management of irrigation using treated wastewater. *Transactions of the ASABE*. 55:5:1711-1721.

Anderson, J. P. E., and Domsch, K.H., 1975. Measurement of bacterial and fungal contribution to respiration of selected agricultural soils. *Can. J. Microbiol*. 21:314-322.

Ayers, R.S. and Westcot, D.W., 1985. *Water quality for agriculture*. Rome: Food and Agriculture Organization of the United Nations. 29:174.

Baath, G.S., Shukla, M.K., Bosland, P.W., Steiner, R.L., and Walker, S.J., 2017. Irrigation water salinity influences at various growth stages of *Capsicum annuum*. *Agricultural Water Management*. 179:246–253. https://doi.org/10.1016/j.agwat.2016.05.028

Babcock, M., Shukla, M.K., Picchioni, G.A., Mexal, J.G., and Daniel, D., 2009. Chemical and physical properties of Chihuahuan Desert soils irrigated with industrial effluent. *Arid Land Research and Management.* 23:1:47–66. https://doi.org/10.1080/15324980802598607

Belkheiri, O., and Mulas, M., 2013. The effects of salt stress on growth, water relations and ion accumulation in two halophyte *Atriplex* species. *Environmental and Experimental Botany*. Special Issue: Phytohormones and Stress. 86:17–28. https://doi.org/10.1016/j.envexpbot.2011.07.001

Bhatt, A., Bhat, N., Santo, A., and Phartyal, S., 2019. Influence of temperature, light and salt on the germination of *deverra triradiata* seeds. *Seed Science and Technology*. 47:1:25-31(7). https://doi.org/10.15258/sst.2019.47.1.03

Brookes, P.C., Landman, A., Pruden, G., and Jenkinson, D.S., 1985. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biology and Biochemistry*. 17:837-842.

Chen, L., Li, C., Feng, Q., Wei, Y., Zheng, H., Zhao, Y., Feng, Y., and Li, H., 2017. Shifts in soil microbial metabolic activities and community structures along a salinity gradient of irrigation water in a typical arid region of China. *Science of the Total Environment*. 598:64–70. https://doi.org/10.1016/j.scitotenv.2017.04.105

Córdova, M., Carrillo-Rojas, G., Crespo, P., Wilcox, B., and Célleri, R., 2015. Evaluation of the Penman-Monteith (FAO 56 PM) Method for calculating reference evapotranspiration using limited data. *Mountain Research and Development*. 35:3:230-239. https://doi.org/10.1659/MRD-JOURNAL-D-14-0024.1

Egamberdieva, D., Renella, G., Wirth, S., and Islam, R., 2010. Secondary salinity effects on soil microbial biomass. *Biology and Fertility of Soils*. 46, 445–449. https://doi.org/10.1007/s00374-010-0452-1

Flores, A.M., Schutte, B.J., Shukla, M.K., Picchioni, G.A., and Ulery, A.L., 2015. Time-integrated measurements of seed germination for salt tolerant plant species. *Seed Science and Technology*. 43:541-547.

Flores, A.M., Shukla, M.K., Daniel, D., Ulery, A.L., Schutte, B.J., Picchioni, G.A., and Fernald, S., 2016. Evapotranspiration changes with irrigation using saline groundwater and RO concentrate. *J. Arid Environ*. 131:35–45.

Flores, A.M., Shukla, M.K., Schutte, B.J., Picchioni, G., and Daniel, D., 2017. Physiologic response of six plant species grown in two contrasting soils and irrigated with brackish groundwater and RO concentrate. *Arid Land Research and Management*. 31:182-203.

Gallaher, J., Artiola, J., and Glenn, E., 2016. Reverse Osmosis Concentrate Management through Halophyte Farming. University of Arizona, Report. 1–51.

Ghermandi, A., Messalem, R., Offenbach, R., and Cohen, S., 2013. Solar desalination for sustainable brackish water management in arid land agriculture. *Renew. Agric. Food Syst*. 29: 255–264.

Gohar, Z.N., Asghar, U., Perveen, F., Sultana, R., and Ahmad, R., 2018. Effect of saline water irrigation on growth and water potential of *Thespesia populnea* (l.) Sol.ex correa. *International Journal of Biology and Biotechnology.* 15:2:255-262.

González-Delgado, A.M., Shukla, M.K., Ulery, A.L., Salim Bawazir, A., and Brady, P.V., 2011. Saturated hydraulic conductivity of self-sealing lining materials for desalination evaporation ponds. *Desalination and Water Treatment*. 29:187-195.

Gorai, M., Ben Romdhane, R., Maraghni, M., and Neffati, M., 2019. Relationship between leaf gas-exchange characteristics and the performance of *Ziziphus spina-christi* (L.) willd. seedlings subjected to salt stress. *Photosynthetica*. 57:3:897-903. https://doi.org/10.32615/ps.2019.093

Hafeez, M., Chatha, Z.A., Khan, A.A., Gulshan, A.B., Basit, A., and Tahira, F., 2020. Comparative analysis of reference evapotranspiration by Hargreaves and Blaney-Criddle equations in semi-arid climatic conditions. *Current Research in Agricultural Sciences.* 7:2:52-57.

Heuermann, D., Gentsch, N., Boy, J., Schweneker, D., Feuerstein, U., Groß, J., Bauer, B., Guggenberger, G., and von Wirén, N., 2019. Interspecific competition among catch crops modifies vertical root biomass distribution and nitrate scavenging in soils. *Scientific Reports.* 9:11531. https://doi.org/10.1038/s41598-019-48060-0

Hibbs, B. J., Creel, B. J, Boghici, R., Hayes, M., Ashworth, J., Hanson A., Samani, Z., Kennedy, J. F., Hann, P., and Stevens, K., 1997. Transboundary Aquifers of the El Paso/Ciudad Juarez/Las Cruces Region: U.S. Environmental Protection Agency, Region 6; Technical Contract Report prepared by the Texas Water Development Board and the New Mexico Water Resources Research Institute, variously paged.

Huang, C.H., Xue, X., Wang, T., De Mascellis, R., Mele, G., You, Q.G., Peng, F., and Tedeschi, A., 2011. Effects of saline water irrigation on soil properties in northwest China. *Environmental Earth Sciences.* 63:701-708.

Kaiser, E.A., Mueller, T., Joergensen, R.G., Insam, H., and Heinemeyer, O., 1992. Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. *Soil Biology and Biochemistry*. 24:675-683.

Khan, M.A., Ozturk, M., Gul, B., and Ahmed, M.Z., 2015. *Halophytes for Food Security in Dry Lands*. Academic Press. https://doi.org/10.1016/C2014-0-01176-8

Li, J., Gao, Y., Zhang, X., Tian, P., Li, J., and Tian, Y., 2019. Comprehensive comparison of different saline water irrigation strategies for tomato production: Soil properties, plant growth, fruit yield and fruit quality. *Agricultural Water Management.* 213:521-533.

Li, S., and Wu, F., 2018. Diversity and co-occurrence patterns of soil bacterial and fungal communities in seven intercropping systems. *Frontiers in Microbiology*. 9:1521.

Li, Y., Xu, J., Liu, S., Qi, Z., Wang, H., Wei, Q., Gu, Z., Liu, X., and Hameed, F., 2020a. Salinity-induced concomitant increases in soil ammonia volatilization and nitrous oxide emission. *Geoderma*. 361:114053.

Li, Y., Xu, J., Liu, X., Qi, Z., Wang, H., Li, Y., and Liao, L., 2020b. Nitrification inhibitor DMPP offsets the increase in N_2O emission induced by soil salinity. *Biology and Fertility of Soils.* 56:1211-1217.

Lucero, M.E., Unc, A., Cooke, P., Dowd, S., and Sun, S., 2011. Endophyte microbiome diversity in micro propagated *Atriplex canescens* and *Atriplex torreyi var griffithsii*. *PLoS One*. 6:3:e17693.

Malash, N.M., Flowers, T.J., and Ragab, R., 2008. Effect of irrigation methods, management and salinity of irrigation water on tomato yield, soil moisture and salinity distribution. *Irrigation Science.* 26:313-323. https://doi.org/10.1007/s00271-007-0095-7

Muhammad, S., Müller, T., and Joergensen, R.G., 2008. Relationships between soil biological and other soil properties in saline and alkaline arable soils from the Pakistani Punjab. *Journal of Arid Environments*. 72:4:448–457. https://doi.org/10.1016/j.jaridenv.2007.06.016

Munns, R., and Tester, M., 2008. Mechanisms of Salinity Tolerance. *Annual Review of Plant Biology*. 59:651–681. https://doi.org/10.1146/annurev.arplant.59.032607.092911

Otgonsuren, B., Rewald, B., Godbold, D.L., and Göransson, H., 2016. Ectomycorrhizal inoculation of *Populus nigra* modifies the response of absorptive root respiration and root surface enzyme activity to salinity stress. *Flora*. 224:123–129. https://doi.org/10.1016/j.flora.2016.07.016

Ozturk, O.F., Shukla, M.K., Stringam, B., Picchioni, G.A., and Gard, C., 2018. Irrigation with brackish water changes evapotranspiration, growth and ion uptake of halophytes. *Agricultural Water Management*. 195:142–153. https://doi.org/10.1016/j.agwat.2017.10.012

Panta, S., Flowers, T., Lane, P., Doyle, R., Haros, G., and Shabala, S., 2014. Halophyte agriculture: success stories. *Environmental and Experimental Botany*. 107:71-83.

Panta, S., Flowers, T., Doyle, R., Lane, P., Haros, G., and Shabala, S., 2016. Growth responses of *Atriplex lentiformis* and *Medicago arborea* in three soil types treated with saline water irrigation. *Environmental and Experimental Botany.* 128:39-50.

Picchioni, G.A., Shukla, M.K., Mexal, J.G., Babcock, M., Ruiz, A., Sammis, T.W. and Rodriguez, D.S., 2012. Land application of treated industrial wastewater on a Chihuahuan Desert Shrubland: implications for water quality and mineral deposition. Arid Land Research and Management. 26:3,.211-226.

Picchioni, G.A., Hooks, T.N., Schutte, B.J., Shukla, M.K., and Daniel, D.L., 2020. Halophyte ion regulation traits support saline adaptation of *Lepidium latifolium*, *L. draba*, and *L. alyssoides*. *Plant Ecology*. 221:295-308. https://doi.org/10.1007/s11258-020-01012-5

Piovan, M.J., Pratolongo, P., Donath, T.W., Loydi, A., and Eckstein, R.L., 2019. Germination response to osmotic potential, osmotic agents, and temperature of five halophytes occurring along a salinity gradient. *International Journal of Plant Sciences*. 180:4:345–355. https://doi.org/10.1086/702663

Reyes-Pérez, J.J., Ruiz-Espinoza, F.H., Hernández-Montiel, L.G., De Lucia, B., Cristiano, G., and Murillo-Amador, B., 2019. Evaluation of glycosyl-hydrolases, phosphatases, esterases and proteases as potential biomarker for NaCl-stress tolerance in *Solanum lycopersicum* L. varieties. *Molecules*. 24:13:2488. https://doi.org/10.3390/molecules24132488

Sammis, T., Sharma, P., Shukla, M.K., Wang, J., and Miller, D., 2012. A water-balance drip-irrigation scheduling model. *Agricultural water management*. 113:30-37.

Sharma, P., Shukla, M.K., Sammis, T.W., Steiner, R.L., and Mexal, J.G., 2012. Nitrate-nitrogen leaching from three specialty crops of New Mexico under furrow irrigation system. *Agricultural water management*. 109:71-80.

Shukla, M.K., 2014. *Soil Physics: An Introduction*. CRC Press, Boca Raton, FL, 58.

Simpson, C.R., Franco, J.G., King, S.R., and Volder, A., 2018. Intercropping halophytes to mitigate salinity stress in watermelon. *Sustainability*. 10:3:681. https://doi.org/10.3390/su10030681

Soliz, D., Glenn, E.P., Seaman, R., Yoklic, M., Nelson, S.G., and Brown, P., 2011. Water consumption, irrigation efficiency and nutritional value of *Atriplex lentiformis* grown on reverse osmosis brine in a desert irrigation district. *Agriculture, Ecosystems and Environment*. 140:3-4:473-483. https://doi.org/10.1016/j.agee.2011.01.012

Tavakkoli, E., Rengasamy, P., and McDonald, G.K., 2010. High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress. *Journal of Experimental Botany*. 61:15:4449-4459. https://doi.org/10.1093/jxb/erq251

Thorup-Kristensen, K., 2006. Effect of deep and shallow root systems on the dynamics of soil inorganic N during 3-year crop rotations. *Plant and Soil*. 288:233-248. https://doi.org/10.1007/s11104-006-9110-7

Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, K., and Bandyapadhyay, B.K., 2006. Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils*. 42:273-277. https://doi.org/10.1007/s00374-005-0037-6

Ungar, I.A., 1977. The relationship between soil water potential and plant water potential in two inland halophytes under field conditions. *Botanical Gazette*. 138:4:498-501. https://www.journals.uchicago.edu/doi/abs/10.1086/336955

Ventura, Y., Eshel, A., Pasternak, D., and Sagi, M., 2015. The development of halophyte-based agriculture: Past and present. *Annals of Botany*. 115:3:529-540. https://doi.org/10.1093/aob/mcu173

Wong, V.N., Dalal, R.C., and Greene, R.S., 2008. Salinity and sodicity effects on respiration and microbial biomass of soil. *Biology and Fertility of Soils*. 44:943-953. https://doi.org/10.1007/s00374-008-0279-1

Yang, C., Liu, N., and Zhang, Y., 2019. Soil aggregates regulate the impact of soil bacterial and fungal communities on soil respiration. *Geoderma*. 337:444-452. https://doi.org/10.1016/j.geoderma.2018.10.002

Yuan, Y., Li, X., Jiang, J., Xue, L., and Craft, C.B., 2020. Distribution of organic carbon storage in different salt-marsh plant communities: A case study at the Yangtze Estuary. *Estuarine, Coastal and Shelf Science*. 243:106900. https://doi.org/10.1016/j.ecss.2020.106900

Zhang, H.S., Zhou, M.X., Zai, X.M., Zhao, F.G., and Qin, P., 2020. Spatio-temporal dynamics of arbuscular mycorrhizal fungi and soil organic carbon in coastal saline soil of China. *Scientific Reports*. 10:9781. https://doi.org/10.1038/s41598-020-66976-w

Zhou, G., Zhang, W., Ma, L., Guo, H., Min, W., Li, Q., Liao, N., and Hou, Z., 2016. Effects of saline water irrigation and N application rate on NH_3 volatilization and N use efficiency in a drip-irrigated cotton field. *Water, Air, & Soil Pollution*. 227:103. https://doi.org/10.1007/s11270-016-2806-2

Zhu, H., Yang, J., Yao, R., Wang, X., Xie, W., Zhu, W., Liu, X., Cao, Y., and Tao, J., 2020. Interactive effects of soil amendments (biochar and gypsum) and salinity on ammonia volatilization in coastal saline soil. *CATENA*. 190:104527. https://doi.org/10.1016/j.catena.2020.104527