# SALTCEDAR (*Tamarix* spp.) LEAF LITTER IMPACTS ON SURFACE SOIL CHEMISTRY: ELECTRICAL CONDUCTIVITY AND SODIUM ADSORPTION RATIO

BY

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"Saltcedar (*Tamarix* spp.) Leaf Litter Impacts on Surface Soil Chemistry: Electrical Conductivity and Sodium Adsorption Ratio," a thesis prepared by Cheryl E. Rosel in partial fulfillment for the degree, Master of Science in Agronomy, has been approved and accepted by the following:

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# DEDICATION

This thesis is dedicated to Mom, Dad, Austin, Tyler, Jeff, Maggie, Bo, and all of my friends who continue to support me in my pursuit of my dreams.

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I would especially like to thank Trine and Tim. Without their help my thesis would, literally, not exist.

## VITA

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ABSTRACT

SALTCEDAR (*Tamarix* spp.) LEAF LITTER IMPACTS ON SURFACE SOIL CHEMISTRY: ELECTROCONDUCTIVITY AND SODIUM ADSORPTION RATIO

BY

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Deciduous *Tamarix* spp. have become naturalized in the US since their introduction in the early 1800's. Adaptations such as salt tolerance contribute to the species' success. According to anecdotal evidence and limited field studies, salt glands on leaves exude salts and may create saline soil environments. However, a quantification of the rate and pattern of soil salinization has not been reported. A greenhouse experiment was performed to quantify *Tamarix* leaf litter (duff) impact on surface soil salinity and sodicity. Three duff treatments (0, 2, and 6 cm thick) and ~33 mm simulated rainfalls were applied to soil at different frequencies in three

consecutive experimental stages. The stages represented three moisture patterns: very wet with little or no soil drying, wet with some soil drying, and complete soil drying. Soil was sampled at 0-1 and 1-5 cm depths and soil-water (1:5) extracts were analyzed for electrical conductivity (EC) and sodium adsorption ratio (SAR). Salt originating from saltcedar duff was transferred to the soil surface via rainfall events. After the initial input occurred, the increase in salinity and sodicity was affected by the frequency of rainfall events. Therefore, Saltcedar duff can considerably increase the surface soil salinity if at least one rainfall event followed by soil dessication occurs. The 0-1 cm soil depth was more susceptible to increases in salinity and sodicity that the 1-5 cm soil depth because of the affects of ion redistribution and accumulation at the soil surface due to water evaporation at the surface. The duff used for this experiment contained $Na^+$, $Mg^{2+}$, $Ca^{2+}$, and $K^+$ salts and $Na^+$ salts were the most prevalent. Therefore, the saltcedar duff used in this experiment altered the cation ratio of the soil in favor of $Na^+$ in both the 0-1 and 1-5 cm soil depths, causing an increase in $SAR_{1:5}$.

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# 1. INTRODUCTION

## 1.1. Saltcedar: an exotic invasive species

Saltcedar is in the family Tamaricaceae and the genus *Tamarix* which includes both deciduous and evergreen species. The tree or shrub is commonly referred to as saltcedar or tamarisk. The common name, saltcedar, refers to its cedar-like appearance and ability to grow in saline environments (Carpenter, 1998).

Several deciduous species, and at least one evergreen species (*Tamarix aphylla*, athel tamarisk), were introduced to the U.S. from Southern Europe or the eastern Mediterranean region in the early 1800's by nurserymen (Horton, 1964; Neill, 1985; Carpenter, 1998). Saltcedar became naturalized in the Southwest in the early 1900's and its spread was facilitated by planting for wind protection, stream bank erosion control, and ornamental value. Only the deciduous species have become extensively naturalized (Carpenter, 1998; Neill, 1985).

Historical records of saltcedar in New Mexico on the Pecos River between the Alamogordo Dam and the New Mexico-Texas border show an exponential increase from approximately 7,000 to 55,000 acres between 1920 and 1961. This increase occurred in other watersheds all over the southwest (Robinson, 1965). Saltcedar has spread into nearly every perennial drainage system in 23 states in the southwest U.S. (Zavaleta, 2000). Robinson (1965) estimated the areal extent of saltcedar in the western U.S. to be approximately 900,000 acres (364,217 hectares) in 1961. Considering the rapid rate of spread of saltcedar, Robinson extrapolated the areal extent to be 1.3 million acres by 1970. Zavaleta (2000) cited a 494,210 acre

(200,000 hectare) increase from the years 1989 to 1999 and reported the areal extent to be from 1,161,395 to 1,606,185 acres (470,000 to 650,000 hectares) in 2000.

Confusion exists surrounding the correct taxonomy of the introduced deciduous species. At least 3 to 6 species (depending on how the taxonomic authority split or lumped species) have been introduced to the U.S. (Duncan, 1994; Carpenter, 1998). Some of the species have hybridized, further confusing their taxonomic designations. However, for land-management purposes, the deciduous *Tamarix* species do not need to be distinguished (Carpenter, 1998). For the following discussions, all naturalized deciduous species will be referred to as *Tamarix* or by common name.

Saltcedar are loosely branched with appressed scaly leaves. The flowers are white or pink and appear most commonly between April and October (Carpenter, 1998; Merkel and Hopkins, 1957). One plant can produce thousands of wind-dispersed seeds every season. A mature seed is extremely small, weighing only 0.00001 g (Wilgus and Hamilton, 1962). Under suitable soil moisture and temperature conditions, the majority of saltcedar seeds will germinate after being deposited on bare alluvial surfaces within the first 24 hours (Merkel and Hopkins, 1957; Shafroth *et al.*, 1995). The seedlings develop an extremely adaptable and extensive root system based on the location of the water table (Merkel and Hopkins, 1957). Saltcedar can grow where the water table is less than 25 ft (7.6 m) and grows best with a water table at 15 ft (4.6 m) or less (Robinson, 1965).

Saltcedar is a facultative phreatophyte, or "well-plant". It has deep roots that draw water from saturated soil near the groundwater table. Native species (e.g., willow or *Salix* spp. and cottonwood or *Populus* spp.) are obligate phreatophytes that

must remain in contact with saturated soil (Duncan, 1994; Anderson, 1982).

Historically, the Rio Grande had an annual spring flood pulse in which native cottonwood seed release and seedling establishment was closely tied (Ellis *et al.*, 2002). Under the normal flood regime, cottonwood had the competitive advantage over saltcedar. Saltcedar seedlings did not survive in the high soil moisture caused by the flooding. However, altered flood regimes, caused by water diversion, groundwater decline, flow regulation, channelization, or damming, result in a changed flood frequency (loss of flood pulse), lowered water tables and increased soil salinity on floodplains. Saltcedar is better adapted to the altered conditions than native cottonwood; therefore, it has a competitive advantage. Saltcedar can tolerate significantly longer dry periods, lower water tables, and higher water and soil salinity than native phreatophytes (Busch and Smith, 1995; Nagler *et al.*, 2005; Devitt *et al*., 1997). When native plant survival is reduced, saltcedar continues to thrive, evapotranspire, and further lower the water table which supports claims of extreme water use.

There have been many estimates of evapotranspirational water loss from *Tamarix* but little agreement in the literature. Varied experimental conditions such as ground water depth, stand density, soil and water salinity, ground cover, and climate may affect water use by *Tamarix* and native phreatophytes, thus making generalizations based on published data difficult. Even so, water use by *Tamarix* stands has been estimated, using various methods, to be from 0.83-3.6 m $yr^{-1}$. Stated more often in the literature, the range is narrower (0.7-1.3 m $yr^{-1}$) (Nagler *et al.*, 2005; Van Hylckama, 1970). Recent experiments by Nagler *et al.* (2005) show that

*Tamarix*, willow, and cottonwood stands have similar water use. This is in contrast to earlier reports of *Tamarix* having unusually high water use compared to willow and cottonwood (Weeks *et al*., 1987).

The units of evapotranspiration used for these comparisons (m $yr^{-1}$) refer to the amount of water lost through the leaves via transpiration and the water loss due to evaporation of water from the soil affected by the plant or stand (directly below the plant or stand). However, the amount of evaporative loss is minimal compared to the amount of transpirational loss. Because of this, evapotranspiration is usually derived from a transpirational water-loss measurement only, therefore reported as a length per time measurement. It is possible to normalize this measurement with area (below the plant or stand) and obtain a volume measurement; however, this does not produce reliable results and is not typically reported in the literature (Rolston St. Hilaire, Pers. Comm., 2006).

### 1.2. Saltcedar and salinity

Soluble salts are naturally present in the environment, and in arid and semiarid regions they tend to accumulate in soils and surface waters. In general, low rainfall prevents leaching of salts through the soil profile and high evaporation rates further concentrate salts (Shainberg, 1975). The Rio Grande in New Mexico presents a more specific illustration of salinity issues in arid regions. The Rio Grande increases in salt content as it travels south across New Mexico to Texas. Dissolved solids increase from 40 mg $L^{-1}$ (~0.1 dS $m^{-1}$, considered to be low salinity by Essington, 2004) at its headwaters in Colorado to 750 mg $L^{-1}$ (~1.2 dS $m^{-1}$, considered to be medium salinity

by Essington, 2004) at El Paso, TX. Farther downstream at Fort Quitman, TX, the dissolved solids reach 2,000 mg $L^{-1}$ (~3.1 dS $m^{-1}$, considered to be high salinity be Essington, 2004). The salinity increase may be caused by weathering reactions of rock and soil, inflows of saline subsurface waters, anthropogenic inputs (domestic waste, fertilizers, and soil amendments), evaporation, and transpirational losses from riparian vegetation (Phillips *et al.*, 2003).

When soils come into contact with salinized water that eventually evaporates, the salts are left as a deposit in the soil. Both the quantity and composition of salts deposited in soil is important. Excessive quantities of soluble salts can be harmful to plants by interfering with water uptake. The most common salts in saline soils are $Cl^-$ and $SO_4^{2-}$ salts of $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $K^+$ (Sumner *et al.*, 1998) Also, high concentrations of certain ions may be toxic to plants (e.g. borate and chloride) or may alter soil characteristics (e.g. $Na^+$ degrades soil structure) (Shainberg, 1975). A saturated paste extract electrical conductivity ($EC_{se}$) of 4 dS $m^{-1}$ or above is considered saline and not suitable for growing most agronomic crops (U.S. Salinity Lab, 1954).

In arid regions, sodicity (excess $Na^+$) of surface water and soil often presents a problem. In the Rio Grande, sodicity usually increases along with salinity (Miyamoto *et al.*, 1995). Sodium hazard is commonly reported as sodium adsoption ratio (SAR), which specifically refers to the activity of exchangeable $Na^+$ present is soil or water relative to the activities of exchangeable $Mg^{2+}$ and $Ca^{2+}$ (U.S. Salinity Lab, 1954). Both $Mg^{2+}$ and $Ca^{2+}$ are common ions present in soils and water of arid regions and they have a greater charge density than $Na^+$. They tend to flocculate clay particles,

which maintain soil structure. As $Na^{+}$ on the exchange phase increases compared to $Mg^{2+}$ and $Ca^{2+}$, clay dispersion can occur and disrupt the hydrologic functioning of soil (Sparks, 2003). An $SAR_{se}$ of 13 or above is considered sodic (U.S. Salinity Lab, 1954).

Native phreatophytes are sensitive to salinity. For example, willow (*Salix gooddigii*) and cottonwood (*Populus fremontii*) seedlings cannot tolerate irrigation water (iw) EC of approximately 2 dS $m^{-1}$ or more (Jackson *et al.*, 1990). For native plants competing to establish in the same habitat as saltcedar, saline soil reduced their survival. It is especially important to consider the salt tolerance of germinating seeds. Cottonwood seed germination is reduced at $EC_{iw}$ above 4.5 dS $m^{-1}$. Willow seeds will germinate at the surprisingly high $EC_{iw}$ of approximately 9 dS $m^{-1}$ (Jackson *et al.*, 1990). Planting prescriptions at the Bosque del Apache National Wildlife Refuge (NWR) recommend a soil salinity of 1-2 for cottonwood and 1-2.5 for willow (Taylor, 1998a). However, the soil depth, method of analysis, and the growth stage of the plant were not specified.

Unlike many plants, saltcedar can tolerate high salt concentrations in the soil and groundwater. It has been observed growing in Death Valley where ground water salt concentrations reach 50,000 mg $L^{-1}$ (~78 dS $m^{-1}$). However, saltcedar thrives where the salt concentrations are low or moderate (Robinson, 1965).

Waisel (1972) classified saltcedar as a "salt-resisting" (does not require salt for survival), "salt-exuding" (secretes excess salt) Euhalophyte. Euhalophytes are plants that can grow in both highly saline habitats and non-saline environments (Waisel, 1972; Hem, 1967). As cited by Thomson (1975), *Tamarix* species have salt

glands, which are structures that allow them to exude excess mineral ions in order to regulate salt concentrations in their tissues resulting in salt crystal formation on the leaves of *Tamarix*. Hem (1967) noted that "The green leaves of saltcedar plants commonly carry small cubic crystals which are readily seen with the aid of a hand lens."

Salt secretion depends on the environment that saltcedar roots are growing in. Secretion is non-selective and will actively remove a variety of ions found in the groundwater or saturated soil. Specifically, the cation composition of salt secretions are correlated to the cation composition of irrigation solutions in controlled experiments (cited in Thomson, 1975). For example, Kleinkopf and Wallace (1974) observed that when the $Na^+$ concentration of an irrigation solution was increased, *Tamarix* secretion of $Na^+$ also increased. Hem (1967) observed and quantified various ions present on the leaves of *Tamarix* and noted that plants had the highest $Na^+$ and $Cl^-$ contents where the groundwater was known to have a high salinity. He also concluded that the amounts and composition of salts on saltcedar leaves may be influenced by more than just groundwater composition, but also the time of year, growth and transpiration rates, and rainfall frequency. Rainfall will tend to wash the leaves, transferring salts to the soil directly below the plant. However, Hem (1967) noted that the quantities of salt transferred to the soil are unknown. In addition to salt inputs washed from the saltcedar leaves to surface soil, decomposing leaves on the soil surface (dropped in autumn) could potentially transfer greater quantities of salt to the soil than washing of live, green leaves by rainfall alone (Hem, 1967).

Anecdotal evidence and published literature indicate that saltcedar may

contribute to increased soil salinity and sodicity. High soil salinities associated with saltcedar, but not necessarily caused by saltcedar, have been reported by Busch and Smith (1995), Anderson (1995), Sher *et al.* (2002), Ladenburger *et al.* (2005), and Glenn *et al.* (1998).

In saltcedar removal and restoration efforts, soil salinity (along with texture, and depth to groundwater) is one of the most important site characteristics used to determine the suitability of a site for revegetation (Taylor, 1998b). Learning more about the effect of saltcedar on soil salinity may aid in restoration efforts if there is also a way to minimize the salt's effects.

The objective of this study was to determine whether salts are transferred from *Tamarix* leaf litter (duff) to the surface soil (0-5 cm) after rainfall events and to quantify the amount in a controlled greenhouse study. For the purposes of this study, the surface soil is defined as the upper 0-5 cm of soil. We hypothesized that saltcedar duff will significantly increase the salinity and/or sodicity of the surface soil.

## 2. MATERIALS AND METHODS

A greenhouse study and duff leaching experiment were performed to meet the objectives stated in the previous section.

### 2.1 Greenhouse Experiment

On 12 Dec. 2005, duff, consisting of saltcedar leaves, twigs, and seeds that fell in the autumn of 2005 were collected from a 45 acre pasture (Pasture #18, 32˚ 32' 55.99" N 106˚ 59' 39.28" W) on the Chihuahuan Desert Rangeland Research Center (CDRRC) in Dona Ana County, NM (*Figure 1*). This saltcedar infestation is relatively light, compared with the monotypic infestations common along the Rio Grande, and most likely started during a flood event in the early 1980's. The saltcedar stand inhabits alluvial deposits originating from Lytten Canyon with a yearly average depth to groundwater of approximately 1.2 m (Robert McNeely, Pers. Comm., 2006). Salinity of the groundwater of pasture #18 during the summer of 2005 was approximately 0.9 dS $m^{-1}$ (Carlos Ochoa, Pers. Comm., 2006). The rainfall data for March-Dec. of 2005 is reported in Appendix D.

Duff from under the canopies of *Tamarix* trees was raked by hand into 42-gal heavy duty (3-mil) black plastic contractor bags. Care was taken to avoid raking up surface soil or other plants. The duff was transported to the greenhouse at Fabian Garcia Science Center west of New Mexico State University, Las Cruces, NM.

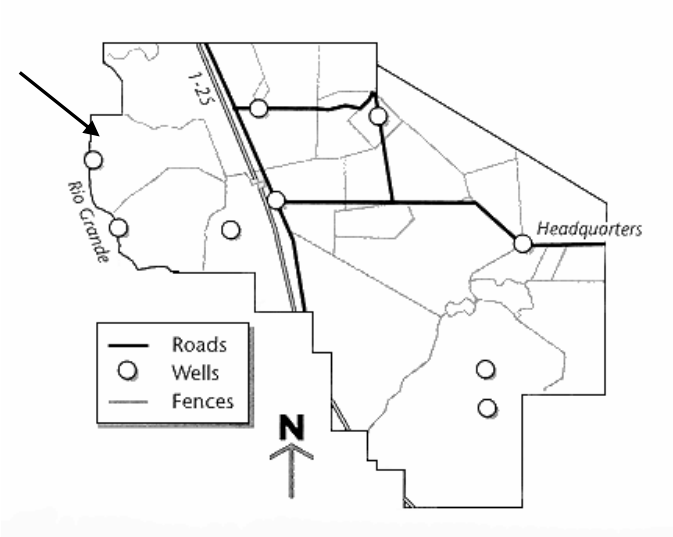


*Figure 1*: Collection site on CDRRC Pasture #18 (see arrow), latitude and longitude: 32˚ 32’ 55.99” N 106˚ 59’ 39.28” W, elevation: approximately 4,000 ft.

Brazito sandy loam surface soil (mixed, thermic Typic Torripsamment) was collected from the southwest corner of the easternmost patch of pine trees north of University Avenue on the north side of the Fabian Garcia Agricultural Science Center. The Brazito sandy loam is slightly alkaline, nonsaline, nonsodic, has low organic matter content, and low nutrient levels (*Table 1*).

Drainage holes were drilled into 18 plastic containers with the dimensions of 41 cm x 61 cm (0.25 $m^2$). The containers were lined with weed control fabric (Easy Gardener, Waco, TX) to allow water drainage but prevent soil loss. On 19 Dec. 2005, unsieved, air-dried, homogenized soil was put into each of the 18 containers to a depth of approximately 10 cm. Aluminum pans lined with 3-mil plastic bags (to prevent any metal contamination) were attached to the underside of the greenhouse benches under each container to collect leachate. Soil samples were collected from each container on 20 Dec. 2005 to establish a baseline EC and SAR. Baseline EC and

SAR values were established by sampling both soil depths in each plot before duff treatments were applied then averaging the results. Saturated paste extracts were also analyzed for the experimental soil.

*Table 1*: Brazito Sandy Loam soil analysis by the Soil, Water, and Air Testing Lab at NMSU, Las Cruces, NM).

| **Test Parameter** | **Results** |
|---|---|
| pH of saturation paste | 7.8 |
| [1]Electrical conductivity (EC) | 1.18 dS $m^{-1}$ |
| [2]Magnesium concentration | 1.31 $mmol_c$ $L^{-1}$ |
| [2]Calcium concentration | 5.65 $mmol_c$ $L^{-1}$ |
| [2]Sodium concentration | 5.79 $mmol_c$ $L^{-1}$ |
| Sodium adsorption ratio (SAR) | 3.1 |
| Exchangeable Na % (ESP) | 3.2 |
| [3]Organic Matter | 0.59% |
| [4]$NO_3$-N | 14.1 mg $kg^{-1}$ |
| [5]Phosphorus | 6.7 mg $kg^{-1}$ |
| [6]Potassium | 60 mg $kg^{-1}$ |
| Texture of soil by feel | sandy loam |

[1]Electrical conductivity of a saturation paste extract
[2] Concentration from a saturation paste extract analyzed by ICP
[3]Organic matter, Walkley-Black method
[4]1:5 soil:water extract, Cadmium Reduction Column
[5]$NaHCO_3$ extractable, Olsen method
[6]1:5 soil:water extract analyzed by ICP

Three duff treatments were applied to the soil on 9 Jan. 2006 in a completely randomized design with 6 replications of each treatment. The control treatment had no duff per 0.25 $m^2$ (0 cm thickness), treatment 1 had 225 g of duff per 0.25 $m^2$ (~2 cm thickness), and treatment 2 had 450 g of duff per 0.25 $m^2$ (~6 cm thickness). Treatment 1 represented a natural duff layer one would expect to find in the field and treatment 2 represented an exaggerated duff layer that would rarely be found in the field (Personal comm. Sandy Tartowski, 2005) (*Figure 2*). The containers with soil

and duff treatments are referred to as experimental plots in the following explanations.

Three liters (~0.5 in or ~33 mm) of reverse osmosis water were applied to each plot at predetermined intervals using a two-gal capacity hand sprayer to simulate rainfall events (see Appendix A1 for calculations). The reverse osmosis water had an average EC of 0.04 dS $m^{-1}$ and SAR of 0. The reverse osmosis water was used to ensure that any salts added to the soil were from the duff treatments only.

The 0-1 cm and 1-5 cm soil depths were sampled from each plot using a spatula with markings to indicate depth in cm. One sample was taken per plot per sampling event. Samples were randomly taken from locations on an imaginary grid pattern on each plot (*Figure 3*). Locations on the grid were determined for each plot for each sampling time using a lottery method (Kuehl, 2000). The duff was removed by cutting it along the perimeter of the sampling location with a pocket knife and lifting it out. Then soil samples were removed and the remaining hole was filled in with fresh soil to prevent preferential water flow. The cut-out duff was placed back on the soil. Each location on the grid was only sampled once.

The application of water began on 10 Jan. 2006 and consisted of three Stages based on watering frequency. The watering frequencies were chosen to represent rainfall patterns in New Mexico (monsoons and dry periods). Overlap occurred in the dates of Stages I and II and Stages II and III due to certain data points meeting the criteria to be in more than one Stage (*Table 2*).

- **Stage I** – Water was applied every seven days beginning on 10 Jan. 2006 and ending on 30 Jan. 2006. Soil samples were taken six days after each watering (every 7 days). This stage represents a wet period, similar to late summer monsoons.

- **Stage II** – Water was applied every 14 days beginning on 24 Jan. 2006 and ending on 27 Feb. 2006. Soil samples were taken every seven days. This Stage allowed for more drying of the soil than Stage I. This stage represents an intermediate of Stage I and Stage III.

- **Stage III** – No water was applied during this Stage beginning on 21 Feb. 2006 and ending on 10 April 2006. Soil samples were taken every 14 days (and on 6 March because it was also a Stage II sampling date). This Stage allowed for soil desiccation to occur, such as in the arid southwest where saltcedar is commonly found.

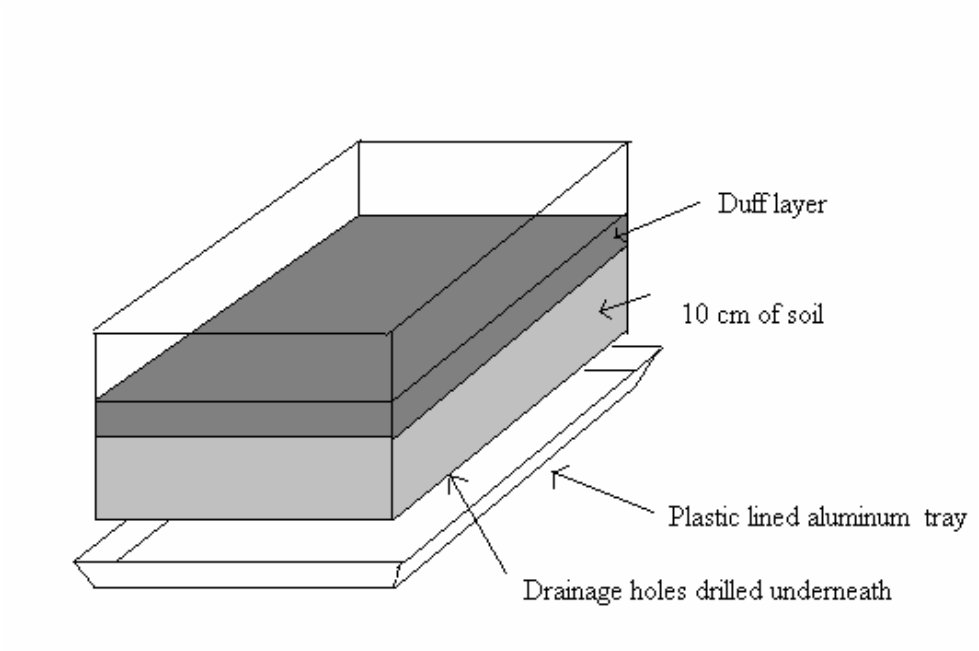


*Figure 2*: Experimental plots, 41 cm x 61 cm (0.25 $m^2$)

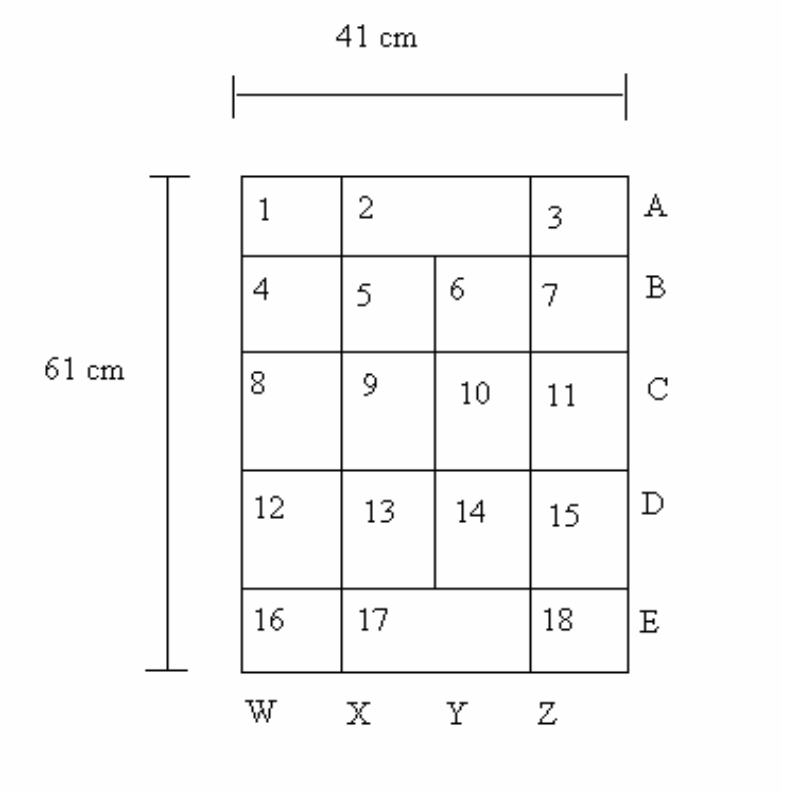


*Figure 3*: Imaginary grid pattern used to locate the randomly selected sampling positions

The EC, pH, and SAR were measured on 1:5 soil:water extracts for each sample (See Appendix B1 for extraction details). The same was done for any leachate produced throughout the experiment and, due to lack of leaching, the control plots were deliberately leached after the experiment was terminated.

*Table 2*: Sampling and watering dates for experimental Stages I, II, and III began on 10 Jan. and ended on 10 April.

| Stage | Date | Procedure performed |
|---|---|---|
| I | 1/10/06 | 1st watering |
| I | 1/16/06 | 1st sample collection |
| I | 1/17/06 | 2nd watering |
| I | 1/23/06 | 2nd sample collection |
| I & II | 1/24/06 | 3rd watering |
| I & II | 1/30/06 | 3rd sample collection |
| II | 2/6/06 | 4th sample collection |
| II | 2/7/06 | 4th watering |
| II | 2/13/06 | 5th sample collection |
| II | 2/20/06 | 6th sample collection |
| II & III | 2/21/06 | 5th watering |
| II & III | 2/27/06 | 7th sample collection |
| II & III | 3/6/06 | 8th sample collection |
| III | 3/13/06 | 9th sample collection |
| III | 3/27/06 | 10th sample collection |
| III | 4/10/06 | 11th sample collection |

The EC was measured using a temperature-compensating Fisher Accumet conductivity 2-cell body type with 1.0 cm cell constant (Fisher Scientific, Pittsburgh, PA). The pH was measured using a liquid-filled combination electrode and Beckman Φ72 benchtop pH meter. Calcium, $Mg^{2+}$, and $Na^{+}$ concentrations in the extracts were measured using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP). The SAR was calculated using the following equation (also see Appendix A2):

$$SAR_{1:5}\ (mmol^{1/2}\ L^{-1/2}) = [Na^{+}] / [Ca^{2+} + Mg^{2+}]^{1/2}\ .$$

The ICP results of the concentrations of $Na^{+}$, $Ca^{2+}$, and $Mg^{2+}$ in the 1:5 extracts were in meq $L^{-1}$ so it was necessary to convert the concentrations to mmol $L^{-1}$ for calculating SAR using the above equation.

The EC and SAR were statistically analyzed separately. Stages I, II, and III were also analyzed separately. Data were initially analyzed by repeated measures analysis using the GLM procedure (SAS version 9.1, SAS Institute, Cary, NC), with the following factors: duff treatment, plot, and soil depth. The repeated measures analysis in GLM was done to evaluate potential unequal correlation between sampling dates by the Greenhouse-Geisser and Huynh-Feldt techniques (Kuel, 2000). In no case was a problem with unequal correlation detected. Therefore, data were re-analyzed by a split-split-plot analysis of variance using the GLM and MIXED procedure (SAS version 9.1, SAS Institute, Cary, NC) and only these results will be reported. In this analysis, the whole plot was a completely randomized design with duff treatment and plot as the whole experimental unit. The split-plot factor was soil

depth and the split-split-plot factor was sampling date. The GLM procedure was used to calculate Mean Squares, F-statistics, and P-values. The MIXED procedure was used to calculate means and standard errors. A 5% ($\alpha = 0.05$) significance level was used for all statistical tests.

The pH was not statistically analyzed due to fluctuations that occurred in the deionized water used to dilute the samples; therefore, the differences in pH were not caused by duff treatments.

The first tests to consider are associated with the interactions of each factor (duff treatment, soil depth, and sampling date) in all combinations. A statistical interaction occurs when the effect of one factor varies with changes in another factor. Significant interactions occurred between experimental factors and they were addressed starting with the three-way interaction (duff treatment x soil depth x sampling date) ending with the two-way interactions (duff treatment x soil depth, duff treatment x sampling date, and soil depth x sampling date). If the interactions are such that averaging a response variable over the levels of another factor will give a meaningless result, then discussing the main effects is not meaningful either. Mean plots were made to investigate the relevant interactions.

The next tests to consider for the split-plot analyses are associated with the main effects of treatment, soil depth, and sampling date. If a significant main effect of treatment occurred, the thickness of the duff layer (0, 2, or 6 cm) placed on each plot affected the mean of the response variable ($EC_{1:5}$ or $SAR_{1:5}$) in the surface soil. If there was a significant main effect of soil depth, the mean of the response variable of interest was different between the 0-1 cm soil depth and the 1-5 cm soil depth. If

there was a significant main effect of sampling date, time affected the mean of the response variable of interest.

## 2.2. Duff leaching

Water-extractable ions leached out of saltcedar duff were analyzed. Two methods were modified from Hem (1967) and used to leach the saltcedar duff for different periods of time. The first method soaked the duff for a 24 hour period and represented long term, or repeated leaching of salts, that may occur as duff decomposes under a tree over more than one season. The second method represented the leaching of salts that may occur after only one rainfall event.

Method 1 (24-hour leaching):

This method represents ions potentially transferred to the soil during initial duff decay. Twenty-five g of duff were air-dried in the laboratory. A subsample of 2 g was oven-dried at 67˚ C for 2 days to determine moisture content. Five g of the air dry duff (three replications and one blank) were put in a beaker to which 100 mL of deionized water were added. The beaker was covered with parafilm and allowed to stand, with occasional stirring, for 24 hours at room temperature. After 24 h, the solution was filtered through Whatman 2V paper and quantitatively transferred to a 250 ml volumetric flask and brought to volume. The ion concentrations of the filtered solution were analyzed by ICP and the results were reported as a percentage of oven-dried sample weight.

Method 2 (washing, brief contact time):

This method represents the ions potentially transferred to the surface soil after one or more rainfall events. Five g air-dried duff (three replications and one blank) was placed in a funnel lined with Whatman 2V paper. The duff was washed three times with the same 125 ml of deionized water and brought to volume in a 250 mL in a volumetric flask. The ion concentrations of the filtered solution were analyzed by ICP and the results were reported as a percentage of oven-dried sample weight.

## 3. RESULTS AND DISCUSSION

### 3.1. Comparison of saturation paste extract to 1:5 extract

Soil:water (1:5) extracts were used for this experiment to measure changes in salinity over time. Using 1:5 soil:water extracts to determine EC and SAR has some advantages and some limitations when compared with the saturated paste extract. The 1:5 extracts require less soil than saturated paste extracts, but they are much more dilute and less representative of riparian field conditions. Soil:water (1:5) extracts were justified in this study because our plots were small and required multiple sampling over time.

What was important for this experiment was to compare relative changes in $EC_{1:5}$ and $SAR_{1:5}$. Any error that occurred due to the increased soil:water dilution for this experiment is of low concern when comparing relative changes (Rhoades, 1996). All $EC_{1:5}$ and $SAR_{1:5}$ experimental results were compared with the pre-experiment baseline results for 1:5 dilutions.

The $EC_{1:5}$ results throughout the experiment (Stages I-III) ranged from 0.15 dS $m^{-1}$ to 1.5 dS $m^{-1}$, in the 0-1 cm soil depth representing a ten-fold increase in salinity over the baseline values. Sumner *et al.* (1998) stated that for soils with 10-20% clay, an $EC_{1:5}$ of approximately 0.45 dS $m^{-1}$ is highly saline, a soil in which only salt tolerant crops can survive. Sumner's estimated value can be used as a rough estimate to compare the experimental $EC_{1:5}$ values to; however, this value was measured on a different soil than the one used for this experiment.

Dispersion due to high soil $Na^+$ concentrations would be minimal in a soil

with low clay content, as used in this experiment. However, $Na^+$ made up 61% of the total $Mg^{2+}$, $Ca^{2+}$, $K^+$, and $Na^+$ washed from saltcedar duff (see duff leaching results). For this reason, $SAR_{1:5}$ was used as another, possibly more sensitive, measure of soil salinity rather than a dispersion hazard per se.

The $SAR_{1:5}$ results throughout the experiment ranged from 0.69 to 3.81 in the 0-1 cm soil depth, representing more than a five-fold increase in sodicity over the baseline values determined for the soil before treatments were imposed.

### 3.2. Greenhouse Experiment

#### 3.2.1. Soil EC and SAR (Stages I-III)

At the beginning of the experiment, the soil had a baseline $EC_{1:5}$ of 0.15 dS $m^{-1}$ (standard error = 0.003) and a baseline $SAR_{1:5}$ of 0.69 (standard error = 0.015).

Statistical analyses indicate that duff thickness influenced surface soil $EC_{1:5}$ and $SAR_{1:5}$, and that surface soil $EC_{1:5}$ and $SAR_{1:5}$ were affected differently with respect to soil depth in all experimental Stages (I-III) (*Tables 3-5*). Statistical significance is denoted by P-values of $\leq 0.05$. The degrees of freedom, Mean Squares, and F-statistics associated with the effect of each factor are also reported.

Not all interactions were the same for all experimental Stages, so each Stage will be discussed separately to determine whether there were reasons to invalidate the significance of one or more of the tests of main effects in one or more experimental Stage (see *Figures*: *4-7*, Stage I; *8-12*, Stage II; *13-18*, Stage III).

Stage I:

The results of the split-split-plot analysis of variance for both $EC_{1:5}$ and $SAR_{1:5}$ are shown in *Table 3*. The analysis indicates that the main effects of duff thickness and soil depth significantly affected the surface soil $EC_{1:5}$ and $SAR_{1:5}$; however, $EC_{1:5}$ and $SAR_{1:5}$ were not affected by the main effect of sampling date (*Table* 3, also see Apendix C1 for Table of main effect means). Significant interactions occurred and must be considered. Each interaction in Stage I resulted in the same general pattern for $EC_{1:5}$ and $SAR_{1:5}$. These patterns made interpretation of the significant main effects reasonable. The interactions occurred among sampling date x treatment x soil depth (three-way, *Figures 4* and *5*), sampling date x soil depth (two-way, *Figure 6*), and treatment x soil depth (two-way, *Figure 7*) and they will be discussed in that order.

As seen in *Figures 4* and *5*, the differences in $EC_{1:5}$ and $SAR_{1:5}$ that occurred between the two soil depths in response to duff thickness are not the same through time, indicated by the significant three-way interactions. After one simulated rainfall, the $EC_{1:5}$ and $SAR_{1:5}$ in the 0-1 cm soil depth were much higher than in the 1-5 cm soil depth. Over time, as watering continued, the differences in $EC_{1:5}$ and $SAR_{1:5}$ at each soil depth decreased. The *Figure 4* and *5* both show the Stage I three-way interaction; however, the axes are different in *Figure 4* compared to *Figure 5*. This provides two different views of the three-way interaction.

As seen in *Figure 4a* and *4b*, after the initial simulated rainfall of Stage I, both $EC_{1:5}$ and $SAR_{1:5}$ in the 0-1 cm soil depth of the 2 and 6 cm duff treated plots

increased sharply to a maximum, then decreased more gradually with continued rainfall events. The $EC_{1:5}$ of the 2 and 6 cm duff treatments in the 0-1 cm soil depth increased by three and four times over the baseline, respectively (*Figure 4a*). The $SAR_{1:5}$ of the 2 and 6 cm duff treatments increased slightly more than $EC_{1:5}$, by almost four and five times over the baseline, respectively (*Figure 4b*). The 1-5 cm soil increased in $EC_{1:5}$ and $SAR_{1:5}$ only slightly over the baseline for the duff treated plots and the control decreased slightly under the baseline (*Figures 4c* and *4d*). The control $EC_{1:5}$ and $SAR_{1:5}$ of both soil depths remained unchanged for the duration of Stage I. After continued weekly watering, it appears that the 0-1 cm soil depth $EC_{1:5}$ and $SAR_{1:5}$ would gradually return to baseline values. The 1-5 cm soil depth $EC_{1:5}$ and $SAR_{1:5}$ appeared to level off, and would have eventually decreased to baseline values with continued watering.

As seen in *Figure 5*, the $EC_{1:5}$ and $SAR_{1:5}$ for the 0-1 cm soil depth decreased from 16 Jan. through 30 Jan. The $EC_{1:5}$ of the 1-5 cm soil depth rose slightly. The $SAR_{1:5}$ of the 1-5 cm soil depth rose after two rainfall events, but began to drop back down after a third. There was no change in the salinity or sodicity of either soil depth under the control treatment (0 cm duff). The decreased differences in $EC_{1:5}$ and $SAR_{1:5}$ between soil depths over time were due to soluble salt and $Na^+$ movement through the upper surface soil after each rainfall event. The salts contributing to $EC_{1:5}$ and $SAR_{1:5}$ under the duff treated plots appeared to leach through the upper surface soil very quickly.

The sampling date x soil depth interaction shows the averaged response variable (either $EC_{1:5}$ or $SAR_{1:5}$) for each duff thickness (0, 2, 6 cm) for each soil

depth across sampling dates (*Figure 6*). The interaction mimics the field-situation where duff thickness is unknown, but time of sampling and soil depth are known. Both $EC_{1:5}$ and $SAR_{1:5}$ were initially higher in the upper surface soil than in the 1-5 cm soil depth and decreased with time, driving the two-way interaction. The leaching of ions through the upper surface into the deeper soil reduced differences over time with continued rainfall, regardless of duff treatment. Eventually, the lower soil $EC_{1:5}$ and $SAR_{1:5}$ would either level off or decrease with continued weekly watering.

The thickest duff layer (6 cm) caused the greatest increase in $EC_{1:5}$ and $SAR_{1:5}$ and the greatest difference in $EC_{1:5}$ and $SAR_{1:5}$ between the two soil depths when considering the treatment x soil depth interaction (*Figure 7*). The treatment x soil depth interaction mimics the field-situation where time of sampling is unknown, but the duff thickness and soil depth are known. Therefore, despite frequent rainfalls, higher soil salinity and sodicity may be found under thicker saltcedar duff layers.

In summary, saltcedar duff increased the surface soil salinity and sodicity in Stage I (weekly rainfall events) as indicated by the significant main effect of duff treatment. Also, $EC_{1:5}$ and $SAR_{1:5}$ showed a similar pattern indicating that $Na^+$ is a major contributing ion from the duff. However, frequent rainfalls seem to suggest that the salinity and sodicity caused by the duff will reduce with time.

*Table 3*: Stage I analysis of variance table for $EC_{1:5}$ and $SAR_{1:5}$. Abbreviations are as follows: degrees of freedom (DF), P-values (P), F-statistics (F), and mean squares (MS).

| | | $EC_{1:5}$ | | | $SAR_{1:5}$ | | |
|---|---|---|---|---|---|---|---|
| **Effect** | **DF** | **P** | **F** | **MS** | **P** | **F** | **MS** |
| Treatment | 2 | < .0001 | 80.91 | 0.67 | < .0001 | 140.2 | 21.98 |
| Plot(Treatment), error a | 15 | 0.7108 | 0.74 | 0.01 | 0.9459 | 0.45 | 0.16 |
| Soil Depth | 1 | < .0001 | 351.7 | 0.84 | < .0001 | 454.7 | 23.10 |
| Treatment x Soil Depth | 2 | < .0001 | 59.71 | 0.14 | < .0001 | 68.02 | 3.46 |
| Soil Depth x Plot(Treatment), error b | 15 | 0.9711 | 0.39 | 0.00 | 0.0791 | 0.79 | 0.05 |
| Sampling Date | 2 | 0.2822 | 1.32 | 0.02 | 0.1002 | 2.49 | 0.90 |
| Treatment x Sampling | 4 | 0.6254 | 0.66 | 0.01 | 0.6986 | 0.55 | 0.20 |
| Sampling Date x Plot(Treatment), error c | 30 | 0.0094 | 2.41 | 0.02 | <.0001 | 5.64 | 0.36 |
| Sampling Date x Soil Depth | 2 | 0.0004 | 10.13 | 0.06 | <.0001 | 29.78 | 1.92 |
| Sampling Date x Treatment x Soil Depth | 4 | 0.0446 | 2.78 | 0.02 | 0.0008 | 6.32 | 0.41 |
| Sampling Date x Soil Depth x Plot(Treatment), error d | 30 | -- | -- | 0.01 | -- | -- | 0.06 |

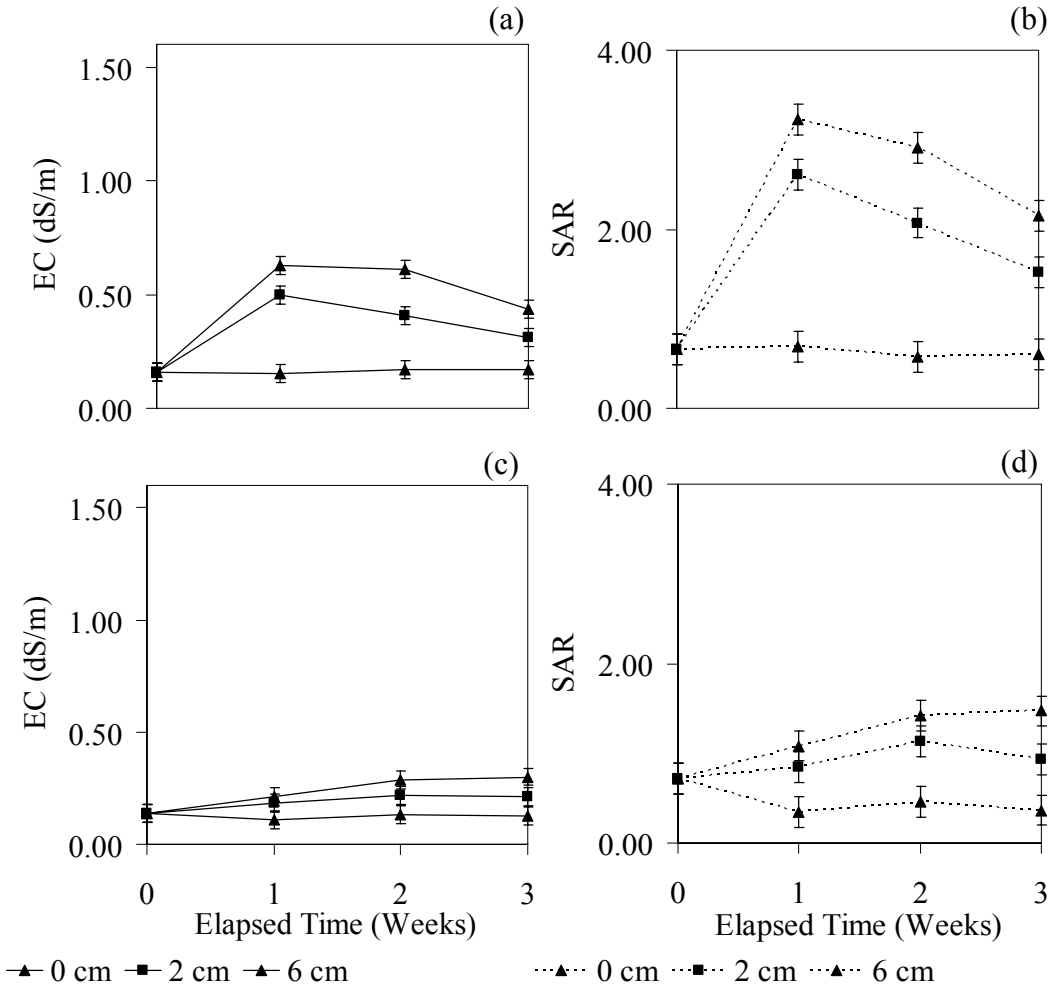


*Figure 4*: Shows the Stage I three-way (sampling date x treatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b) in the 0-1 cm soil depth and $EC_{1:5}$ (c) and $SAR_{1:5}$ (d) in the 1-5 cm soil depth. Week '0' shows the pre-experiment $EC_{1:5}$ and $SAR_{1:5}$.

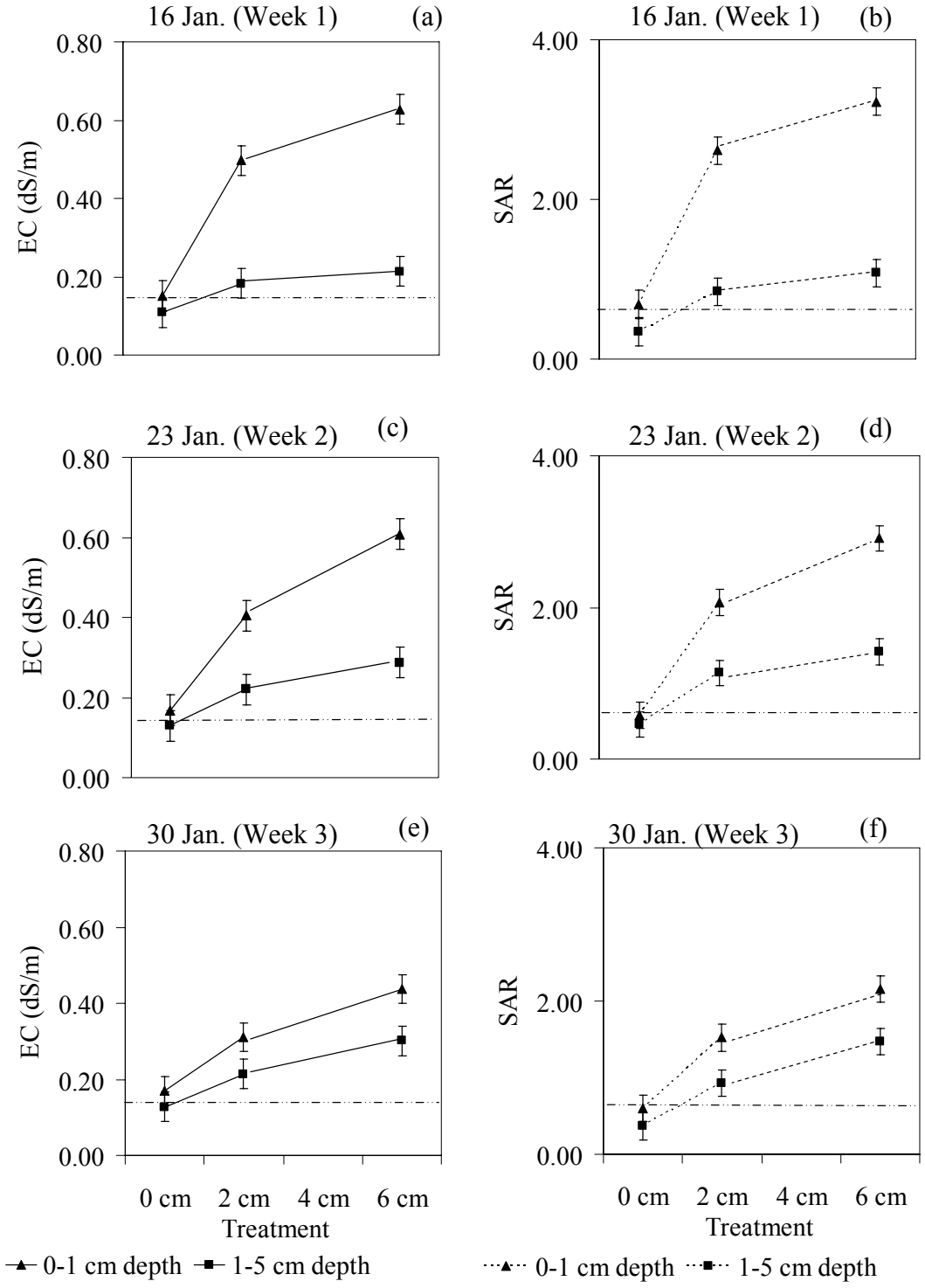


*Figure 5*: Shows the Stage I three-way (sampling date x treatment x depth) interactions for $EC_{1:5}$ (a, c, e) and $SAR_{1:5}$ (b, d, f) at each sampling date. The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

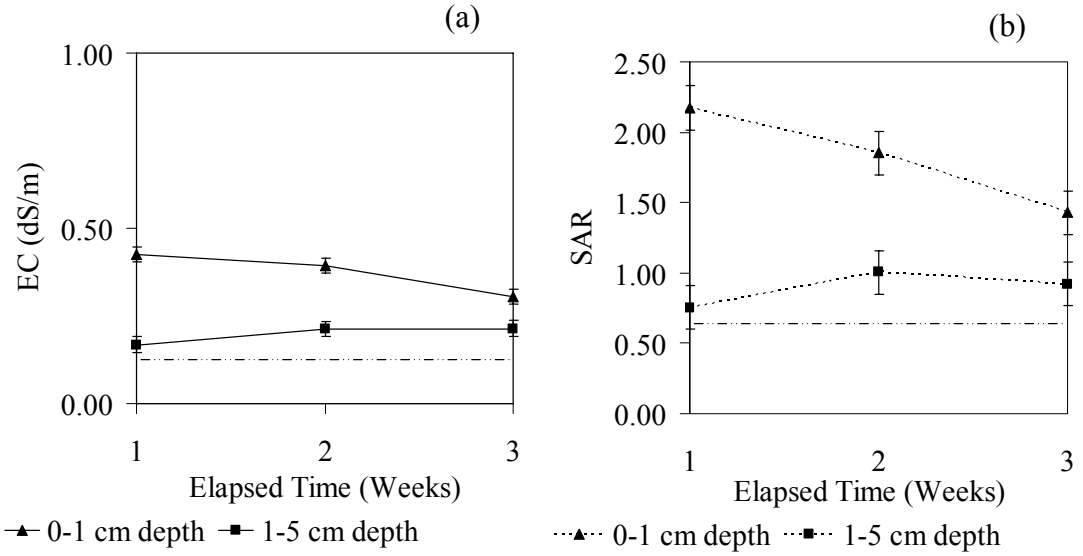


*Figure 6*: Shows the Stage I two-way (sampling date x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

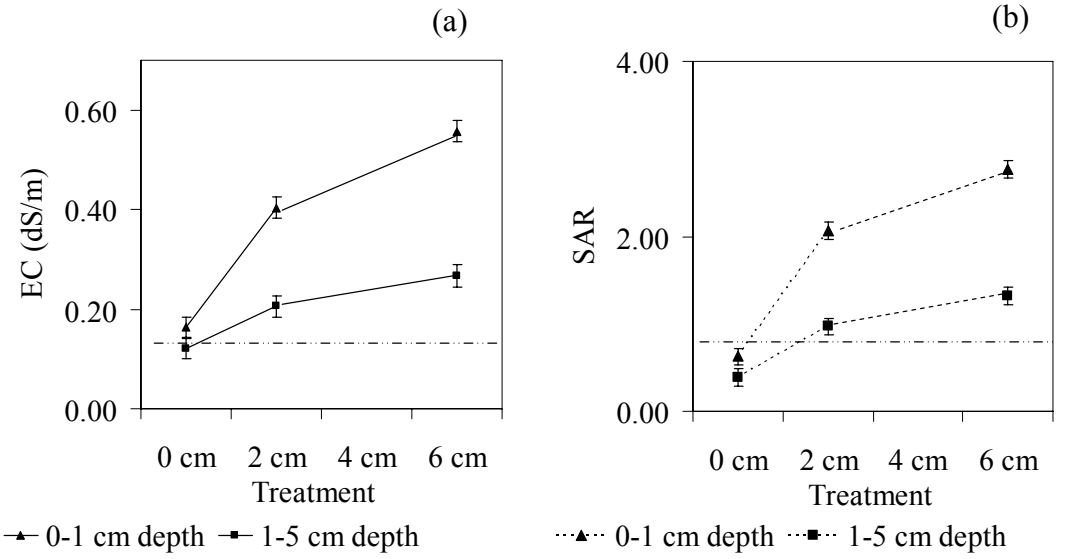


*Figure 7*: Shows the Stage I two-way (treatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

Stage II:

The results of the split-split-plot analysis of variance for both $EC_{1:5}$ and $SAR_{1:5}$ are shown in *Table 4*. The analysis indicates that the main effects of duff thickness, soil depth, and sampling date significantly affected the surface soil $EC_{1:5}$ and $SAR_{1:5}$ (*Table 4*, also see Appendix C2 for Table of main effects means). Significant interactions occurred and must be considered. The patterns of interactions for $EC_{1:5}$ and $SAR_{1:5}$ had some differences and some similarities; however, the patterns are such that interpretation of the significant main effects is reasonable. Interactions occurred, for $EC_{1:5}$, among sampling date x treatment x soil depth (three-way, *Figures 8, 9* and *10*), sampling date x soil depth (two-way, *Figure 11*), and treatment x soil depth (two-way, *Figure 12*). Only one significant interaction occurred for $SAR_{1:5}$ among sampling date x soil depth (two-way, *Figure 11*), but the same interaction plots are included for both $EC_{1:5}$ and $SAR_{1:5}$ for comparison.

*Table 4*: Stage II analysis of variance table for $EC_{1:5}$ and $SAR_{1:5.}$ Abbreviations are as follows: degrees of freedom (DF), P-values (P), F-statistics (F), and mean squares (MS).

| | | $EC_{1:5}$ | | | $SAR_{1:5}$ | | |
|---|---|---|---|---|---|---|---|
| **Effect** | **DF** | **P** | **F** | **MS** | **P** | **F** | **MS** |
| Treatment | 2 | <.0001 | 19.85 | 0.31 | <.0001 | 39.32 | 25.71 |
| Plot(Treatment), error a | 15 | 0.0649 | 1.85 | 0.02 | 0.0034 | 2.63 | 0.65 |
| Soil Depth | 1 | <.0001 | 372.01 | 0.88 | <.0001 | 371.21 | 21.66 |
| Treatment x Soil Depth | 2 | 0.0029 | 8.87 | 0.02 | 0.3489 | 1.13 | 0.07 |
| Soil Depth x Plot(Treatment), error b | 15 | 0.8856 | .57 | 0.00 | 0.0583 | 1.75 | 0.06 |
| Sampling Date | 5 | <.0001 | 8.28 | 0.08 | <.0001 | 11.72 | 2.62 |
| Treatment x Sampling | 10 | 0.2056 | 1.38 | 0.01 | 0.2803 | 1.24 | 0.28 |
| Sampling Date x Plot(Treatment), error c | 75 | <.0001 | 2.47 | 0.01 | <.0001 | 6.71 | 0.22 |
| Sampling Date x Soil Depth | 5 | <.0001 | 11.71 | 0.05 | <.0001 | 16.10 | 0.54 |
| Sampling Date x Treatment x Soil Depth | 10 | 0.0007 | 5.57 | 0.02 | 0.0562 | 1.91 | 0.06 |
| Sampling Date x Soil Depth x Plot(Treatment), error d | 75 | -- | -- | 0.00 | -- | -- | 0.03 |

As seen in *Figures 8*, *9* and *10*, the differences in $EC_{1:5}$ that occurred between the two soil depths in response to duff thickness are not the same through time, as indicated by the significant three-way interaction. Watering took place every two weeks and soil was sampled weekly. Both the $EC_{1:5}$ and $SAR_{1:5}$ fluctuated with soil moisture, but only the $EC_{1:5}$ showed a significant interaction. In general, soil sampled on the week following watering showed little difference in $EC_{1:5}$ and $SAR_{1:5}$ between depths and between duff treatments. Soil sampled after the plots were allowed to dry for two weeks had greater differences due to increases in $EC_{1:5}$ and $SAR_{1:5}$ of the 0-1 cm soil depth. Surprisingly, the three-way interaction that occurred during Stage II (for $EC_{1:5}$ only) was driven by the increases and decreases in $EC_{1:5}$ of the control plots at the 0-1 cm soil depth. The *Figures 8*, *9* and *10* all show the Stage II three-way interaction; however, the axes are different in *Figures 8* compared with *Figures 9* and *10*. This provides two different views of the three-way interaction.

As seen in *Figure 8a* and *8b*, the 0-1 cm soil depth $EC_{1:5}$ and $SAR_{1:5}$ for all duff treatments (0, 2, 6 cm) fluctuated through time. The fluctuation was due to soil moisture. The $EC_{1:5}$ and $SAR_{1:5}$ increased as the soil would begin to dry and then decreased as another rainfall was applied. However, for the 0-1 cm soil depth the $EC_{1:5}$ and $SAR_{1:5}$ were never lower than the baseline and never higher than the initial peak after the very first rainfall event that occurred in Stage I. In the 1-5 cm soil depth (*Figure 8c*), the $EC_{1:5}$ of the duff treated plots was slightly higher than the control, but there was almost no fluctuation as in the 0-1 cm soil depth. The $SAR_{1:5}$ *Figure 8d*) of the 1-5 cm soil depth for the duff treated plots showed fluctuations over time revealing a shift in the ion ratio in favor of $Na^+$. However, the effect was

slightly attenuated when compared to the 0-1 cm soil depth. The 1-5 cm soil depth $EC_{1:5}$ remained steady and $SAR_{1:5}$ decreased below the baseline.

As seen in *Figure 9a*, on 30 Jan. (week 1), the $EC_{1:5}$ of the control plots and the duff treated plots looked very similar to what was observed in Stage I; the control soil showed little difference between depths, the salinity increased with increasing duff thickness, and the difference in salinity between soil depths increased with increasing duff thickness. However, on 6 Feb. (*Figure 9c,* week 4), the $EC_{1:5}$ of the 0-1 cm soil depth of the control plots increased in above the other treatments. This was seen again on 20 Feb. (*Figure 10a,* week 6), which was the next sampling time after the plots had dried for two weeks. The soil under the 2 and 6 cm duff treatments increased as well, but not as much as the control. The $SAR_{1:5}$ (*Figure 9d, f* and *Figure 10b, f*) of the 0-1 cm soil depth under the control treatment did not increase as much as the $EC_{1:5}$ when the soil was allowed to dry for two weeks, therefore there was no significant three-way interaction ($p = 0.0562$). Despite apparent accumulation of salts, the control plots did not receive any additional $Na^+$ from saltcedar duff so an increase in $SAR_{1:5}$ was not observed.

The soil, regardless of any saltcedar duff treatments, was highly susceptible to evaporative accumulation of salts in the 0-1 cm soil depth. This is shown by the sampling date x soil depth interactions of $EC_{1:5}$ and $SAR_{1:5}$ (*Figure 11*). The $EC_{1:5}$ and $SAR_{1:5}$ in the 0-1 cm soil depth increased when the soil was allowed two weeks to dry after watering. The effect was attenuated in the 1-5 cm depth averaging over all treatments. Attenuation was likely due to the soil being wetter at the lower depth. The 0-1 cm soil depth dried more, therefore more evaporative accumulation of salts

occurred compared to the 1-5 cm depth. This resulted in not only higher $EC_{1:5}$ and $SAR_{1:5}$ but also greater differences in $EC_{1:5}$ and $SAR_{1:5}$ between soil depths on drier weeks for all treatments.

Over the course of Stage II, there was a larger $EC_{1:5}$ difference that occurred between soil depths in the control than for the duff treated plots, therefore driving a treatment x soil depth interaction (for $EC_{1:5}$ only) (*Figure 12a*). The unexpectedly high 0-1 cm soil depth $EC_{1:5}$ for the control plots was caused by soil drying. This was due to redistribution of salts rather than salt inputs by duff. Note that the average $EC_{1:5}$ for the 1-5 cm soil depth dipped below the baseline value, indicating salts were drawn from the 1-5 cm soil depth into the 0-1 cm soil depth as water evaporated from the soil surface. The $SAR_{1:5}$ for the 1-5 cm soil depth also dipped below the baseline value. However, this was most likely due to leaching that occurred during Stage I, because this was not coupled to an unexpectedly high increase in $SAR_{1:5}$ in the upper soil depth and there was no additional input of $Na^+$ from saltcedar duff.

In summary, during Stage II, the surface soil was still being affected by salt inputs from saltcedar duff that occurred during Stage I, as indicated by the significant main effect of duff treatment. The fluctuation of $EC_{1:5}$ appears to be caused by evaporative accumulation of salts two weeks after watering, as opposed to only one week after watering, attributed to redistribution of ions as evaporation occurred and not the addition of soluble salts, particularly $Na^+$. If watering continued at the Stage II frequency (every 2 weeks) the salinity of the 0-1 cm depth would likely continue to fluctuate because the soil did not get enough water to leach the salts completely through the soil profile before drying enough to allow redistribution and some

evaporative salt accumulation to occur at the surface. This happened to a greater extent in the control plots because there was no duff to help retain soil moisture, thus more soil drying occurred. It was necessary to let all plots dry out equally (see Stage III) to determine if the $EC_{1:5}$ of the control plots was really increasing more than the duff-treated plots.

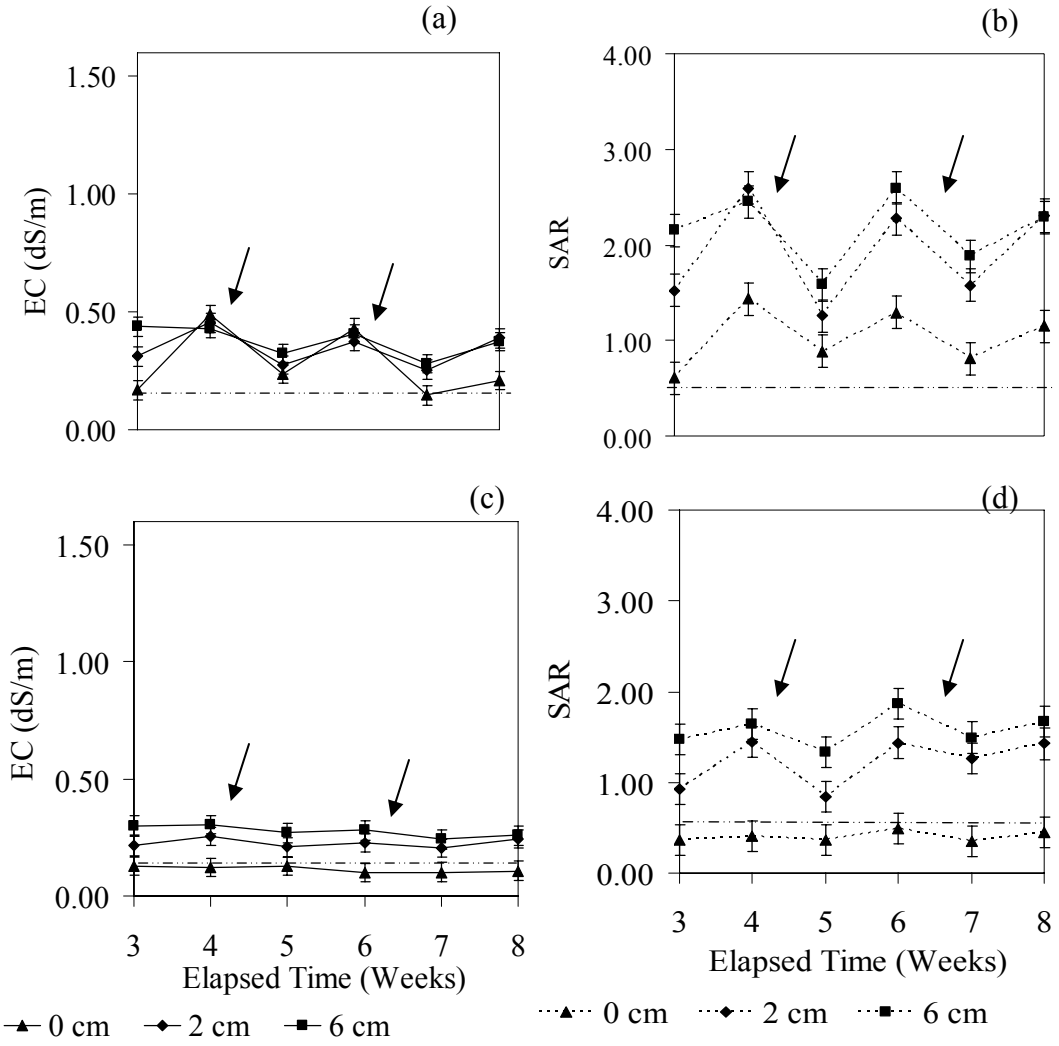


*Figure 8*: Shows the Stage II three-way (sampling date x treatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b) in the 0-1 cm soil depth and $EC_{1:5}$ (c) and $SAR_{1:5}$ (d) in the 1-5 cm soil depth. The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph and approximate dates of simulated rainfall are indicated by arrows.

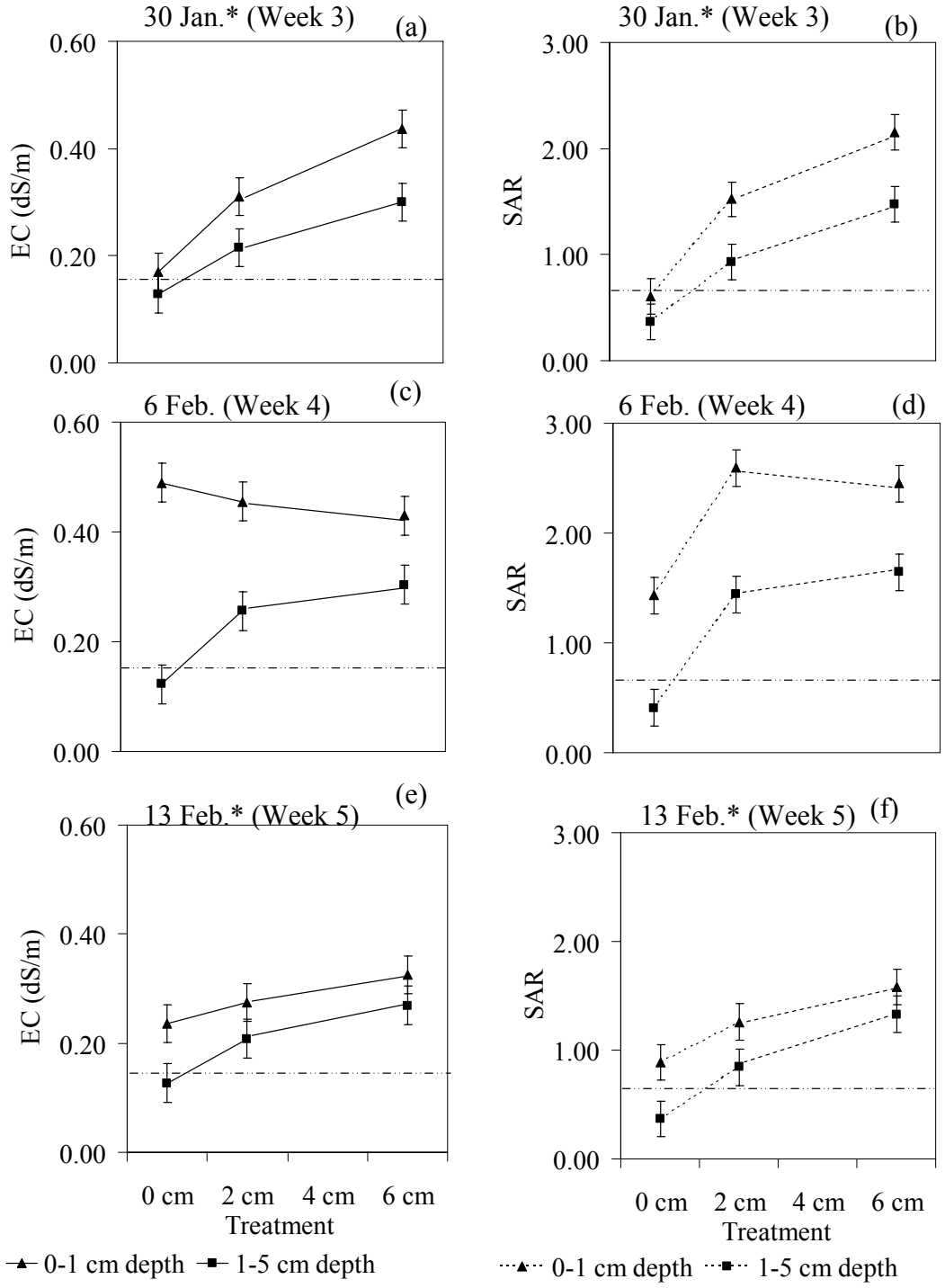


*Figure 9* (Continued on *Figure 10*): Shows the Stage II three-way (sampling date x treatment x depth) interactions for $EC_{1:5}$ (a, c, e) and $SAR_{1:5}$ (b, d, f). Graphs representing soil one week after watering are indicated by an asteric (*) by the date. The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

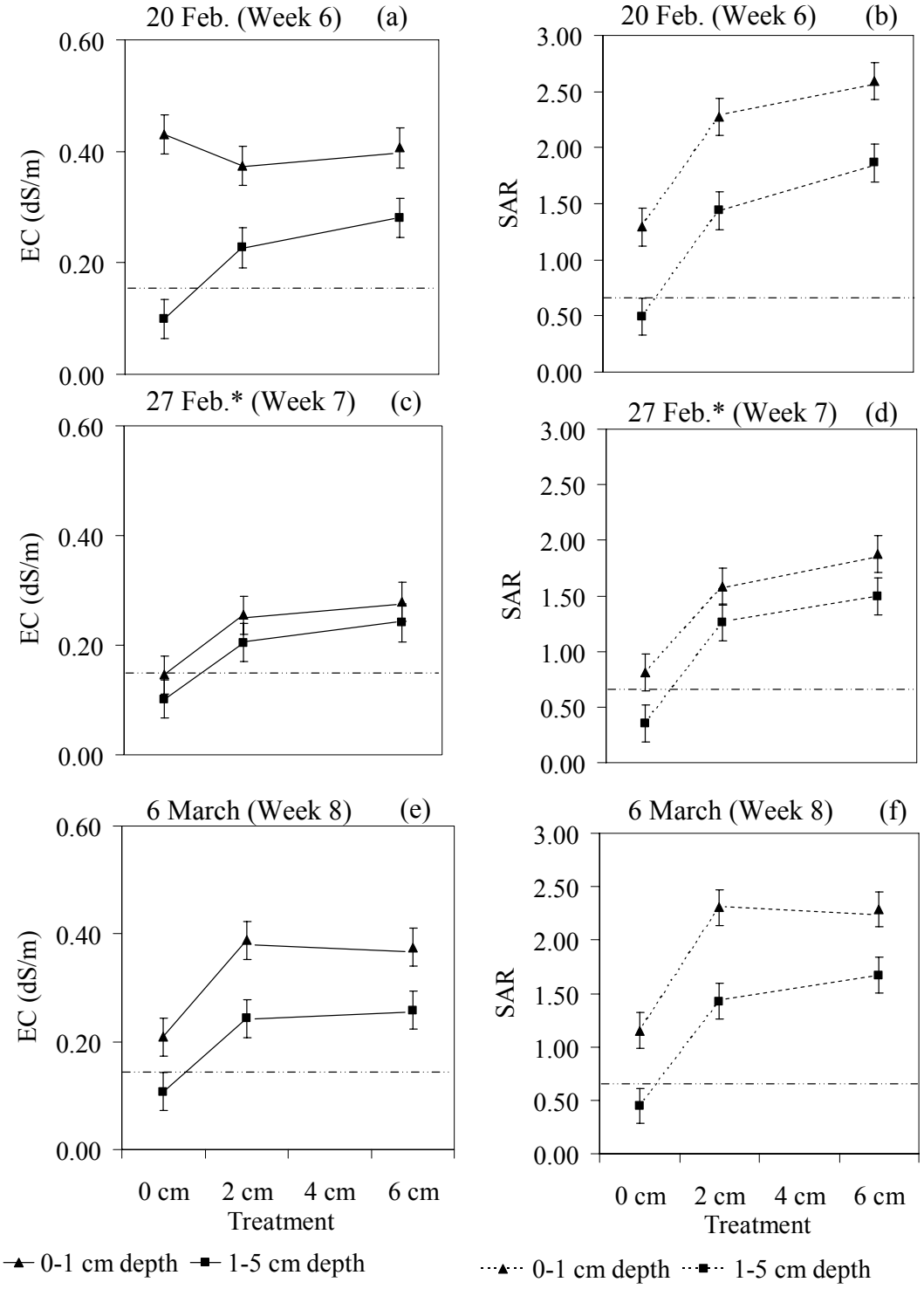


*Figure 10* (continued from *Figure 9*): Shows the Stage II three-way (sampling date x treatment x depth) interactions for $EC_{1:5}$ (a, c, e) and $SAR_{1:5}$ (b, d, f). Graphs representing soil one week after watering are indicated by an asteric (*) by the date. The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

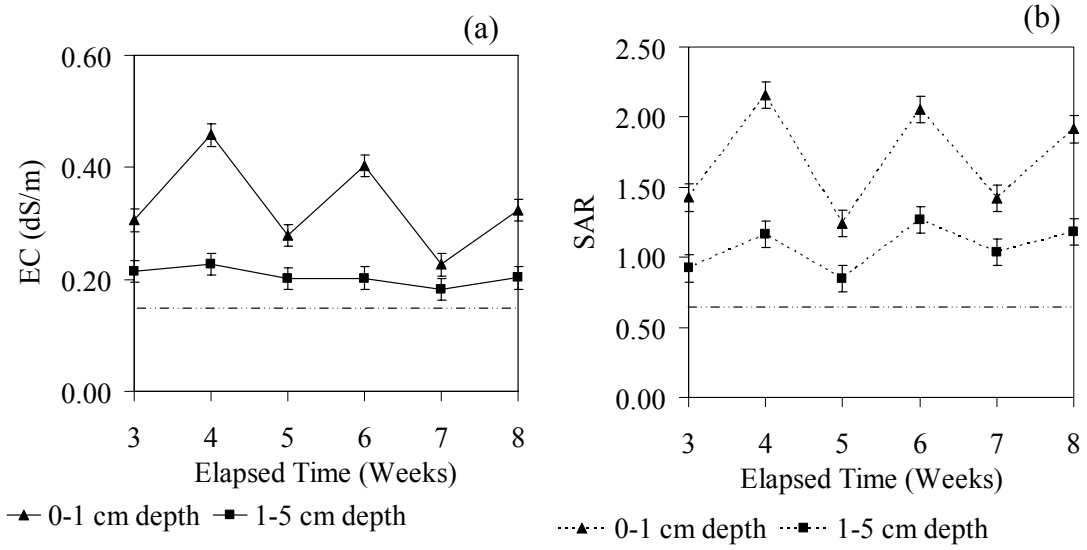


*Figure 11*: Shows the Stage II two-way (sampling x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

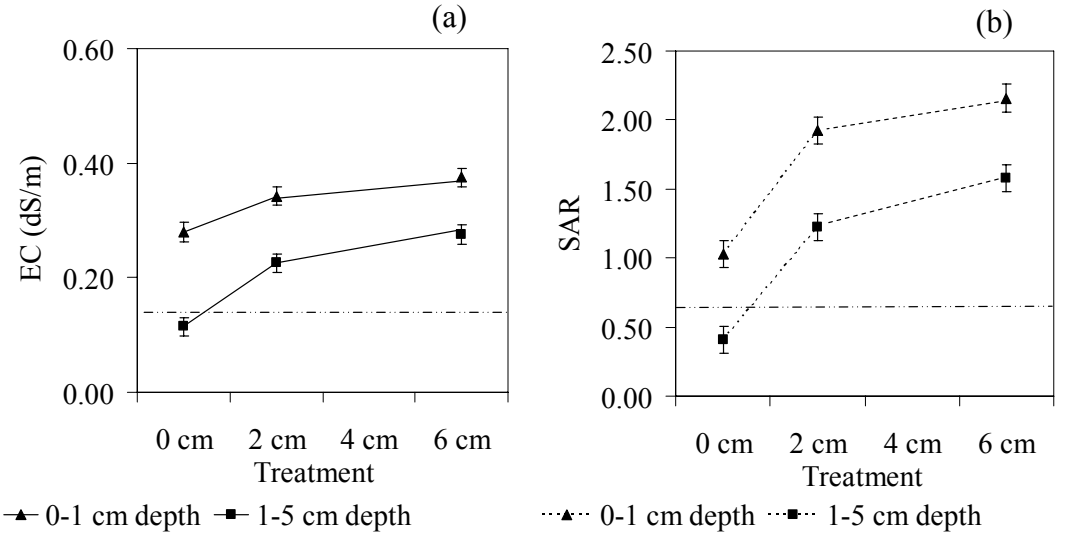


*Figure 12*: Shows the Stage II two-way (treatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ values are indicated by a horizontal dashed line on each graph.

Stage III:

The results of the split-split-plot analysis of variance for both $EC_{1:5}$ and $SAR_{1:5}$ are shown in *Table 5*. The analysis indicates that the main effects of duff thickness, soil depth, and sampling date significantly affected the surface soil $EC_{1:5}$ and $SAR_{1:5}$ (*Table 5*, also see Appendix C3 for Table of main effects means). Significant interactions occurred and must be considered. Each interaction resulted in the same general pattern for $EC_{1:5}$ and $SAR_{1:5}$. These patterns made interpretation of the significant main effects reasonable. The interactions occurred among sampling date x treatment x soil depth (three-way, *Figures 13*, *14* and *15*), sampling date x soil depth (two-way, *Figure 16*), treatment x sampling (for $EC_{1:5}$ only) (two-way, *Figure 17*), and treatment x soil depth (two-way, *Figure 18*).

As seen in *Figures 13*, *14* and *15*, the differences in $EC_{1:5}$ and $SAR_{1:5}$ that occurred between soil depths in response to duff thickness are not the same through time, as indicated by the three-way interaction. The difference in $EC_{1:5}$ and $SAR_{1:5}$ between soil depths increased with progressive sampling ending with high $EC_{1:5}$ and $SAR_{1:5}$ values in the 0-1 cm depth of the duff treated plots only. The *Figures 13*, *14* and *15* show the Stage III three-way interaction; however, the axes are different in *Figure 13* compared with *Figures 14* and *15*. This provides two different views of the three-way interaction.

As seen in *Figure 13a*, In Stage III, the $EC_{1:5}$ of the 0-1 cm soil depth increased with increased soil drying under the 0, 2, and 6 cm duff treatments ending in $EC_{1:5}$'s of three, seven, and ten times over the baseline value, respectively. The 1-5

cm depth $EC_{1:5}$ (*Figure 13c*) showed a very slight increase in $EC_{1:5}$ for the 2 and 6 cm duff treated plots and no change in the control plots. The $SAR_{1:5}$ (*Figure 13b*) of the 0-1 cm soil depth increased under the 2 and 6 cm duff treatments ending in $SAR_{1:5}$'s of more than four and five times over the baseline value, respectively. The control plot $SAR_{1:5}$ decreased below the baseline value. The 1-5 cm soil depth $SAR_{1:5}$ (*Figure 13d*) increased to a lesser extent than in the 0-1 cm soil depth (for duff treated plots). The $SAR_{1:5}$ in the 1-5 cm soil depth of the control plots did not change.

As seen in *Figures 14* and *15*, the soil was wet from watering the week before at the beginning of Stage III (27 Feb., week 7, *Figure 14a and 14b*), and was then allowed to dry out completely (*Figure 15c* and *15d*, week 13). Both $EC_{1:5}$ and $SAR_{1:5}$ of the 0-1 cm soil depth increased as sampling continued and the soil dried due to evaporative redistribution and accumulation of salts as water evaporated from the soil surface. When considering only $EC_{1:5}$, it seems that all of the excess salts were redistributed to the upper soil surface. However, when considering $SAR_{1:5}$, it seems that the 1-5 cm soil depth was left with an altered ratio of cations, pushed in favor of $Na^+$ (see $SAR_{1:5}$ plots in *Figures 14* and *15*).

Regardless of duff thickness, the upper soil surface showed a significant increase in $EC_{1:5}$ and $SAR_{1:5}$ as the soil was allowed to completely dry, indicated by the Stage III sampling date x soil depth interaction (*Figure 16*). Again, salts were moved to the upper soil surface (*Figure 16a*) and, when considering $SAR_{1:5}$, (*Figure 16b*) there was a higher ratio of $Na^+$ left in the 1-5 cm soil surface.

The $EC_{1:5}$ of the 0-1 cm soil depth for all duff thicknesses were similar until week 9 (*Figure 17a*). At this point, the 0-1 cm duff treated soil $EC_{1:5}$ began to

diverge from the control, which caused the treatment x sampling date interaction. The $SAR_{1:5}$ (*Figure 17b*) was consistently higher in the 0-1 cm soil depth compared to the 1-5 cm soil depth for the duff treated plots, therefore there was no particular point of divergence and no significant treatment x sampling date interaction ($p = 0.0738$). The $EC_{1:5}$ was not high for the early sampling dates, but the $SAR_{1:5}$ revealed the altered ratio of cations in favor of $Na^+$.

Regardless of the Stage III sampling date, the $EC_{1:5}$ and $SAR_{1:5}$ are much higher in the 0-1 cm soil depth when compared to the 1-5 cm soil depth and the control at both depths. This is indicated by the treatment x depth interactions (*Figure 18*). Therefore, in Stage III, the duff treatments greatly affected the surface soil $EC_{1:5}$ and $SAR_{1:5}$ in the 0-1 cm depth. The 1-5 cm depth was also increased, but to a lesser extent for both $EC_{1:5}$ and $SAR_{1:5}$.

In summary, Salt input from the saltcedar duff coupled to soil dessication increased the surface soil salinity and sodicity, mostly in the 0-1 cm depth during Stage III indicated by the significant main effect of duff treatment. The Stage III results represent the soluble salt and $Na^+$ movement in the soil when all plots were allowed equal drying. The control plots did not actually become more saline than the duff treated plots, as suggested in Stage II. Also, the ratio of $Na^+$ was increased in both the upper and lower soil depths.

*Table 5*: Stage III analysis of variance table for $EC_{1:5}$ and $SAR_{1:5.}$ Abbreviations are as follows: degrees of freedom (DF), P-values (P), F-statistics (F), and mean squares (MS).

| | | $EC_{1:5}$ | | | $SAR_{1:5}$ | | |
|---|---|---|---|---|---|---|---|
| **Effect** | **D** | **P** | **F** | **MS** | **P** | **F** | **MS** |
| Treatment | 2 | < .0001 | 29.87 | 0.81 | < .0001 | 55.66 | 26.60 |
| Plot(Treatment), error a | 15 | 0.4651 | 1.03 | 0.03 | 0.0128 | 2.41 | 0.48 |
| Soil Depth | 1 | < .0001 | 272.73 | 4.44 | < .0001 | 545.46 | 49.15 |
| Treatment x Soil Depth | 2 | <.0001 | 18.77 | 0.31 | < .0001 | 29.87 | 2.69 |
| Soil Depth x Plot(Treatment), error b | 15 | 0.5350 | 0.93 | 0.02 | 0.0195 | 2.14 | 0.09 |
| Sampling Date | 4 | <.0001 | 30.64 | 0.84 | <.0001 | 18.05 | 2.71 |
| Treatment x Sampling | 8 | <.0001 | 5.47 | 0.15 | 0.0738 | 1.92 | 0.29 |
| Sampling Date x Plot(Treatment), error c | 60 | 0.0402 | 1.58 | 0.03 | <.0001 | 3.56 | 0.15 |
| Sampling Date x Soil Depth | 4 | <.0001 | 48.28 | 0.84 | <.0001 | 56.45 | 2.38 |
| Sampling Date x Treatment x Soil Depth | 8 | <.0001 | 12.50 | 0.22 | <.0001 | 21.34 | 0.90 |
| Sampling Date x Soil Depth x Plot(Treatment), error d | 60 | -- | -- | 0.02 | -- | -- | 0.04 |

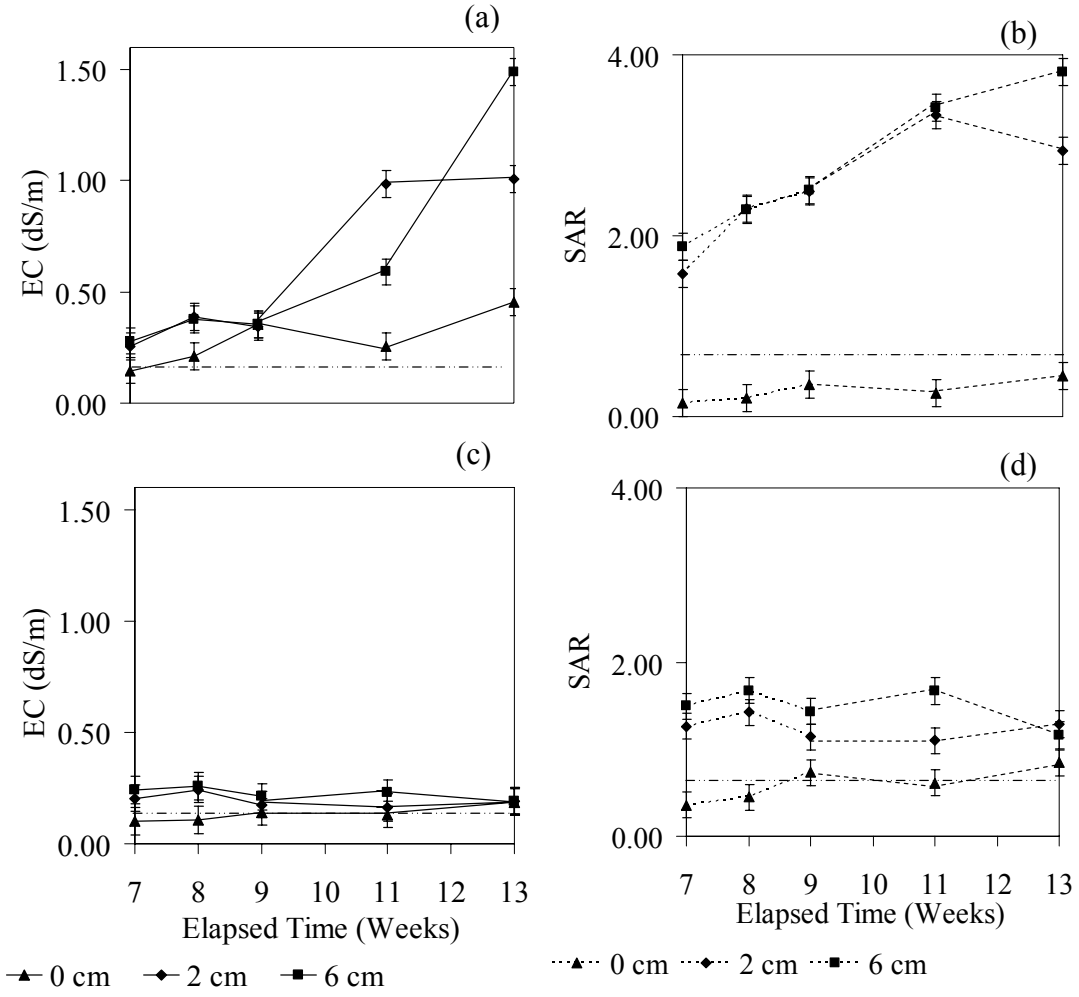


*Figure 13*: Shows the Stage III three-way (sampling date x teatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b) in the 0-1 cm soil depth and for $EC_{1:5}$ (c) and $SAR_{1:5}$ (d) in the 1-5 cm soil depth. The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by horizontal dashed lines on each graph.

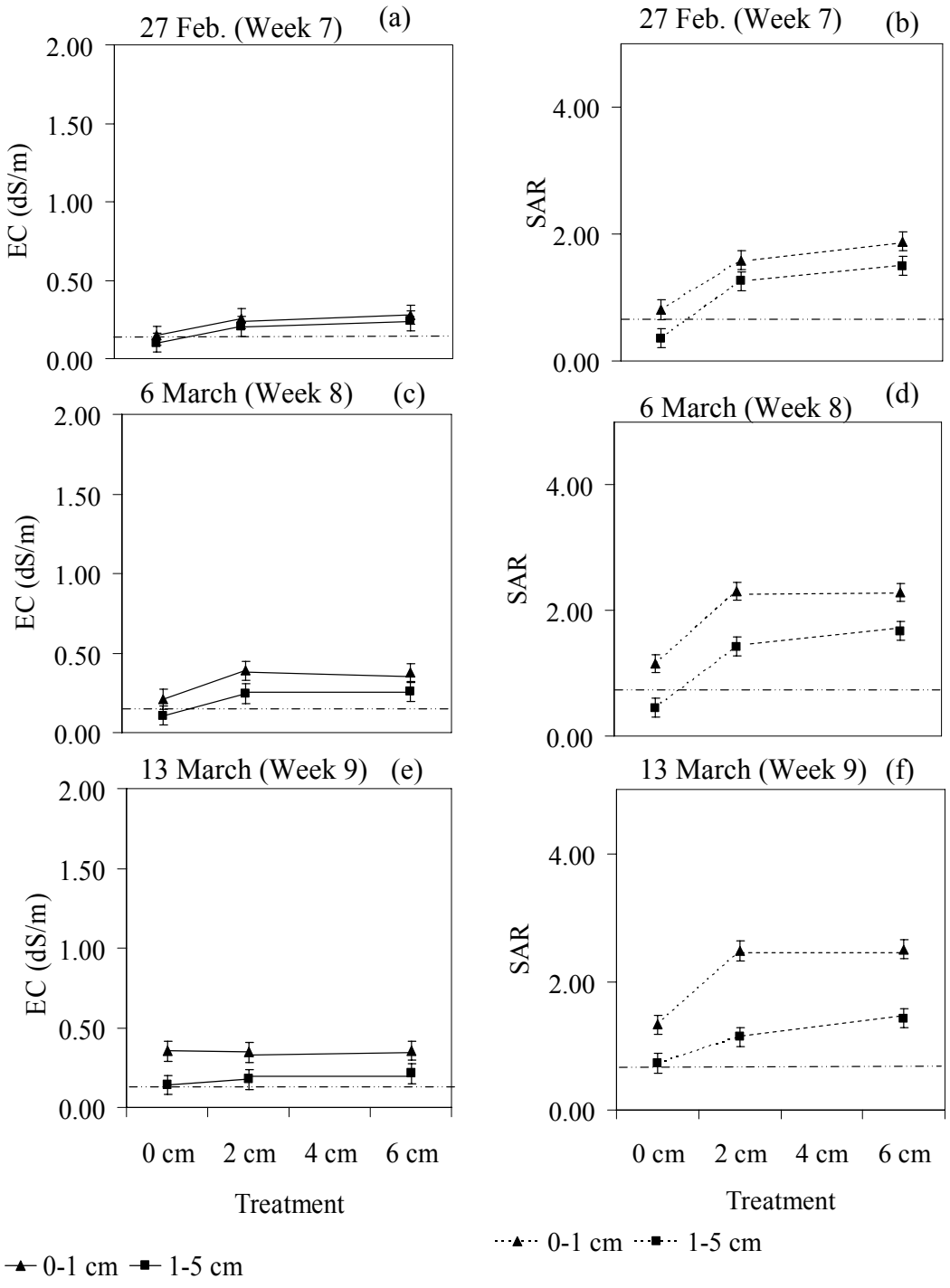


*Figure 14* (continued on *Figure 15*): Shows the Stage III three-way (treatment x soil depth x sampling date) interactions for $EC_{1:5}$ (a, c, e) and $SAR_{1:5}$ (b, d, f). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by horizontal dashed lines on each graph.

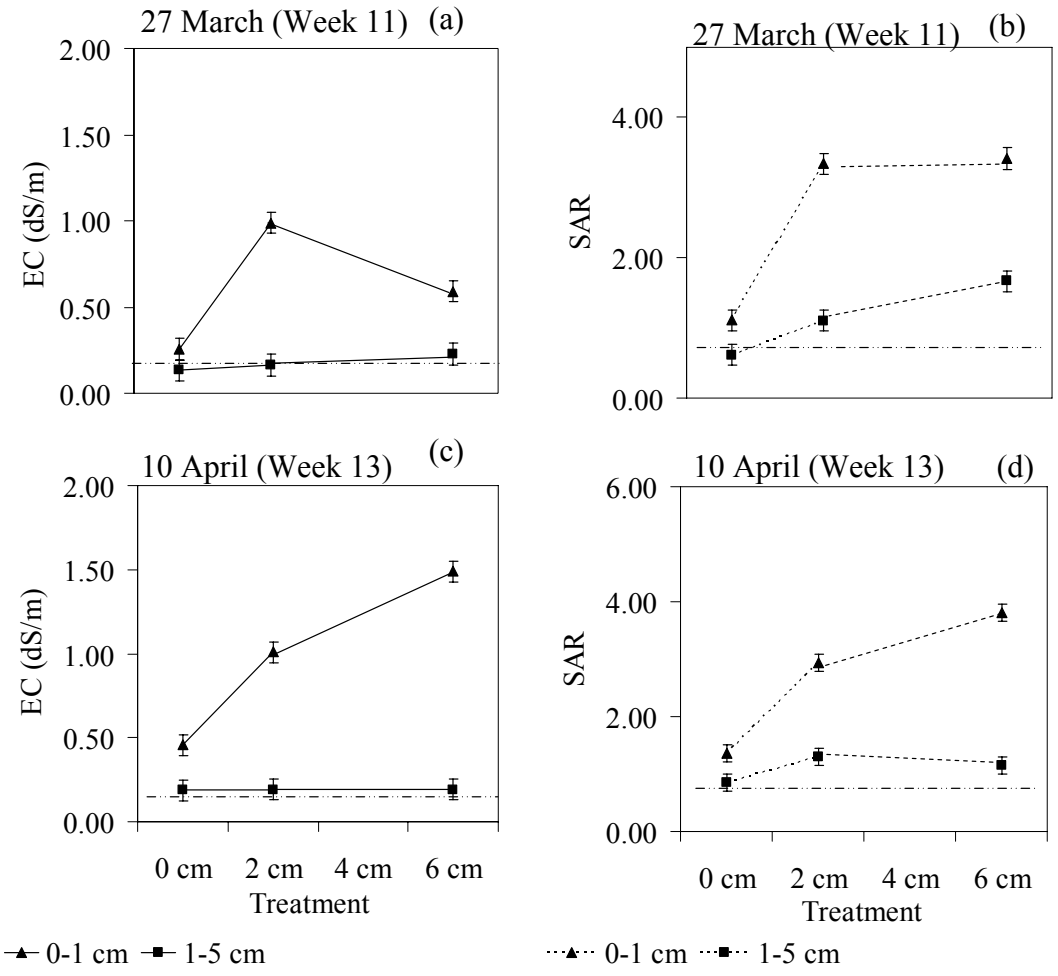


*Figure 15* (continued from *Figure 14*): Shows the Stage III three-way (treatment x soil depth x sampling date) interactions for $EC_{1:5}$ (a, c) and $SAR_{1:5}$ (b, d). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by horizontal dashed lines on each graph.

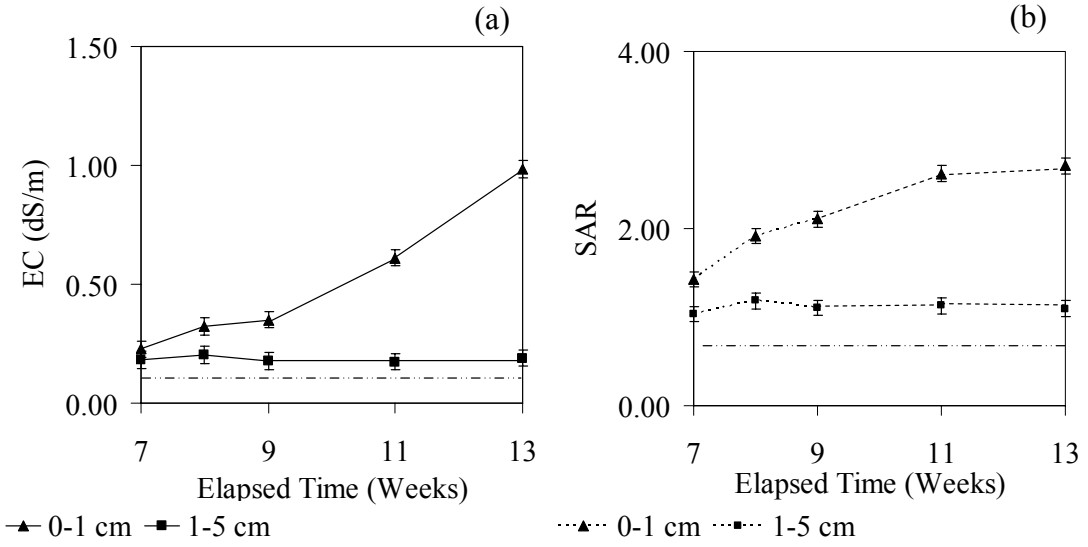


*Figure 16*: Shows the Stage III two-way (sampling date x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

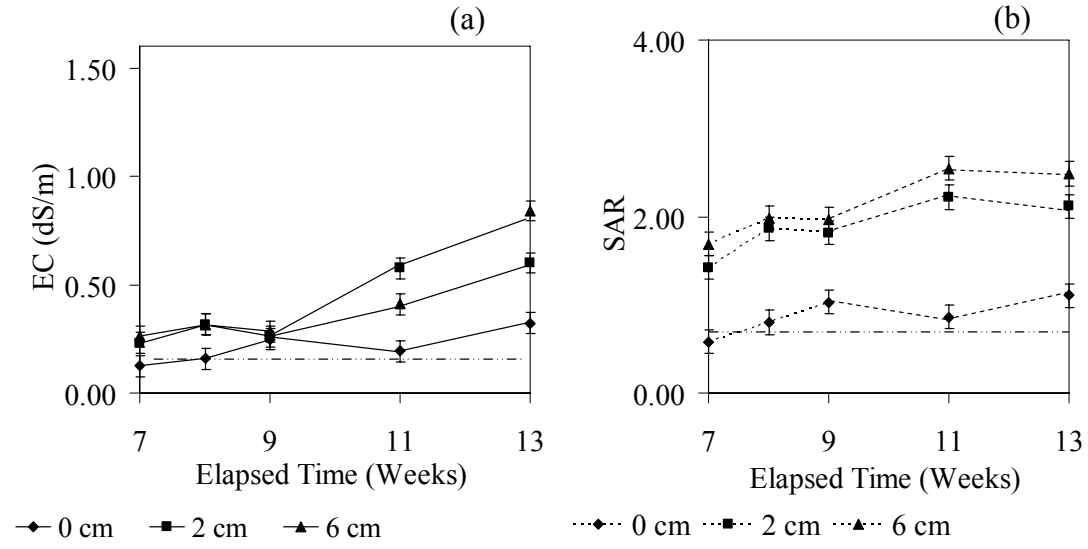


*Figure 17*: Shows the Stage III two-way (treatment x sampling date) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

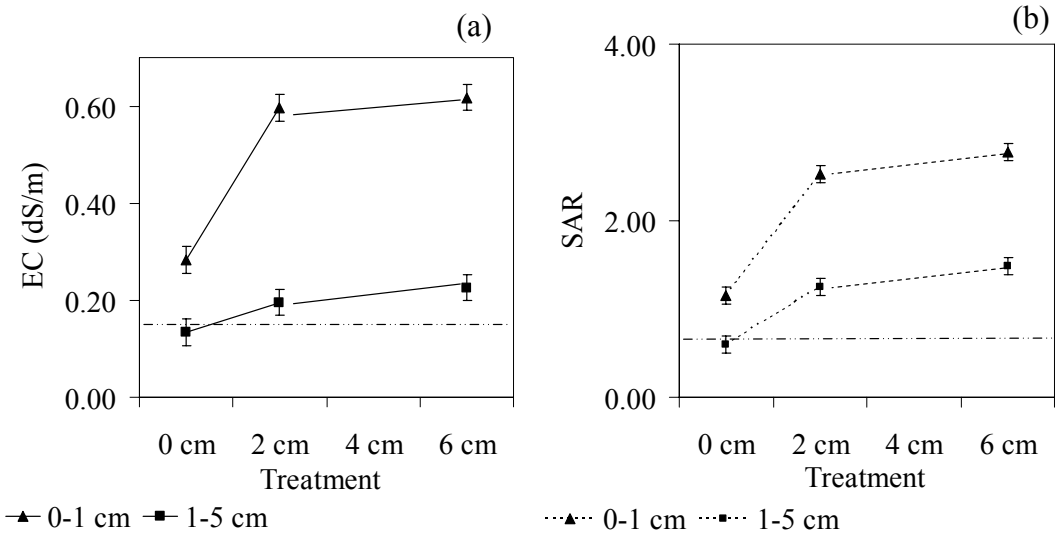


*Figure 18*: Shows the Stage III two-way (treatment x soil depth) interactions for $EC_{1:5}$ (a) and $SAR_{1:5}$ (b). The baseline $EC_{1:5}$ and $SAR_{1:5}$ are indicated by a horizontal dashed line on each graph.

Considering all three experimental Stages, the results show potentially large increases in salinity and sodicity as a result of salts leached from saltcedar duff because of simulated rainfall. These increases would likely occur in the field as well. For example, non-random samples from the 0-2 cm soil depth taken directly under live saltcedar trees from the Bosque del Apache National Wildlife Refuge (NWR) showed a maximum $EC_{se}$ of 47 dS $m^{-1}$ and a maximum $SAR_{se}$ of 30.8 (Rosel and Ulery, 2005 abstract). The very high $EC_{se}$ and $SAR_{se}$ found below the live saltcedar trees on the Bosque del Apache NWR may have been caused by the accumulation of salts from *Tamarix* duff falling on the ground year after year. This experiment represents only one season. The Bosque del Apache NWR is located further north on the Rio Grande than the CDRRC, where the duff for this experiment was collected.

Based in research stating the salinity and sodicity of the Rio Grande increases as it runs south, the water near the Bosque del Apache NWR should have a lower salinity than the water near CDRRC, therefore the high soil salinity and sodicity on the Bosque del Apache can not be explained by a higher salinity of the Rio Grande (Miyamoto *et al*., 1995).

### 3.2.2. Plot Leachate (Stages I-III)

Leachate (excess water drained from plots) occurred only three times throughout the experiment, and this occurred during Stage II only (third, fourth, and fifth watering). It took several rainfall events to completely saturate the soil and move water (containing dissolved salts) completely through the soil profile. The control plots did leach after any of the rainfall events and so they were deliberately leached after the termination of the experiment to compare the salt composition of the control leachates with treated plot leachates. The leachates were analyzed for EC and SAR.

The EC of the leachate for the duff treated plots decreased with subsequent watering, but the SAR slightly increased (*Figures 19* and *20*). The ratio of $Na^+$ to $Mg^{2+}$ and $Ca^{2+}$ was altered in favor of $Na^+$ with increased watering. More salts were present in the leachate from the 6 cm duff treated plots, an intermediate amount of salts was present for the 2 cm duff layer, and the least for the 0 cm duff layer.

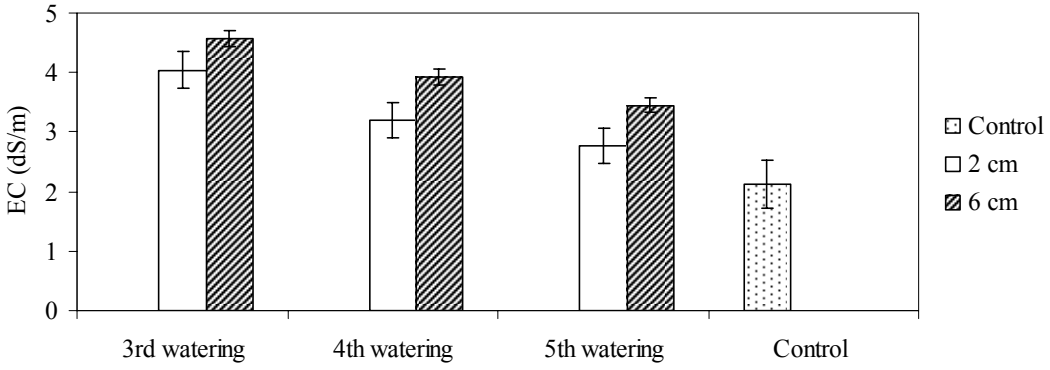


*Figure 19*: Shows the EC of leachate that occurred (during Stage II only). Control plots were deliberately leached for comparison, resulting in only one data point.

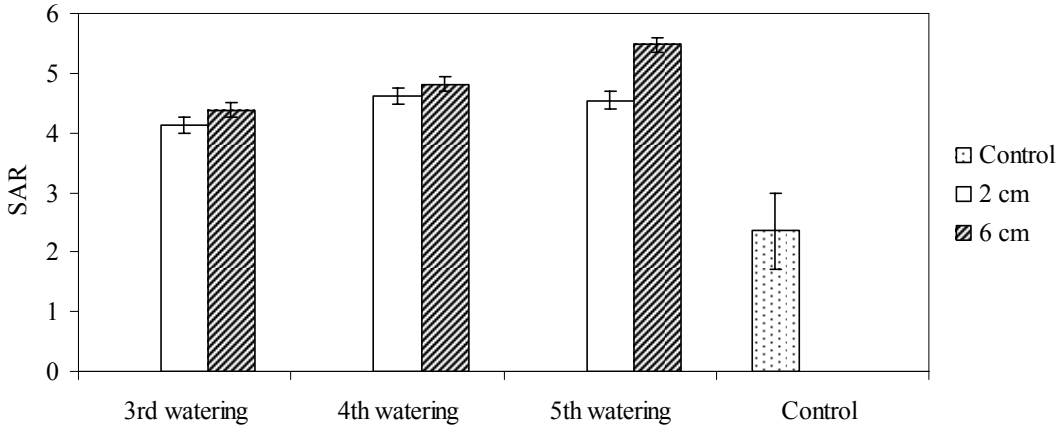


*Figure 20*: Shows the SAR of leachate that occurred (during Stage II only). Control plots were deliberately leached for comparison, resulting in only one data point.

### 3.3. Duff Leaching

The two different duff leaching methods were meant to mimic the result of transferring ions from saltcedar duff to the surface soil after either one rainfall or after duff decomposition has begun. The cations, $Ca^{2+}$, $K^{+}$, $Mg^{2+}$, $Na^{+}$ that commonly contribute to soil salinity are reported here (Sumner *et al*., 1998). One would expect more total cations to be transferred during decomposition than just a brief washing of the leaves from rainwater. This conclusion assumes that the salts present on leaf surfaces do not represent the concentrations of all of the salts contained on and within the plant leaf tissue. If decomposition occurs, all of the salts (in tissues and on leaf surfaces) will be available for transfer to the soil.

The 24-hour leaching resulted in not only higher concentrations of cations, but different relative amounts of cations compared to the brief washing. In both methods, $Na^{+}$ was the predominant cation (*Figures 21* and *22*). Sodium made up 61% of $Ca^{2+}$, $K^{+}$, $Mg^{2+}$, $Na^{+}$ in the brief washing, but only 45% in the 24-hour leaching (cation percentages on a leaf dry-weight basis are reported in *Figures 23* and *24*). Sodium salts tend to be more soluble than $Mg^{2+}$, $Ca^{2+}$, and $K^{+}$ salts, therefore extended contact with water (as in the 24-hour leaching) increased the concentrations of $Mg^{2+}$, $Ca^{2+}$, and $K^{+}$ relative to $Na^{+}$ cations as other salts slowly dissolved. The high percentage of $Na^{+}$ being released into the soil compared to the other cations has significance for SAR.

Hem's (1967) cation analysis yielded different results than this experiment, probably because he analyzed live, green *Tamarix* leaves (10-15% moisture content by weight) as opposed to dead leaf litter, or duff (~8% moisture content by weight).

Hem (1967) also reported cation concentrations in terms of air-dried leaf weight and the results of this experiment were reported in terms of oven-dried leaf weight. His methods for ion analysis were not reported more specifically, except to say that the "$Na^+$ and $K^+$ content was calculated from the difference between determined cations and anions."

Most notably, the $Na^+$ concentrations from the Hem's brief washing were low compared with this experiment (*Figure 25*). The $Ca^{2+}$ and $Mg^{2+}$ concentrations reported by Hem (1967) were similar to the results for this experiment for the brief washing. The overall amounts of $Na^+$, $Mg^{2+}$, and $Ca^{2+}$, and $K^+$ are relatively similar to the results of this experiment. Unfortunately, Hem did not analyze for $Na^+$ in the 24 hour duff soaking (*Figure 26*). The $Ca^{2+}$ and $Mg^{2+}$ concentrations are slightly higher than the results for this experiment, but similar.

The differences in ion content were most likely caused by differences in water salinity near *Tamarix*. The salinity of the water nearby Hem's plants (reported only for leaves used in the brief washing) was higher than the salinity of the water nearby the plants used for this experiment (Kleinkopf and Wallace, 1974; Hem 1967). The salinities of the rivers and wells near Hem's sampling sites ranged from ~2.9 dS $m^{-1}$ to 44 dS $m^{-1}$. The EC of the groundwater well near the *Tamarix* used for this experiment was ~ 0.9 dS $m^{-1}$ (Carlos Ochoa, Pers. Comm., 2006). The saltcedar from Hem's experiment was exposed to more soluble salts, whereas the plants used for this experiment may have been exposed to less salinity in general, but more $Na^+$, reflected by the cations transferred to the soil.

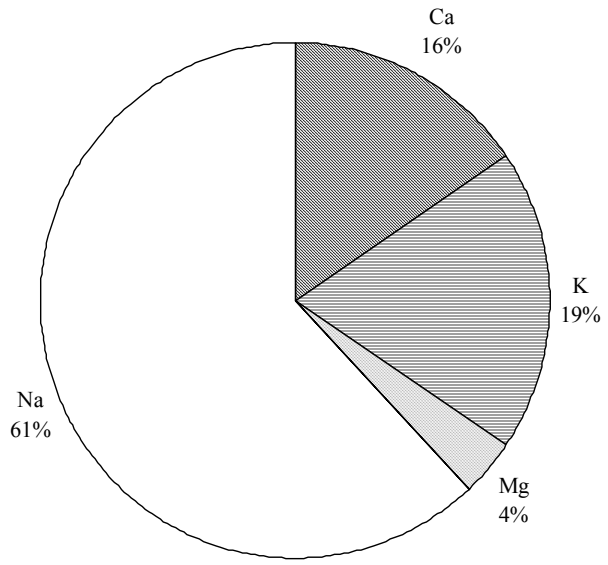


*Figure 21*: Sodium cations make up the majority of the total percentage of common cations in duff leachate from a brief washing, which mimics one rainfall.

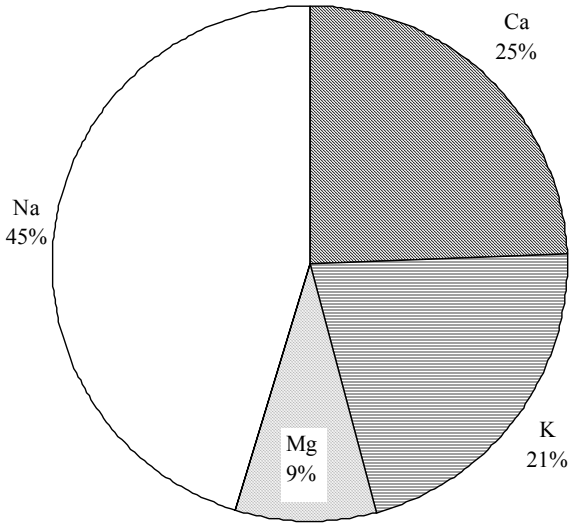


*Figure 22*: Sodium cations make up the majority of the total percentage of common cations in duff leachate from a 24 hour soaking, which mimics duff decomposition.

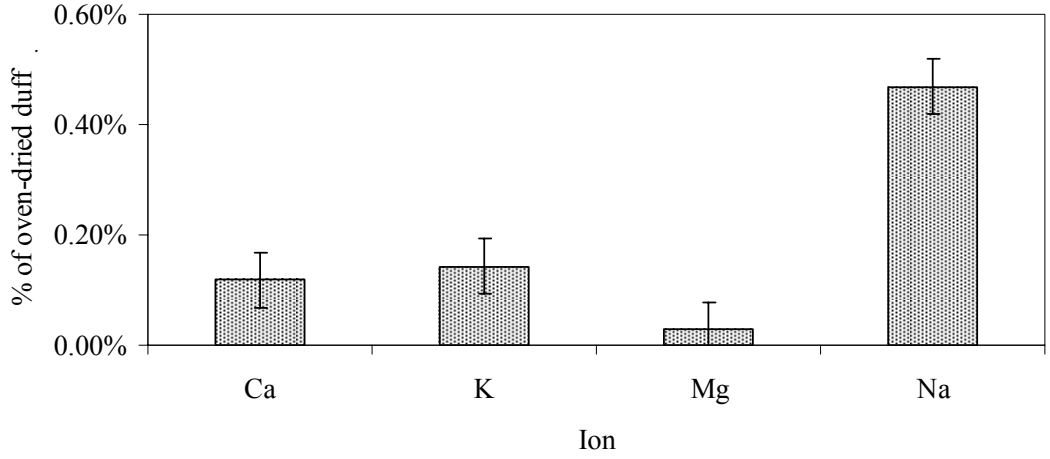


*Figure 23*: Cation percentages of oven-dried duff (by weight) from a brief washing, which mimics one rainfall. The average EC was 0.3 dS $m^{-1}$ and pH was 6.

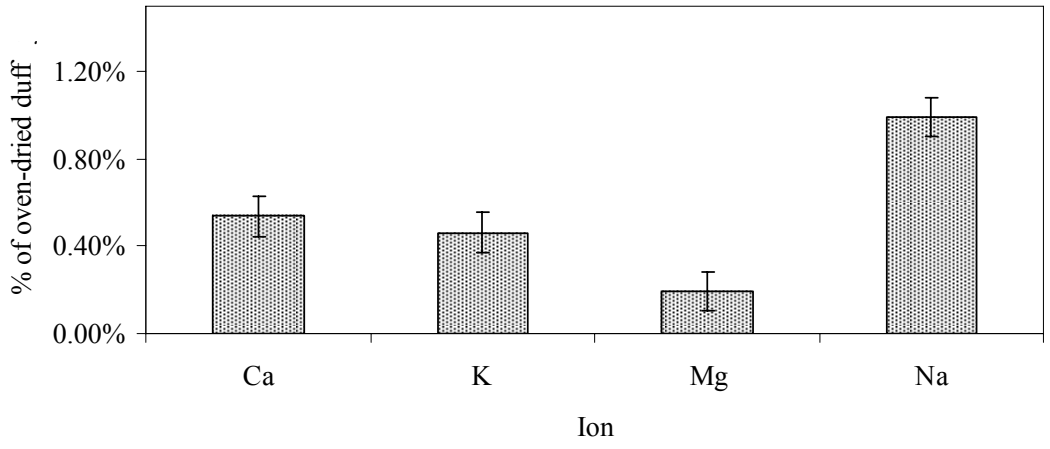


*Figure 24*: Cation percentages of oven-dried duff (by weight) from a 24-hour soaking, which mimics duff decomposition. The average EC was 1.6 dS $m^{-1}$ and pH was 5.

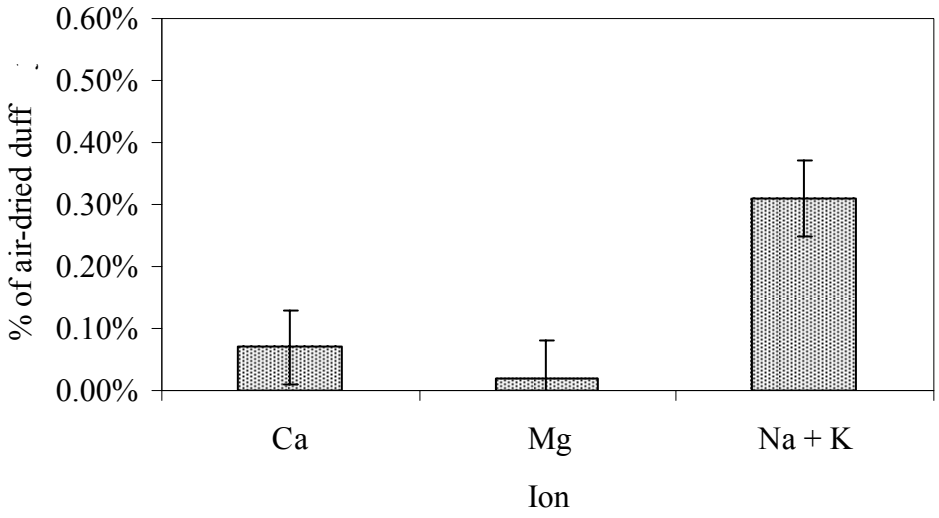


*Figure 25*: Ion percentage of air-dried duff (by weight) from washing (brief contact time) which mimics one rainfall. The average EC was 1.2 dS $m^{-1}$ and pH was not reported (from Hem 1967).

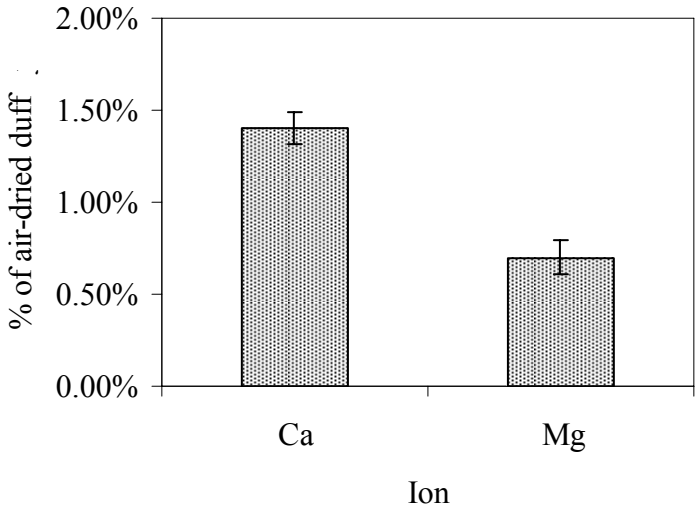


*Figure 26*: Ion percentage of air-dried duff (by weight) from 24-hour soaking which mimics duff decomposition. The average EC and pH was not reported (from Hem 1967).

# 4. CONCLUSIONS

Salt originating from saltcedar duff was transferred to the soil surface via rainfall events. After the initial input occurred, the increase in salinity and sodicity was affected by the frequency of rainfall events. Therefore, Saltcedar duff can considerably increase the surface soil salinity if at least one rainfall event followed by soil dessication occurs. The 0-1 cm soil depth was more susceptible to increases in salinity and sodicity that the 1-5 cm soil depth because of the affects of ion redistribution and accumulation at the soil surface due to water evaporation at the surface. The duff used for this experiment contained $Na^{+}$, $Mg^{2+}$, $Ca^{2+}$, and $K^{+}$ salts and $Na^{+}$ salts were the most prevalent. Therefore, the saltcedar duff used in this experiment altered the cation ratio of the soil in favor of $Na^{+}$ in both the 0-1 and 1-5 cm soil depths, causing an increase in $SAR_{1:5}$.

## 5. FUTURE RESEARCH

In the future, similar studies using more experimental material would be useful so that saturated paste extracts may be analyzed instead of 1:5 soil:water extracts. In a future experiment, maintaining the same soil moisture contents across all treatments as opposed to the control plots drying out more quickly than duff-treated plots would provide a better picture of salt movement during wetting and drying cycles. A similar study using different soil textures and/or different organic matter contents would also be useful. Soil texture and organic matter content could influence the pattern of salt movement from the saltcedar duff. The question remains as to whether a particular soil texture or organic matter content would make the soil more susceptible or more resilient to salt inputs from saltcedar duff. A long-term study with multi-year accumulation of duff would be useful to see if there is a cumulative effect of the duff falling on the soil year after year to explain the high salinity and sodicity of field samples at the Bosque del Apache NWR. Finally, more conclusive native plant seed germination experiments would help determine if the salinities caused by saltcedar duff inhibit native plant establishment.

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# APPENDICES

A: CALCULATIONS

**A1. Volume of water applied to benchtop "plots", or containers:**

Plots were 0.41 m x 0.61 m = 0.25 $m^2$ area

Depth of water needed for each plot was ~0.5 in = ~1.3 cm = 0.013 m water

0.25 $m^2$ x 0.013 m = 0.003 $m^3$ water volume was needed for each plot

1000 L = 1 $m^3$

0.003 $m^3$ x 1000 L = **3 L water was needed for each plot per simulated rainfall event**

**A2. Equation for calculating SAR:**

$$SAR_{1:5} \ (mmol^{1/2} L^{-1/2}) = [Na^+] / [Ca^{2+} + Mg^{2+}]^{1/2}$$

Concentrations of $Na^+$, $Ca^{2+}$, and $Mg^{2+}$ in the 1:5 extracts were converted from meq $L^{-1}$ (ICP results) to mmol $L^{-1}$ for calculating SAR.

B: METHODS

**B1. 1:5 soil: water (w/w) extraction:**

1. Weigh out a small amount of field moist soil (2-4 g), record weight, and place in a labeled 50-ml centrifuge tube. No correction is needed for moisture content.
2. Calculate weight of water needed for each soil sample (5x the weight of sample)
3. Add correct weight of deionized water to each sample.
4. After water has been added to all samples, place all centrifuge tubes on a shaker (low setting) for 1 hour.
5. Centrifuge at 2,000 rpm for 30 minutes until supernatant is clear.
6. Decant the supernatant, refrigerate to preserve, and measure EC, pH, and SAR within one week.

C: MEANS OF MAIN EFFECTS

*Table C1*: The Stage I main effects means and standard errors for $EC_{1:5}$ and $SAR_{1:5}$.

| Effect | $EC_{1:5}$ (dS $m^{-1}$) | St. Error | $SAR_{1:5}$ | St. Error |
|---|---|---|---|---|
| 0 cm duff treatment | 0.142 | 0.019 | 0.506 | 0.090 |
| 2 cm duff treatment | 0.305 | 0.019 | 1.518 | 0.090 |
| 6 cm duff treatment | 0.412 | 0.019 | 2.043 | 0.090 |
| 0-1 cm soil depth | 0.375 | 0.013 | 1.818 | 0.057 |
| 1-5 cm soil depth | 0.198 | 0.013 | 0.893 | 0.057 |
| 16-Jan | 0.300 | 0.019 | 1.465 | 0.090 |
| 23-Jan | 0.303 | 0.019 | 1.428 | 0.090 |
| 30-Jan | 0.260 | 0.019 | 1.174 | 0.090 |

*Table C2*: The Stage II main effects means and standard errors for $EC_{1:5}$ and $SAR_{1:5}$.

| Effect | $EC_{1:5}$ (dS $m^{-1}$) | St. Error | $SAR_{1:5}$ | St. Error |
|---|---|---|---|---|
| 0 cm duff treatment | 0.197 | 0.015 | 0.718 | 0.095 |
| 2 cm duff treatment | 0.284 | 0.015 | 1.573 | 0.095 |
| 6 cm duff treatment | 0.325 | 0.015 | 1.869 | 0.095 |
| 0-1 cm soil depth | 0.333 | 0.009 | 1.703 | 0.057 |
| 1-5 cm soil depth | 0.205 | 0.009 | 1.070 | 0.057 |
| 30-Jan | 0.260 | 0.018 | 1.174 | 0.091 |
| 6-Feb | 0.343 | 0.018 | 1.662 | 0.091 |
| 13-Feb | 0.240 | 0.018 | 1.045 | 0.091 |
| 20-Feb | 0.303 | 0.018 | 1.660 | 0.091 |
| 27-Feb | 0.205 | 0.018 | 1.230 | 0.091 |
| 6-Mar | 0.263 | 0.018 | 1.549 | 0.091 |

*Table C3*: The Stage III main effects means and standard errors for $EC_{1:5}$ and $SAR_{1:5}$.

| **Effect** | **$EC_{1:5}$ (dS $m^{-1}$)** | **St. Error** | **$SAR_{1:5}$** | **St. Error** |
|---|---|---|---|---|
| 0 cm duff treatment | 0.209 | 0.021 | 0.876 | 0.089 |
| 2 cm duff treatment | 0.396 | 0.021 | 1.696 | 0.089 |
| 6 cm duff treatment | 0.422 | 0.21 | 1.942 | 0.089 |
| 0-1 cm soil depth | 0.500 | 0.016 | 2.154 | 0.056 |
| 1-5 cm soil depth | 0.190 | 0.016 | 1.109 | 0.056 |
| 27-Feb | 0.205 | 0.028 | 1.230 | 0.077 |
| 6-Mar | 0.263 | 0.028 | 1.549 | 0.077 |
| 13-Mar | 0.264 | 0.028 | 1.603 | 0.077 |
| 27-Mar | 0.392 | 0.028 | 1.874 | 0.077 |
| 10-Apr | 0.587 | 0.028 | 1.902 | 0.077 |

D: RAINFALL DATA

*Table D1*: The rainfall data (inches) from March-December of 2005 were recorded using rain gauges located throughout CDRRC land. Very little rainfall was recorded during the autumn months. (www.nmsu.edu/~dars/gauge_data_2000-2004.html)

| MAR | APRIL | MAY | JUN | JULY | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|
| 0.4 | 0.3 | 0.9 | 0.0 | 0.5 | 1.0 | 1.5 | 0.8 | 0.0 | 0.0 |
| 0.5 | 0.3 | 0.7 | 0.0 | 0.2 | 0.8 | 1.0 | 0.9 | 0.0 | 0.0 |
| 0.5 | 0.4 | 0.9 | 0.0 | 0.2 | 0.7 | 1.3 | 0.8 | 0.0 | 0.0 |
| 0.6 | 0.6 | 1.0 | 0.0 | 0.1 | 0.7 | 1.2 | 0.8 | 0.0 | 0.0 |
| 0.7 | 0.3 | 0.4 | 0.0 | 0.2 | 1.5 | 0.7 | 0.9 | 0.0 | 0.0 |
| 0.6 | 0.5 | 0.4 | 0.0 | 0.2 | 0.7 | 0.8 | 0.8 | 0.0 | 0.0 |
| 0.5 | 0.5 | 0.6 | 0.0 | 0.2 | 0.7 | 0.8 | 0.7 | 0.0 | 0.0 |
| 0.5 | 0.3 | 1.1 | 0.0 | 0.2 | 0.8 | 1.4 | 0.9 | 0.0 | 0.0 |
| 0.5 | 0.3 | 1.0 | 0.0 | 0.2 | 0.8 | 0.9 | 0.8 | 0.0 | 0.0 |
| 0.4 | 0.3 | 0.5 | 0.0 | 0.3 | 1.0 | 1.1 | 0.8 | 0.0 | 0.0 |
| 0.6 | 0.7 | 0.4 | 0.0 | 0.2 | 1.5 | 0.6 | 0.8 | 0.0 | 0.0 |
| 0.2 | 0.4 | 0.8 | 0.0 | 0.9 | 3.0 | 1.9 | 1.2 | 0.0 | 0.0 |
| 0.1 | 0.4 | 0.8 | 0.0 | 0.6 | 1.2 | 2.0 | 1.3 | 0.0 | 0.0 |
| 0.3 | 0.4 | 0.6 | 0.0 | 1.1 | 2.0 | 2.0 | 1.2 | 0.0 | 0.0 |
| 0.5 | 0.4 | 0.4 | 0.0 | 0.3 | 1.5 | 1.0 | 1.0 | 0.0 | 0.0 |
| 0.4 | 0.6 | 0.7 | 0.0 | 0.3 | 1.2 | 1.4 | 0.8 | 0.0 | 0.0 |
| 0.4 | 0.4 | 0.3 | 0.0 | 0.4 | 1.3 | 0.7 | 0.9 | 0.0 | 0.0 |
| 0.5 | 0.5 | 0.3 | 0.0 | 0.5 | 1.2 | 0.6 | 0.9 | 0.0 | 0.0 |
| 0.4 | 0.8 | 0.9 | 0.0 | 0.1 | 0.8 | 0.8 | 0.8 | 0.0 | 0.0 |
| 0.3 | 0.6 | 0.7 | 0.0 | 0.1 | 0.8 | 0.9 | 0.8 | 0.0 | 0.0 |
| 0.2 | 0.5 | 0.4 | 0.0 | 0.2 | 2.3 | 1.4 | 0.9 | 0.0 | 0.0 |

**Averages**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **0.4** | **0.5** | **0.7** | **0.0** | **0.3** | **1.2** | **1.1** | **0.9** | **0.0** | **0.0** |