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Evaluation Of Soil Sustainability Along The Rio Grande In West Texas: Changes In Salt Loading And Organic Nutrients Due To Farming Practices

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EVALUATION OF SOIL SUSTAINABILITY ALONG THE RIO GRANDE IN WEST TEXAS:
CHANGES IN SALT LOADING AND ORGANIC NUTRIENTS DUE TO FARMING PRACTICES

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by

Christine Lynn Cox

2012

DEDICATION

This thesis is dedicated to my loving parents, without their support I would not be who I am today. Thank you for always being there for me.

EVALUATION OF SOIL SUSTAINABILITY ALONG THE RIO GRANDE IN WEST
TEXAS: CHANGES IN SALT LOADING AND ORGANIC NUTRIENTS DUE TO
FARMING PRACTICES

by

CHRISTINE LYNN COX

THESIS

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Secondly I would like to thank the Ivey Family for allowing me to use their farms and informing me of irrigation times. There are four specific people in this rather large family that have had an impact on me: Steve and Kevin (Alfalfa and Pecan 2), Art (Pecan 1) and Mark (Cotton). While working in the fields over the 2011 irrigation season Steve accompanied me often on sample collection trips. He is a wealth of knowledge about farming practices, crop performance and made going to the field an awesome experience.

Thirdly I would like to thank my parents. Thank you both for being supportive and helping me along this journey.

ABSTRACT

Growing populations demand an increase in the amount of food being produced, which in turn, puts pressure on the productivity and sustainability of soils. The use of flood irrigation from the Rio Grande has greatly increased the salinity, sodicity, and enhanced leaching of nutrients in the Rio Grande Basin soils. To evaluate soil health, water and soil samples were collected from two pecan, one cotton, and one alfalfa field in western Texas. Each site was equipped with sensors to measure soil moisture, temperature, and electrical conductivity (EC), along with lysimeters at depths of 15, 30, and 60 cm to collect soil water samples. Soil solution, irrigation water, and drainage water samples were collected during the 2011 irrigation season and analyzed for pH, EC, major elemental chemistry. Soils at each site were collected before irrigation in 2011 and characterized for soil salinity, sodicity and alkalinity, as well as nutrient levels.

The water used for irrigation is high in TDS, and especially enriched in dissolved Na^+ , Cl^- , Ca^{2+} and SO_4^{2-} . With water penetration during flood irrigation, soil water chemistry evolves by dissolving salts in the soils such as gypsum and halite. These salts almost reaches saturation with respect to these two evaporate minerals at 60 cm below ground surface. In contrast, soil water becomes oversaturated with respect to carbonates, in agreement with ~10wt% of pedogenic calcite observed throughout the soil column. The drainage water is chemically similar to the irrigation water, suggesting that most of the irrigation water has a shallow drainage path. Between irrigation, however, soil water become more concentrated as water is lost through evapotranspiration. Thus, it is reasonable to assume that the salts precipitate out at this stage.

Soil sodicity and salinity increase with depth in cotton and pecan sites and are observed to be over the tolerance levels of cotton and pecan at greater than 30 cm. These observations are in agreement with the facts that pecan orchards are more intensively irrigated and thus have higher salt loading, and that Cotton soils contain a higher clay content. Alfalfa soils however, are generally less sodic. Sodic soils are known to have lower permeability, supporting the observation that irrigation water does not penetrate to deeper soils but flows to drainage canal instead. Salinity affects crop growth by limiting the availability of water and nutrients.

This study demonstrates that the quality of crop soils in the Rio Grande Basin deteriorate over time by irrigation with high TDS Rio Grande water, addition of fertilizers, and other agricultural practices. Irrigation alone loaded approximately one ton per acre of Na, SO_4 , and Cl to the soils in 2011 irrigation season. Organics such as DOC are low in irrigation waters, and are loaded into the soil from

leaf litter. Results from this project contribute to our understanding of salt loading and nutrient cycling in the vulnerable area of the Rio Grande Valley in West Texas.

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INTRODUCTION

Soils are the source of 99.7% of the World's food supply (FAO, 1991-2001). As population continues to grow, the demand on crop production increases. Migration of people into arid and semi-arid environments, with the intent of agricultural production, has led to increased salinization of surface water and shallow groundwater in these regions (Szynekiewicz et al., 2011). Soils in this Rio Grande region of West Texas are developed on river-bed sediments comprised with fluvial-lacustrine facies and Piedmont facies on top of Tertiary rocks (Hawley and Lozinsky, 1992). The Rio Grande Valley is comprised of many farms which produce alfalfa, cotton and pecan. Water demanding crops like pecan require a high irrigation frequency and large amounts of water on the fields (Sammis et al., 2004). High evapotranspiration rates, salt-rich groundwater recharge, and agricultural activities (application of fertilizers and soil cultivation) have led to water degradation and increased salinity (Szynekiewicz et al., 2011). Irrigation with high salinity water can impact trees and crops in a way similar to reactions caused by water stress (Miyamoto, 2010).

Soils form from weathering processes of parent rock or unconsolidated sediments under certain climate conditions (temperature and precipitation) over geological time. Parent rock determines the composition and size of inorganic nutrient pools in the soil (e.g., Stallard, 1992; Anderson et al., 2007; Brantley and White, 2009). Other soil characteristics such as pH, bulk density, porosity, permeability, and particle size, are also inherited from parent sediment composition (Stevens and Walker, 1970). Soil evolution indicates that young soils are abundant in nutrients; however, they do not support high yielding products for long periods of time due to depletion of inorganic nutrients as soils evolve over time. This process has been commonly observed by field studies in soil chronosequences (Wardley et al., 2004; Porder et al., 2007).

The Rio Grande Valley was formed from ancient river-bed deposits from the flow and migration of the Rio Grande River. The valley is comprised of basin floor fluvial-lacustrine facies and Piedmont facies on top of Tertiary rocks (Hawley and Lozinsky, 1992). Present day Rio Grande Valley is composed of Entisols (Miyamoto, 2000) which do not have a recognizable B horizon. Agricultural areas in this region are generally composed of an average two foot layer consisting of fine texture materials (silty clay loam or clay) atop of coarser materials (fine sand to clay loam) (USDA-NRCS, 2010).

Crop growth and product yield is restricted by a number of attributes: drought, bad soil texture (clay and silty clay loam that discourage water infiltration), nutrient limitation, waterlogging, and

oxygen deficiency due to flood irrigation, high sodicity and salinity (Miyamoto and Storey, 1995; Table 1). Soils that contain an electrical conductivity (EC) greater than 4.0 dS/m are considered saline, and soils containing a sodium adsorption ratio (SAR) of greater than 13 are considered sodic. Here SAR is defined as $SAR (mmol^{1/2} L^{-1/2}) = [Na^+]/([Ca^{2+}] + [Mg^{2+}])^{1/2}$ (Essington, 2003), where cation concentrations were measured in water soluble leachates in unit of $mmol L^{-1}$. Salinity affects crop growth by limiting water and nutrients (e.g. P, Zn) obtainable to plants and through toxicity; sodicity affects the soil's permeability. Alfalfa, pecan and cotton are the dominant crops in the Southwest United States and their yields are greatly affected if soil salinities (EC) exceed 2.0, 2.6, and 7.7 dS/m, respectively (Maas and Grattan, 1999; Picchioni et al., 2000). Pecan tree mortality is possible with soil EC's between 6 to 8 dS/m (Miyamoto and Storey, 1995).

Table 1. Indicators for Soil Quality (USDA-NRCS, 2001)

Indicator	Relationship to Soil Health
Soil organic matter (SOM)	Soil fertility, structure, stability, nutrient retention, soil erosion, and available water capacity
<u>PHYSICAL</u>	
Soil structure	Retention and transport of water and nutrients, habitat for microbes, and soil erosion
Depth of soil and rooting	Estimate of crop productivity potential, compaction, and plow pan
Infiltration and bulk density	Water movement, porosity, and workability Water holding capacity Water storage and availability
<u>CHEMICAL</u>	
pH	Biological and nutrient availability
Electrical conductivity	Plant growth, microbial activity, and salt tolerance
Extractable nitrogen (N), phosphorus (P), and potassium (K)	Plant available nutrients and potential for N and P loss
<u>BIOLOGICAL</u>	
Microbial biomass carbon (C) and N	Microbial catalytic potential and repository for C and N
Potentially mineralizable N	Soil productivity and N supplying potential
Soil respiration	Microbial activity measure

(Adapted from: Doran et al., 1996; Larson and Pierce, 1994; and Seybold et al., 1997)

The southwestern US region is arid to semi-arid, with the annual precipitation at El Paso around 8 to 10 inches (WebSoil Survey). With such limited natural rainfall, irrigation is necessary for agricultural success. However, the amounts of irrigation needed vary among crop type. For example, Miyamoto (1983) estimated mature pecan trees need 1310 mm per year during the growing season in the El Paso area. This region uses Rio Grande water from Elephant Butte dam as the major source of irrigation water. Other types of waters used for irrigation include local and regional ground water, return flow, and waters from waste water treatment plants. These waters have different properties such as salinity and amounts of nutrients. Irrigation waters from the Rio Grande in the El Paso Valley area usually have an average salinity of 1.2 dS/m, and accumulations of salts at ~ 20 to 50 tons/acre were expected in a 10-year period if there is no drainage (Miyamoto, 2010).

Agricultural practices have been shown to increase soil erosion and degradation and uses of fertilizers have significantly increased salt contents. Irrigation loads affect soil conditions based on soil leaching, compaction, salt loadings, and permeability. For example, the introduction of flood irrigation has also played a role by adding ions to the soil systems, which will further be redistributed with depth: mobility of surface salts to greater depths even to the deep aquifer systems. The flood irrigation could also potentially leach the soil organic matter. Measures to remediate for undesirable soil pH's, salinity and sodicity include the addition of acids, liming materials, and gypsums. Many farmers in the El Paso area add gypsum and other sulfate granules as well as liquid sulfuric acids yearly to increase soil performance.

The goals of this study are to focus on three major crop types in southwest Texas, USA to (1) evaluate the current soil quality (2) study soil and irrigation water characteristics, and (3) determine the effects of irrigation on soil health and sustainability.

SITE DESCRIPTIONS

Four locations were selected to represent major crops (alfalfa, pecan, and cotton) in the Lower Valley area of El Paso, Texas (Figure 1): one pecan field (Pecan 1) and one cotton field (Cotton) in Tornillo, Texas, one pecan field (Pecan 2) in Clint, Texas, and one alfalfa field (Alfalfa) in Socorro, Texas. Two pecan locations were selected to obtain a better understanding of crop, soil, and water interaction.

Soil texture and composition differ with locations and are mainly controlled by types of ancient river-bed sediments (Table 2). Soil in Socorro (Alfalfa) and Clint (Pecan 2) are considered to be a Harkey silty clay loam, a well-drained soil with an available water capacity of about 9.7 inches. Soil in Tornillo has different compositions at both sites; Cotton is a Saneli silty clay loam while Pecan 1 is a Tigua silty clay. The Saneli silty clay loam is a moderately well drained soil with an available water capacity of 6.5 inches. Tigua silty clay is also a moderately well drained soil but with an available water capacity of 8.4 inches (WebSoil Survey).

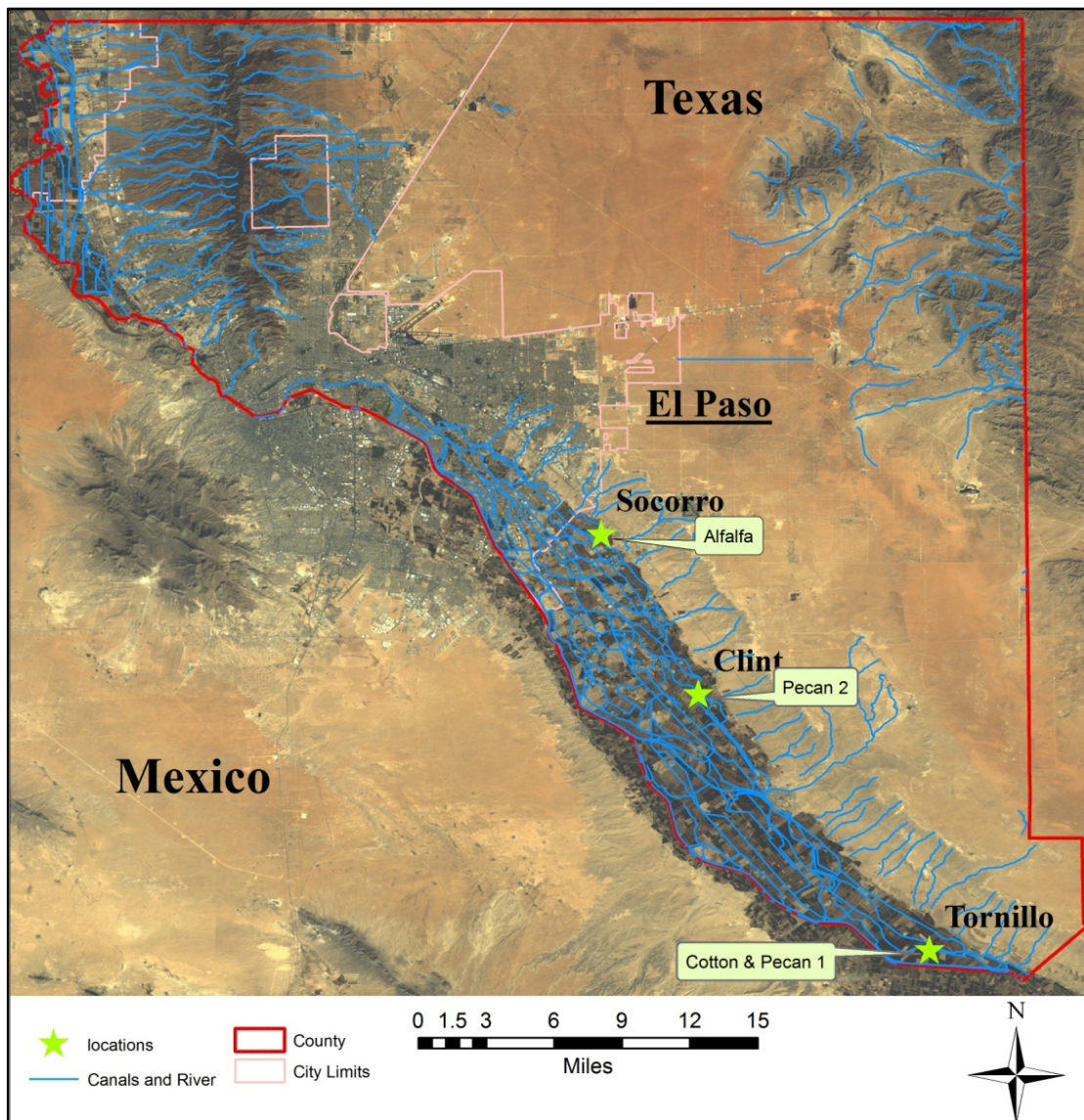


Figure 1: Location map of study sites (indicated by stars) along the USA-Mexico boundary in southwestern Texas.

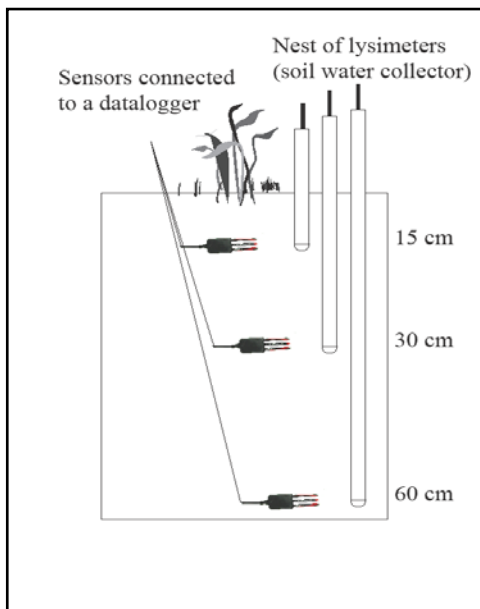


Figure 2: Schematic layout of the lysimeters and the sensors in the soils.

METHODS

Soil Sample Collection and Preparation

Soils samples were collected from each site through a soil pit in April of 2011 before the irrigation season started. Soil pits had an average dimension of 60 cm wide by 80 cm long by 60 cm deep. Samples were collected from the pit wall at 10 cm interval to a depth around 60 cm. After collection, soils were dried at room temperature for 5 days then split with a riffle splitter. One eighth of the samples remained unchanged for bulk analysis while another eighth was ground to a fine powder using a Micronizing Mill.

Water Sample Collection and Preparation

Three types of water were collected to have a better understanding of soil and water interaction: irrigation water (IRW), soil water, and drainage water (DRW). IRW was sampled from canals at each site before the onset of irrigation to the fields. DRW was sampled from the drainage canals after a period of 4 days from the onset of irrigation. This 4-day period gave the water on the field time to infiltrate the soil profile and reach the drainage canal. Soil water collection was obtained by use of 1900-series lysimeters (SoilMoisture Ltc, Barbara, CA) at three depths (15, 30 and 60 cm) from each site as indicated in Figure 2.

Lysimeters were cleaned in the laboratory before installation by a two-step procedure: 10% hydrochloric acid rinse followed by thorough rinse with de-ionized (DI) water. Each site was equipped with a nest of three lysimeters. Installation was conducted by auguring to depths of 15, 30 and 60 cm, then back filling around lysimeters with soil collected from auguring to simulate original soil stratification. A vacuum of 50 centibar was applied to each lysimeter before onset of every irrigation and soil water samples were collected using a tubing and syringe.

Five bottles were collected for each sample if volume allowed, for analyses of cations, anions, alkalinity, dissolved organic carbon (DOC) and total nitrogen (TN). Samples were filtered to 0.45 μm with 25mm syringe filter and placed in 30 ml bottles where they were then refrigerated until analysis. Cation samples were acidified with a few drops of pure nitric acid in the field during collection, while anion samples were left untreated. The alkalinity, DOC and TN samples were filled completely to avoid degassing.

Sample bottles were cleaned by a three-stage procedure: 10% hydrochloric acid, 10% nitric acid, and de-ionized (DI) baths. Glass bottles for DOC and TN collection were combusted at 500°C for three hours to remove organic residue.

Along with sample collection, water samples at each collection were characterized in the field for pH and EC. Orion 012005MD conductivity and VMR symphony pH electrodes were calibrated using two standards respectively: 1413 $\mu\text{S}/\text{cm}$ and 12.9 mS/cm for EC, and 7 and 4 for pH.

A total of 57 samples from all locations were collected for the 2011 irrigation season. During this season seven trips were made to each pecan site, four for cotton, and six for alfalfa. Majority of irrigation events applied to the fields were captured.

Sensor Installation

Each site was equipped with three ECH₂O-5TE (Decagon Devices Inc., Pullman, WA) sensors to measure soil moisture, temperature, and bulk soil EC at depths of 15, 30, and 60 cm, same depths as lysimeters. Data from sensors were collected at five-minute intervals by a datalogger from each field site. Figures 3A-C represent field layout of lysimeters, sensors and dataloggers in selected field sites. Pecan sensors were placed halfway between pecan tree base and canopy to provide an accurate representation of water without disrupting tree water usage. Cotton sensors were located beneath a row of cotton and lysimeters were between individual cotton plants on the same row. No special placement was needed for alfalfa.

Real-time data collected from sensors was also used to determine pore water EC (Hilhorst, 2000), including moisture (raw), temperature, and bulk EC. The values obtained after calculation described the relationship between water that can be extracted from the soil and the ionic conductivity measured in the bulk soil. This equation contains small errors by the empirical value for soil texture and when soil moisture becomes dry or almost dry as discussed later.

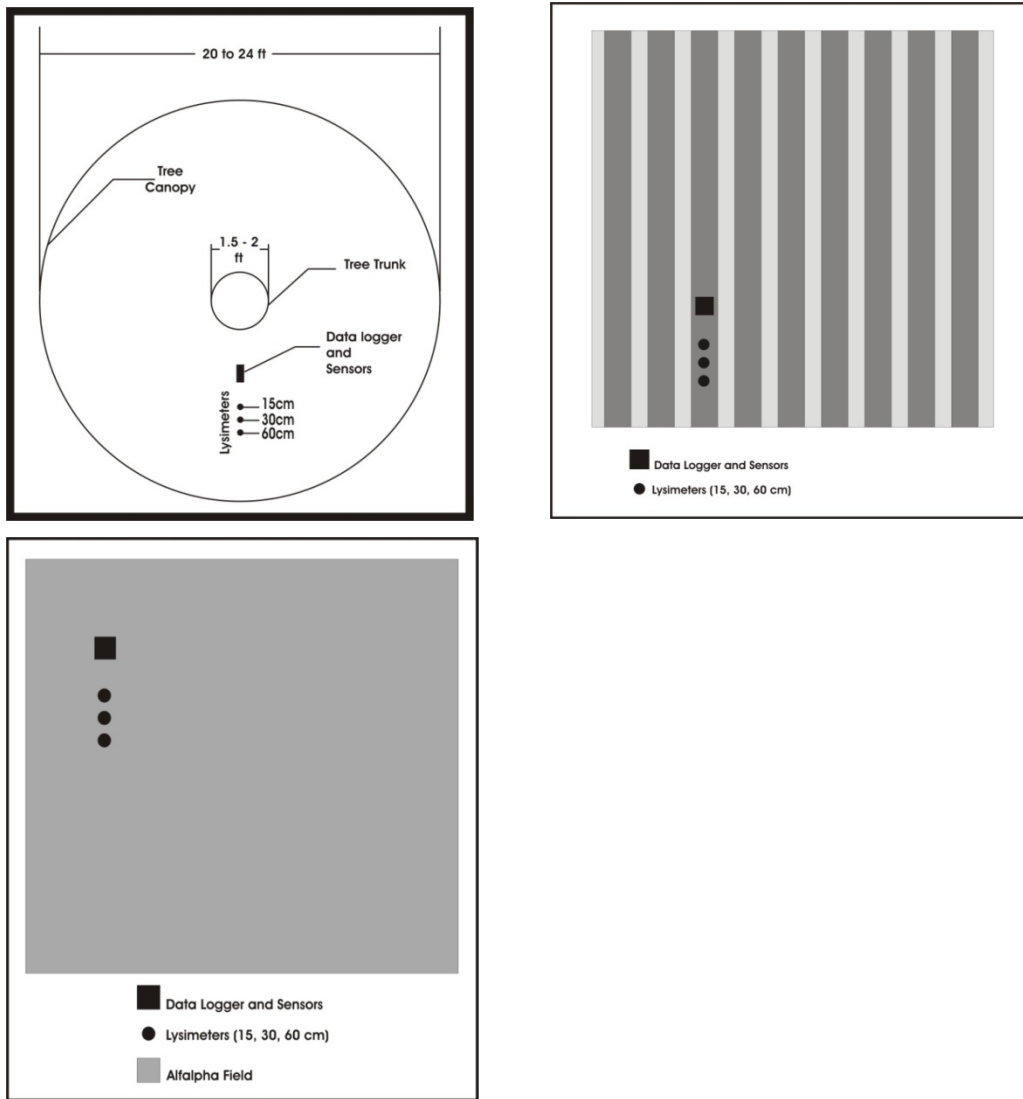


Figure 3: The schematic layout of lysimeters and the sensors in the soil fields. In pecan orchards (A), lysimeters and sensors are located halfway between tree trunk and canopy. In cotton field (B), dark gray rows are indicative of the rows that the cotton plants grow in. In alfalfa field, sensors and lysimeters are located near a corner (C). Notice that figures are not drawn to scale.

Soil Characterization

The bulk soils collected from all four sites were used to determine water soluble, exchangeable and cation exchange capacity (CEC). The major water soluble cations such as K, Ca, Mg, and Na were obtained from saturation paste extraction method (detailed procedure given in Appendix A) and their concentrations were measured by Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-

OES) at Texas A&M AgriLife Extension Center. Soil EC and pH were also measured using the water soluble extracts. Sodium adsorption ratio (SAR, a measure of sodicity) was then determined by water soluble Ca, Mg, and Na concentrations (mmol L^{-1}). Data collected from this procedure was then used to estimate the exchangeable sodium percentage (ESP) from the SAR calculation (Robbins, 1990). The ESP is the sodium to CEC ratio expressed in percentage unit.

Exchangeable cations such as Ca, Mg, and Na, and CEC were determined based on standard methods (Sparks, 1996) and procedures reported in Appendixes B and C respectively. Procedures for extractable cations included an extraction by 1M ammonium acetate (NH_4OAC) followed by determination of concentrations by ICP-OES (Sparks, 1996). CEC of the soil was determined by a three-stage sequential extraction process: 1 M sodium acetate (NaOAC) extraction at pH of 8.2, rinsed once with 33 ml of ethanol, followed by 1M ammonium acetate (NH_4OAC) at pH of 7. Each extraction stage used a total of 99 ml solution, including three times repetition of 33 ml, shaking and centrifuging for 10 minutes at 2000 rpm. The extracts from the 1M sodium acetate were discarded and those from 1M ammonium acetate were combined (~99ml) in a volumetric flask and totaled to 100 ml with pure ammonium acetate for Na analysis on ICP-OES and determination of CEC. Preparation of standards for exchangeable cations and CEC is reported in Appendix D.

Carbon concentrations of the ground soil samples were measured by Lachat IL 550 TOC-TN analyzer. A TOC (total organic carbon) sample was prepared by acidifying ~0.2 -0.5 grams of a ground soil sample with 10% HCl to remove all inorganic carbonate and drying it at 100 °C before analysis. A TC (total carbon, including total inorganic and organic carbon) sample was prepared by weighing ~0.2 - 0.5 grams of the ground soil sample for analysis. All soils were placed in ceramic boats that have been washed and combusted in an oven at 500 °C for 2 hours, and introduced to solid module of the TOC-TN analyzer. Six standards of pure calcite powder with weights between 0.005 and 0.05 grams were used to calibrate C contents.

The difference between TC and TOC for each soil sample is attributed to TIC (total inorganic carbon, i.e., carbonate carbon). Additionally, the carbonate content was quantified for Cotton soil samples following Sherrod et al. (2002), where inorganic carbon content was determined by measuring pressure of CO_2 after acidification of soil samples in a sealed glass bottle. Mixtures of calcite and quartz (inert) powders of different weight ratios were used as standards.

Water Characterization

Chemistry of the water samples were characterized as following. Perkin Elmer 5300 ICP-OES was used to measure cation concentrations of Al, Ca, Fe, K, Mg, Mn, Na, P, Pb, Si and Sr. A Dionex ion chromatograph (IC) was used for analysis of anion concentrations, including Br, Cl, F, NO₃, PO₄, and SO₄. Alkalinity was titrated by use of Mettler Toledo DL15 Titrator and calculated with a Gran plot (Drever, 1997). The DOC and TN were measured by a Lachat IL 550 TOC-TN analyzer.

The water chemistry as well as pH was used as inputs for the geochemical program Somineq. 88 to calculate the saturation indexes of seven evaporite minerals: calcite (CaCO₃), dolomite (CaMg(CO₃)₂), disordered dolomite, gypsum (CaSO₄•2H₂O), halite (NaCl), nacholite (NaHCO₃), and thenardite (Na₂SO₄). We assumed that the water temperature was 22 °C for all three depths, which is the average of all the temperatures collected from the data loggers.

RESULTS

Soil Chemistry

CEC AND EXCHANGEABLE CATIONS

The soil characterization data including CEC, exchangeable cations, water soluble cations, organic and inorganic carbon contents, soil pH, and soil EC, as well as calculated SAR were reported in Table 4. The CEC of Alfalfa and Pecan 2 soils ranges between 0 and 15 meq/100g while that of Cotton and Pecan 1 ranges between 15 and 35 meq/100g (Figure 4). These differences among sites possibly are related to changes in soil textures as discussed below.

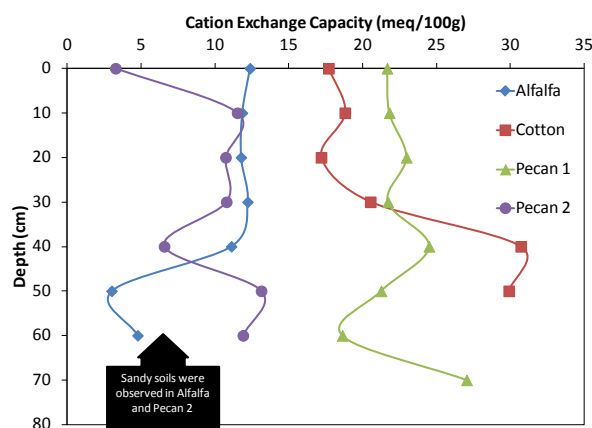


Figure 4. Depth variation of cation exchange capacity (CEC) in studied soils

Exchangeable Ca concentrations in Alfalfa and Pecan 1 soils remain relatively constant around 35 meq/100g until 40 cm, where their concentrations in Pecan 2 and Cotton soils are systematically higher around 40 meq/100g at those depths (Figure 5A). More variation was observed below 40 cm; however, Ca concentrations in Cotton and Pecan 1 soils are always higher than those in Alfalfa and Pecan 2. Especially in Cotton, Ca concentrations up to 60 meq/100g were detected for soils from depth 60 cm. Exchangeable K and Mg concentrations show the same depth trends as Ca in these sites but had much lower concentrations (Figures 5B and 5C). Exchangeable Na shows increases in concentrations with depth in Pecan 1 and Cotton, while it remains relatively constant in Alfalfa (Figure 5D). Na concentrations in Pecan 2 increase with depth until 50 cm where it then decreases from about 4 to 2 meq/100g. This decrease in Pecan 2 coincides with the change in texture found in the soil.

Exchangeable sodium percentage (ESP) show increases in Cotton and Pecan 1 sites with depth, while large fluctuations in Alfalfa and Pecan 2 are observed (Figure 6). A large increase occurred at 50 cm depth where Alfalfa's soil texture changes from more clay rich to sandy.

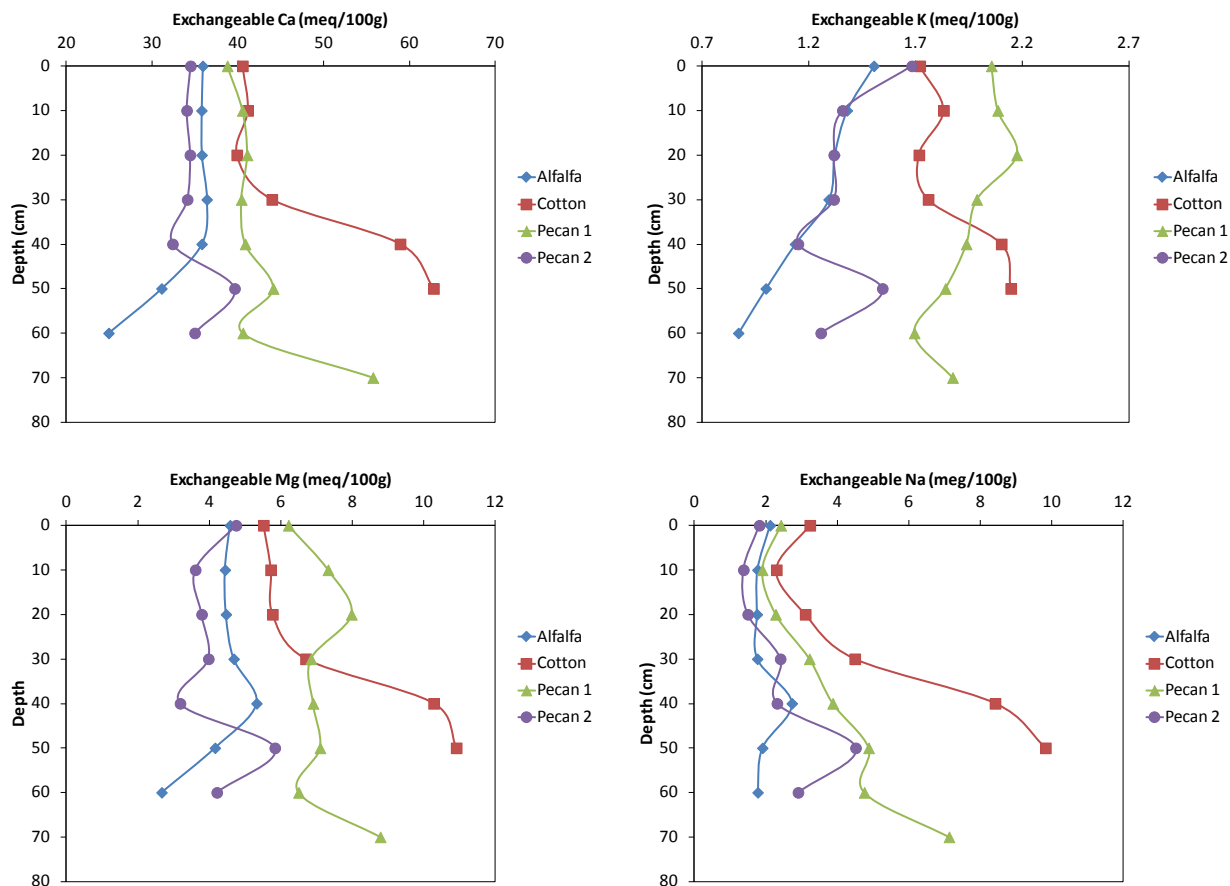


Figure 5: Concentrations of exchangeable Ca (A), K (B), Mg (C), and Na (D) as a function of depth in studied soils.

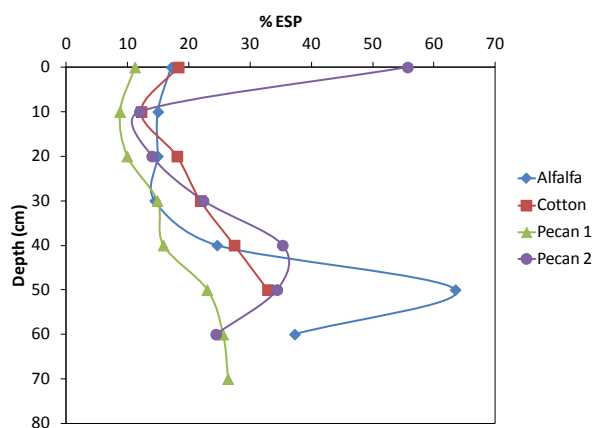


Figure 6: Depth variation of exchangeable sodium percentage (ESP) in four soil profiles.

WATER SOLUBLE CATIONS

Soil pH averages at 8.1 from top soil to 20 cm depth in all four locations (Figure 7A). Beyond 20 cm, small decreases in pH were observed in Alfalfa, Pecan 1 and Pecan 2. Cotton site shows the most variability in pH with the largest decrease below 40 cm depth. Soil EC from the saturation paste shows increases with depth in Cotton, Pecan 1, and Pecan 2 (Figure 7B). In contrast, soil EC in Alfalfa maintains relatively constant with little variation. Saturation percentage (SP) is the maximum amount of water soil can hold calculated from saturation paste method (ratio of amount of water relative to amount of soil in a soil slurry). SP was observed to range from 50 to almost 110%, with higher SP values observed in Cotton and Pecan 1 soils than those from Pecan 2 and Alfalfa (Figure 8). Three out of four sites have soils at depth where SAR is greater than 13: Cotton, Pecan 1, and Pecan 2. Of the four sites, Cotton soils show the highest SAR (Figure 9). Furthermore, the higher SAR values were all observed in deeper soils, but not on shallow soils.

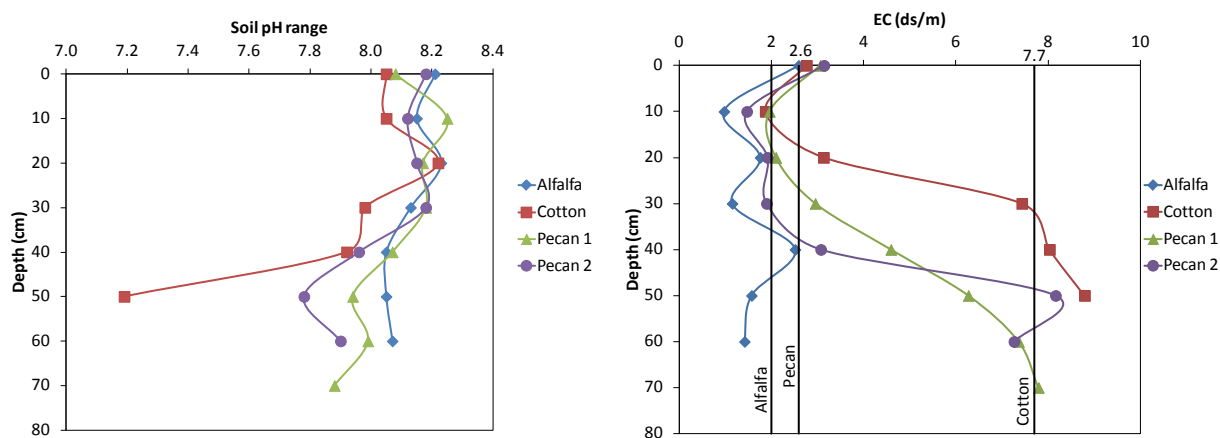


Figure 7: Variation of soil pH (A) and EC (B) as a function of depth as characterized using saturation paste method (see text for details). The tolerance levels of EC for specific crops (alfalfa, pecan and cotton) were plotted as bold vertical lines in B.

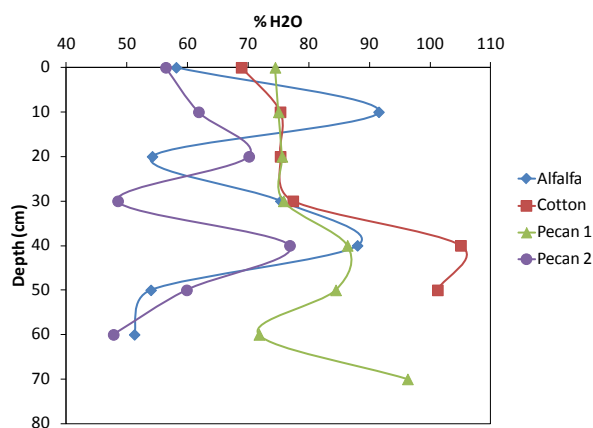


Figure 8: Saturation percentage of soils as a function of depth, reflective of soil texture.

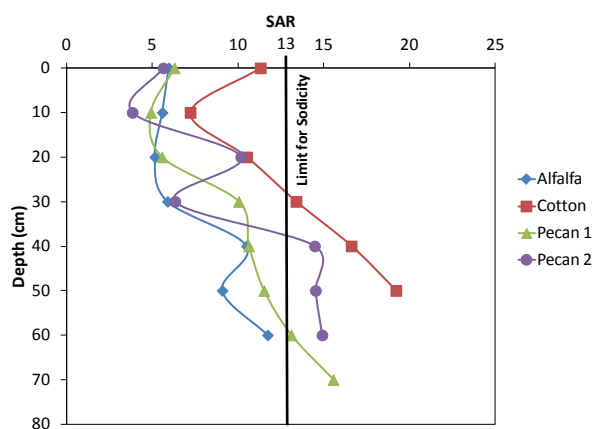


Figure 9: Sodium adsorption ratio (SAR) increases with depth at each soil profile. Soils with SAR values of greater than 13 (black line) are considered sodic.

In all four locations, Na is the dominant cation in the water soluble fraction, ranging from 0.5 to 8 meq/100g. Water soluble sodium concentrations increase with depth in Pecan and Cotton soils but remain relatively constant in Alfalfa (Figure 10A). Cotton soils exhibit the largest increase in sodium concentrations at 20 cm depth and below. Water soluble Mg and Ca behave similarly as Na, but their concentrations are much lower (Figure 10 B and C). Mg and Ca show increases in concentrations except for Alfalfa which decreases slightly with depth. Water soluble potassium shows increases in concentration in Cotton, and decreases in Alfalfa (Figure 10D). Pecan 1 and 2 show slight decreases in water soluble K until 30 cm then concentrations increase in both locations followed by another decrease at 50 cm depth.

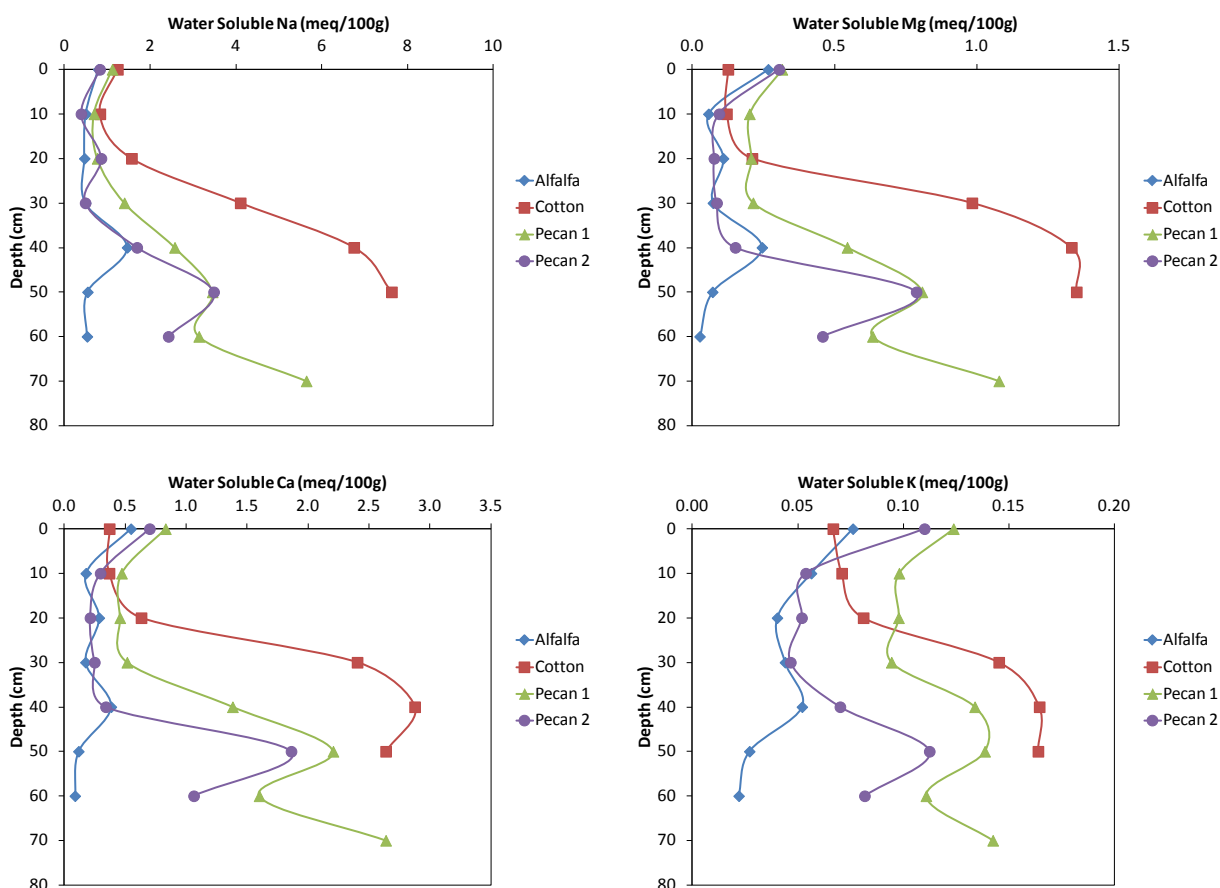


Figure 10: Concentration of Na (A), Mg (B), Ca (C) and K (D) in water soluble fraction of the soils.

C CONTENTS

Total carbon (TC) concentrations are the highest at the surface in both Pecan 1 and Pecan 2 sites (~2.8 wt%) and decrease with depth, especially at 10 cm of depth (to ~ 1.2 wt %) as seen in Figure 11A. Total organic carbon (TOC) concentrations in the soil range from 0.4 to 1.7 wt % and generally decrease with depth (Figure 11B). TIC concentrations were calculated from the differences between TC and TOC and further converted to carbonate contents assuming CaCO_3 stoichiometry. The carbonate wt% changes little among different sites and with depth at each site (Figure 12A). Additionally, TIC of Cotton soils was measured by a pressure-calimeter method (Sherrod et al., 2002) and the data is in agreement with that calculated from difference between TC and TOC within uncertainty (Compare Figures 12A and 12B). The CaCO_3 concentrations slightly decrease with depth, and range between 5.4 and 6.7 wt % in Cotton sites.

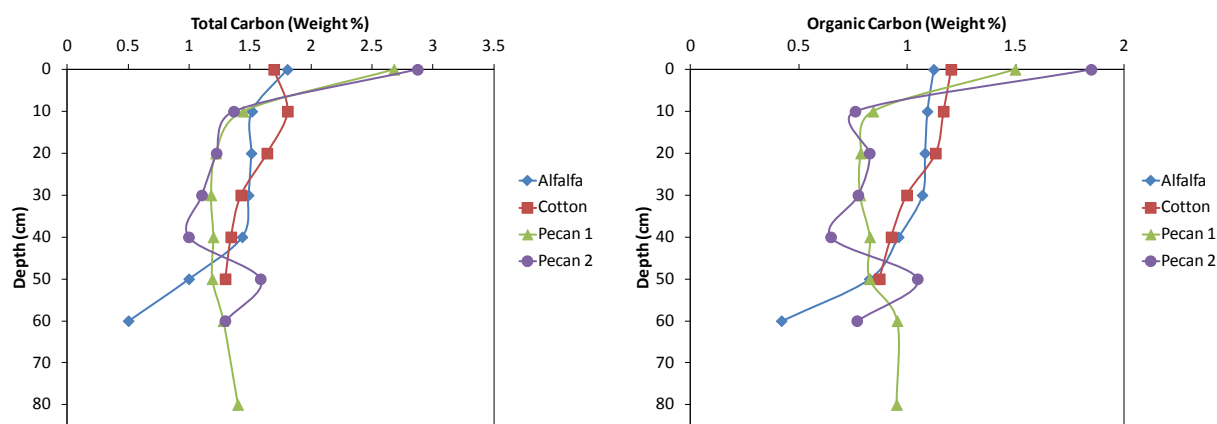


Figure 11: Total carbon (A) and total organic carbon (B) of soils with depth.

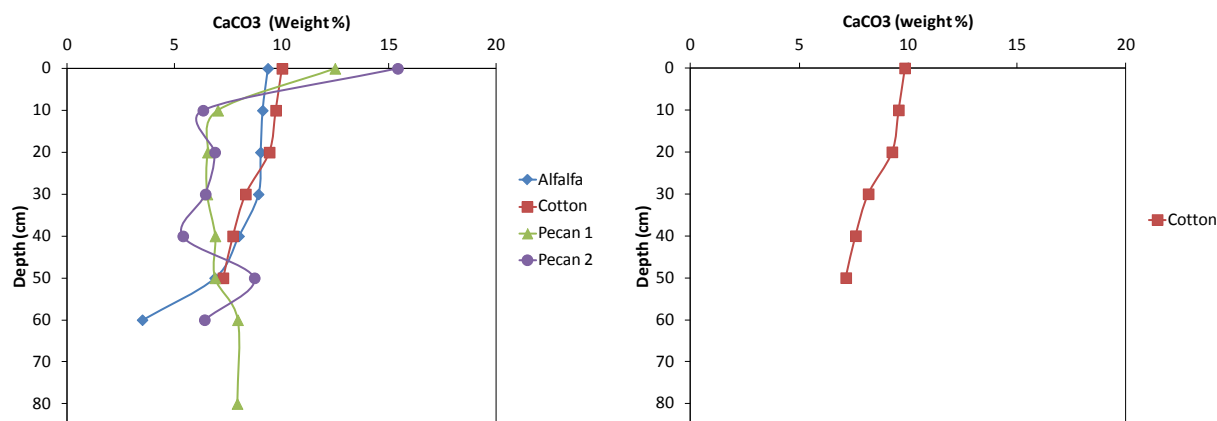


Figure 12: Calcium carbonate contents of soils calculated from inorganic carbon content, through C analyzer (TIC=TC-TOC; A) and from pressure- calcimeter (B, for Cotton only).

SOIL TEXTURE

According to WebSoil Survey (websoilsurvey.com), our Alfalfa and Pecan 2 sites belong to the the Harkey silty clay loam and has 60% silt sized particles, 33% clay and 7% sand. Saneli silty clay found at the Cotton site has a majority of 55% silt, with 37% clay and 8% sand. Tigua silty clay at Pecan 1 is dominated by 50% clay with addition of 45% silt and 5% sand. Soil properties including particle size and their depth variations, as well as the moist bulk density of each location are reported in Table 2.

Table 2. Typical physical properties of studied soils (data from WebsoilSurvey)

Location	Name	Soil Texture	Depth Intervals inches	Sand %	Silt %	Clay %	Available water capacity (in/in)	Moist Bulk Density g/cm ³
Alfalfa	Harkey silty clay laom	Silty clay loam	0 to 12	7	60	33	0.15-0.19	1.45 - 1.55
		Silt loam	12 to 60	14	72	14	0.13-0.19	1.40 - 1.50
Pecan 2	Harkey silty clay laom	Silty clay loam	0 to 12	7	60	33	0.15-0.19	1.45 - 1.55
		Silt loam	12 to 60	14	72	14	0.13-0.19	1.40 - 1.50
Cotton	Saneli silty clay loam	Silty clay loam	0 to 32	8	55	37	0.12-0.18	1.25 - 1.45
		Loamy fine sand	32 to 60	85	7	8	0.03-0.08	1.45 - 1.65
Pecan 1	Tigua silty clay	Silty clay	0 to 10	5	45	50	0.10-0.18	1.25 - 1.40
		Clay	10 to 50	10	25	65	0.10-0.18	1.25 - 1.40
		Silt loam	50 to 60	40	40	20	0.10-0.18	1.45 - 1.65

Water Chemistry

DATA QUALITY CONTROL

Water chemistry data including saturation indexes are reported in Tables 5 and 6. Charge balances were evaluated by calculating the major cation contributions from Ca, K, Mg, and Na, and major anion contributions from Cl, NO₃, SO₄ and alkalinity. All points lie close to the 1:1 line. Water samples from the Alfalfa site have the lowest ionic strength as seen in Figure 13A, while those from Pecan and Cotton sites have the highest. Total positive charge shows correlation with electric conductivity (EC) except for a few samples. Samples start to deviate from the linear trend at higher positive charges (Figure 13B): one soil waters collected from Cotton at 60 cm, and the other from Pecan 2 at 60 cm. These two graphs indicate that our analyses have captured the dominant ions that contribute to charges.

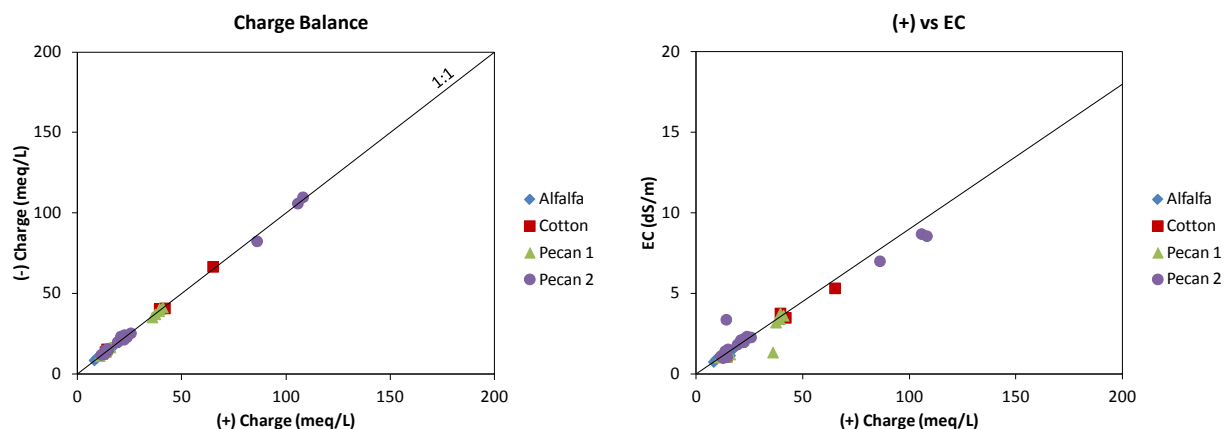


Figure 13: Water data quality is evaluated using charge balance (A) and correlation between total positive charge and EC (B).

CONCENTRATIONS VS DEPTH

Irrigation water (IRW) is arbitrarily placed at the depth of 0 cm, and drainage water (DRW) at 100 cm on all depth profiles. Irrigation water shows the largest variation in pH values compared to soil waters and drainage waters (Figure 14A), probably reflective of different types of water used for irrigation. Generally, pH of waters at all four locations remains relatively neutral throughout the soil observed. Irrigation waters measured at all four locations have an average EC of 3 dS/m. Drainage water, is more similar to irrigation water in chemistry than soil waters at each location as discussed below. EC generally increases with depth, with highest values were observed in Cotton at 60 cm depth (Figure 14B). Soil water alkalinity (mainly as bicarbonate) averages at 6 meq/L as observed in Figure 14C. Soil water from 30 cm of depth shows variations in alkalinity among different sites (Cotton < Pecan < Alfalfa). Similar to other ion concentrations measured, DRW alkalinity is similar to that of IRW.

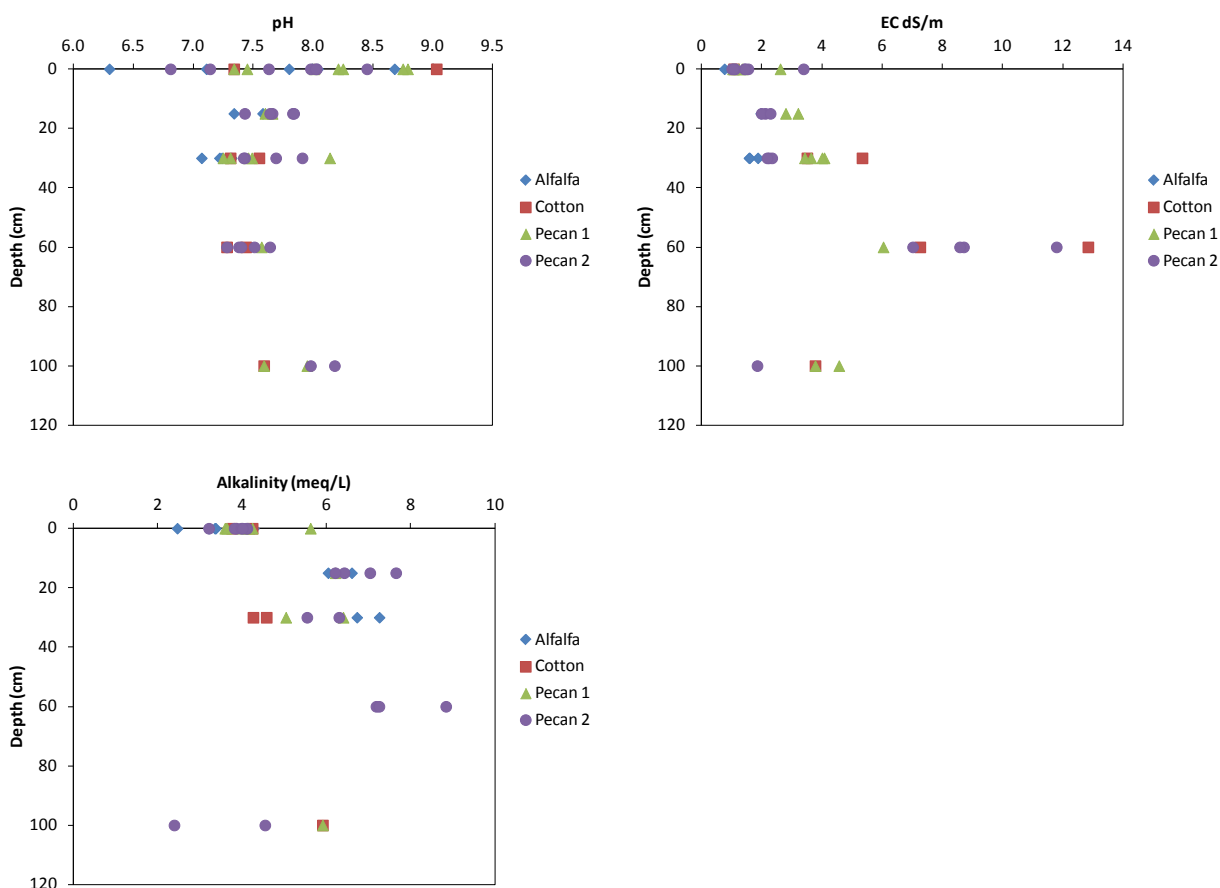
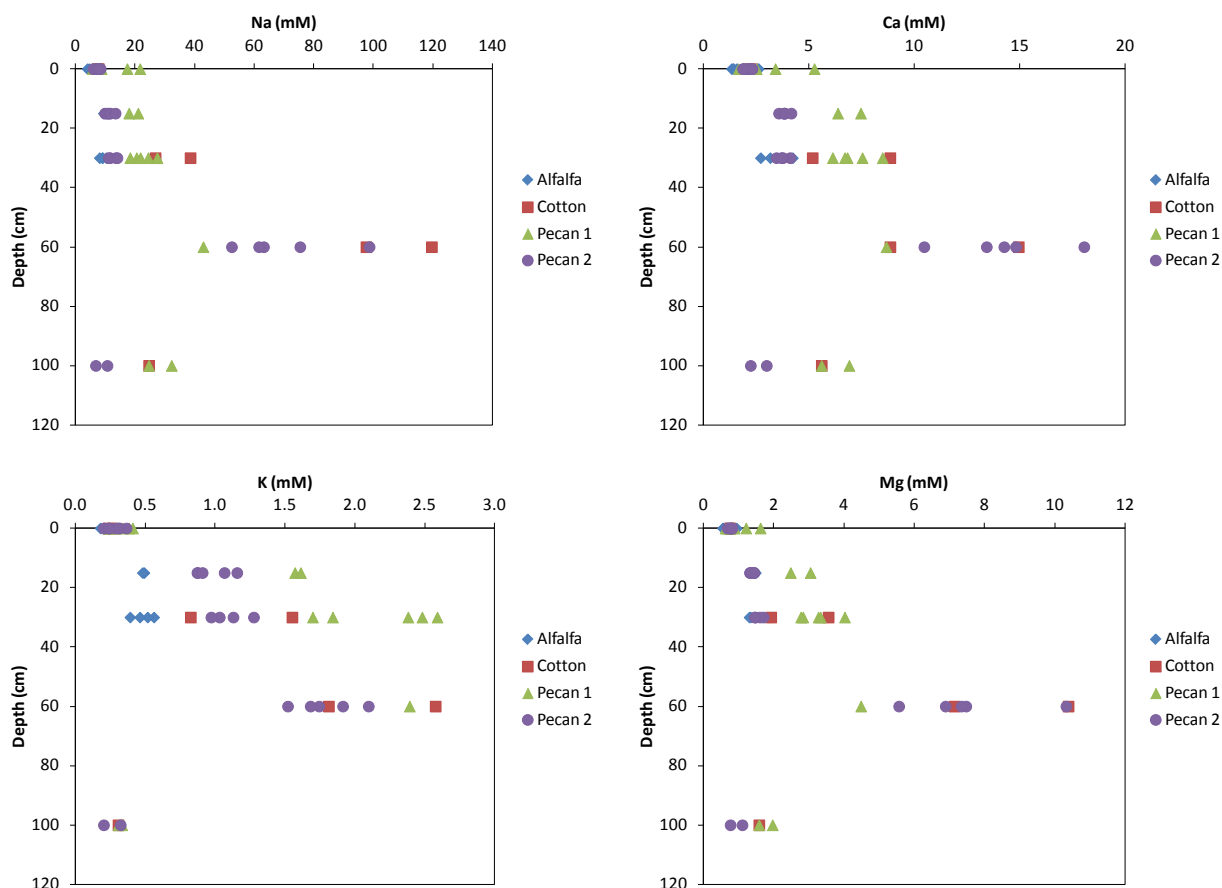


Figure 14: Water pH (A), EC (B), and alkalinity (equivalent bicarbonate, C) were plotted with depth for all four soil profiles. Irrigation water (IRW) and drainage water (DRW) were arbitrarily placed at depth of 0 cm and 100 cm, respectively. Soil waters were from depths of 10, 30 and 60 cm.

Na concentrations in waters increase with depth throughout the soil; the highest concentrations were almost always observed at depth of 60 cm. As the dominant cation, Na concentrations range from 5 to 120 mM in soil waters (Figure 15A). IRW and DRW waters show lower concentrations, ranging from 5 to 21 mM and 6 to 33 mM, respectively. Ca, K and Mg exhibit the same depth trends as Na, but are much lower in concentrations in these waters (Figures 15 B, C, and D respectively). For all these cations, DRW and IRW waters have relatively low concentrations compared to soil waters. Si concentrations in IRW and DRW range from 0 to 0.4 mM, and no depth variations were observed for soil waters (Figure 15E).



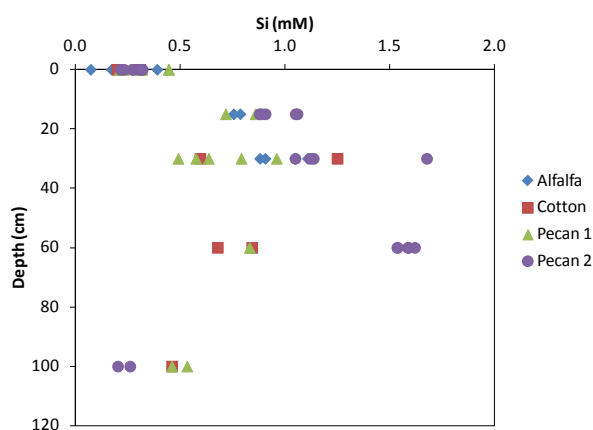


Figure 15: Concentrations of Na (A), Ca (B), K (C), Mg (D) and Si (E) in waters (IRW, soil water, and DRW) vary with depth.

Cl concentrations in soil waters increase with depth to 60 cm, similar to Na. As the dominant anion, Cl concentrations of soil waters range from 1 to 62 mM in concentrations (Figure 16A). An exception was observed in Alfalfa, where concentrations decrease at 30 cm. IRW and DRW show lower but more variable levels of Cl. NO_3 concentrations show increases with depth; highest concentrations were observed at a depth of 60 cm in Pecan 2. Cotton concentrations at 60 cm of depth resemble similar concentrations to 30 cm as seen in Figure 16B. DRW concentrations are very low in NO_3 concentrations and resemble IRW concentrations. SO_4 concentrations show increase by at least 5 times at deeper depth. Highest concentrations were observed in Cotton and 60 cm of depth. DRW resembles IRW with concentrations around 5 mM (Figure 16C). Alkalinity in IRW ranges between 2 and 6 meq/L. Concentrations increase with depth (Figure D) and highest concentrations were observed in soil waters at 60 cm of depth.

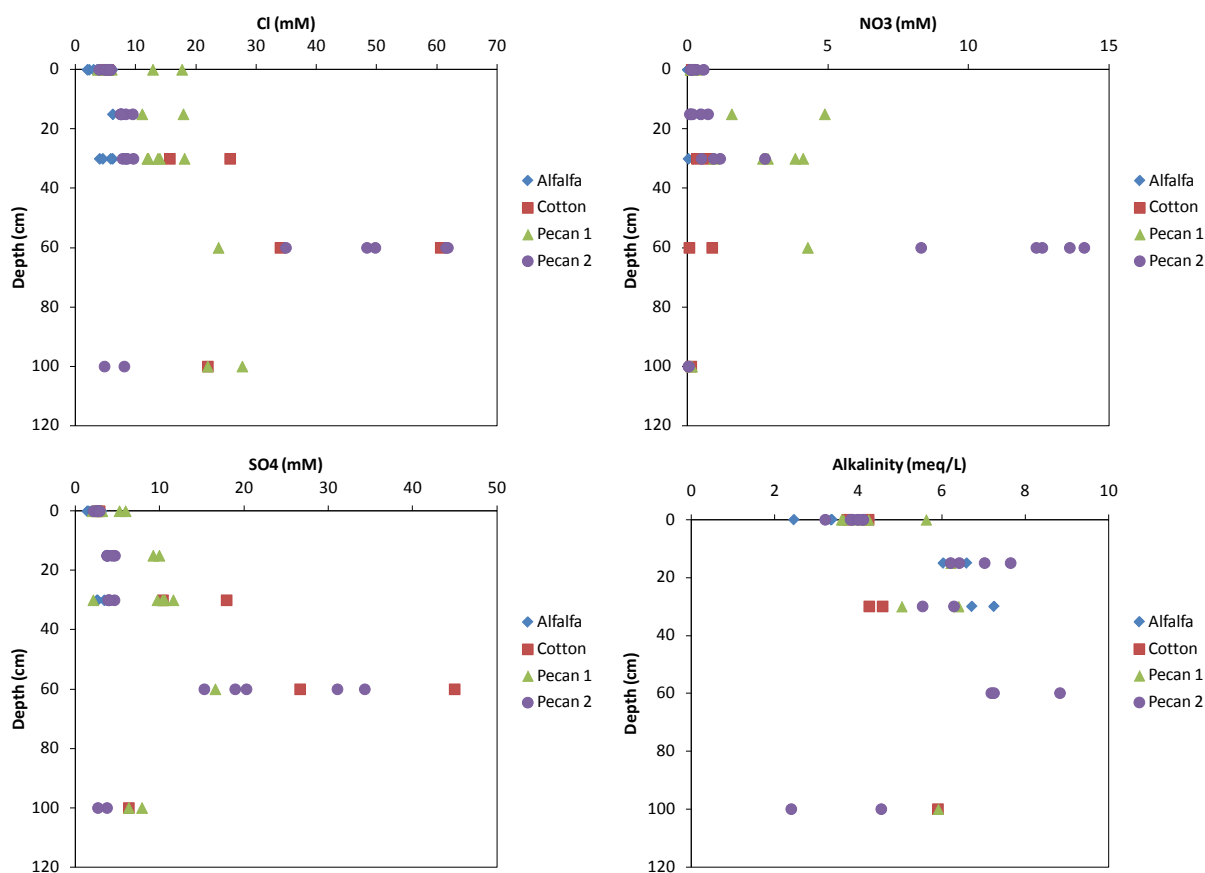


Figure 16: Cl (A), NO₃ (B), SO₄ (C), and Alkalinity as bicarbonate (D) concentrations as a function of depth in water samples (IRW, soil water, and DRW).

Br, F, PO₄, Sr, Al, Fe and Pb are present in these waters at trace levels. Br and F concentrations generally increase with depth to 60 cm in all fields except Alfalfa (Figure 17A, and B). In contrast, IRW and DRW show lower levels of Br. Most of IRW samples show low concentrations in PO₄ and P ranging from 0 to 27 and 0 to 50 μ M respectively as seen in Figure 17 C and D. Some of IRW however have PO₄ concentrations above 25 μ M, probably due to additional PO₄ fertilizers. PO₄ concentrations decrease with depth in soil waters. Soil waters from Pecan 2 show the highest concentrations of Sr and those from the Alfalfa have the lowest concentrations among all four sites. Similar to major ions, Sr concentrations increase with depth as seen in Figure 17E. Al, Fe and Pb concentrations were all below detection limit in soils from all four sites.

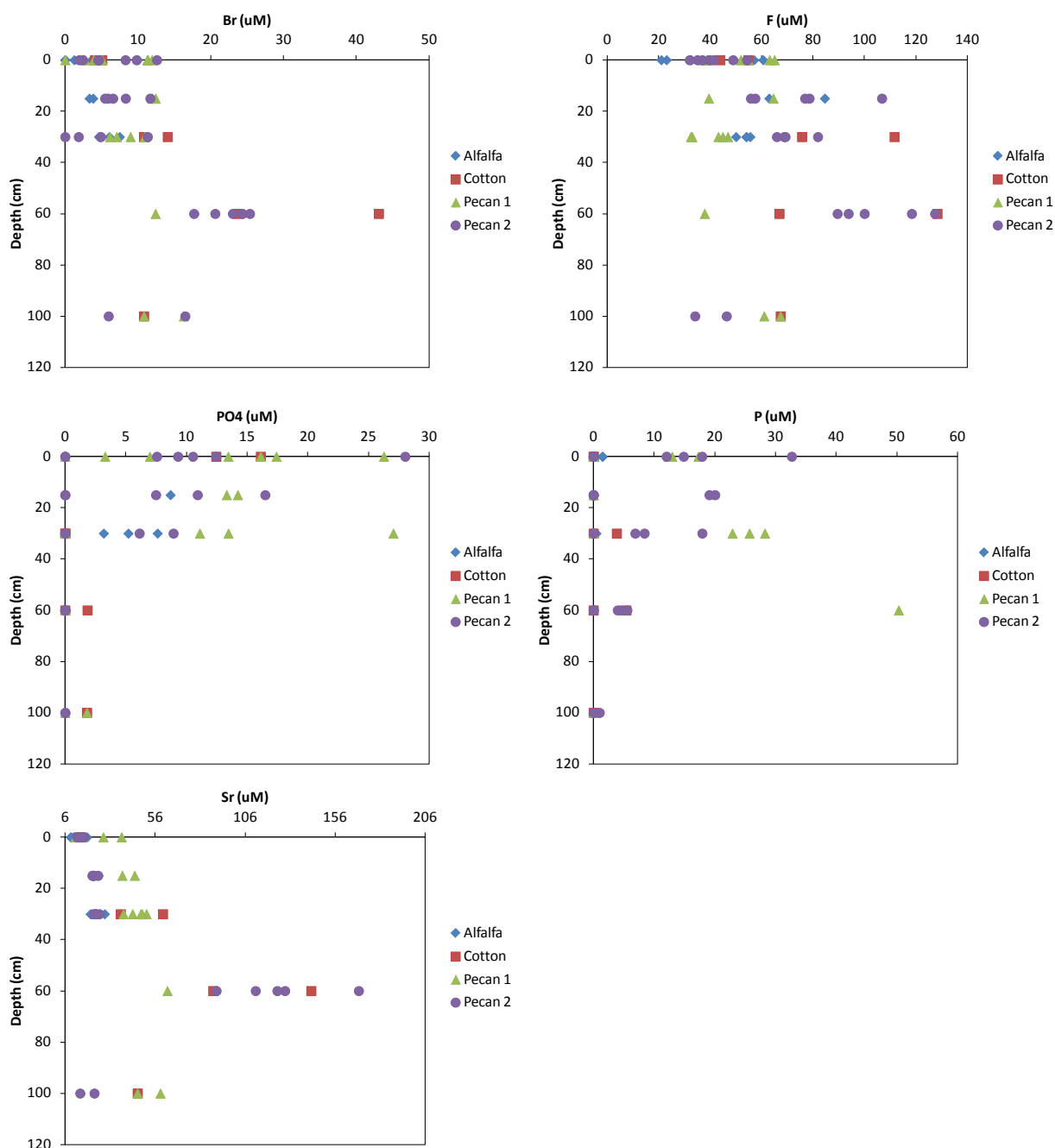


Figure 17: Concentrations of trace elements (Br (A), F (B), PO₄ (C), P (E), and Sr (E)) as a function of depth in water samples (IRW, soil water, and DRW).

ELEMENTAL RATIOS

Interestingly, SO₄ and Ca concentrations in irrigation, soil, and drainage waters (Figure 18A) fall closely onto a 1:1 line, especially when SO₄ concentrations are less than 10 mM. Above 10 mM, SO₄ concentrations become higher than Ca concentrations. Similarly, Na and Cl concentrations show a 1:1

correlation (Figure 18B). As Na concentrations increase, samples deviate further from the 1:1 line. Ca and Sr concentrations show linear correlation, with Sr/Ca ratios around 7:1 ($\mu\text{M}/\text{mM}$) (Figure 18C).

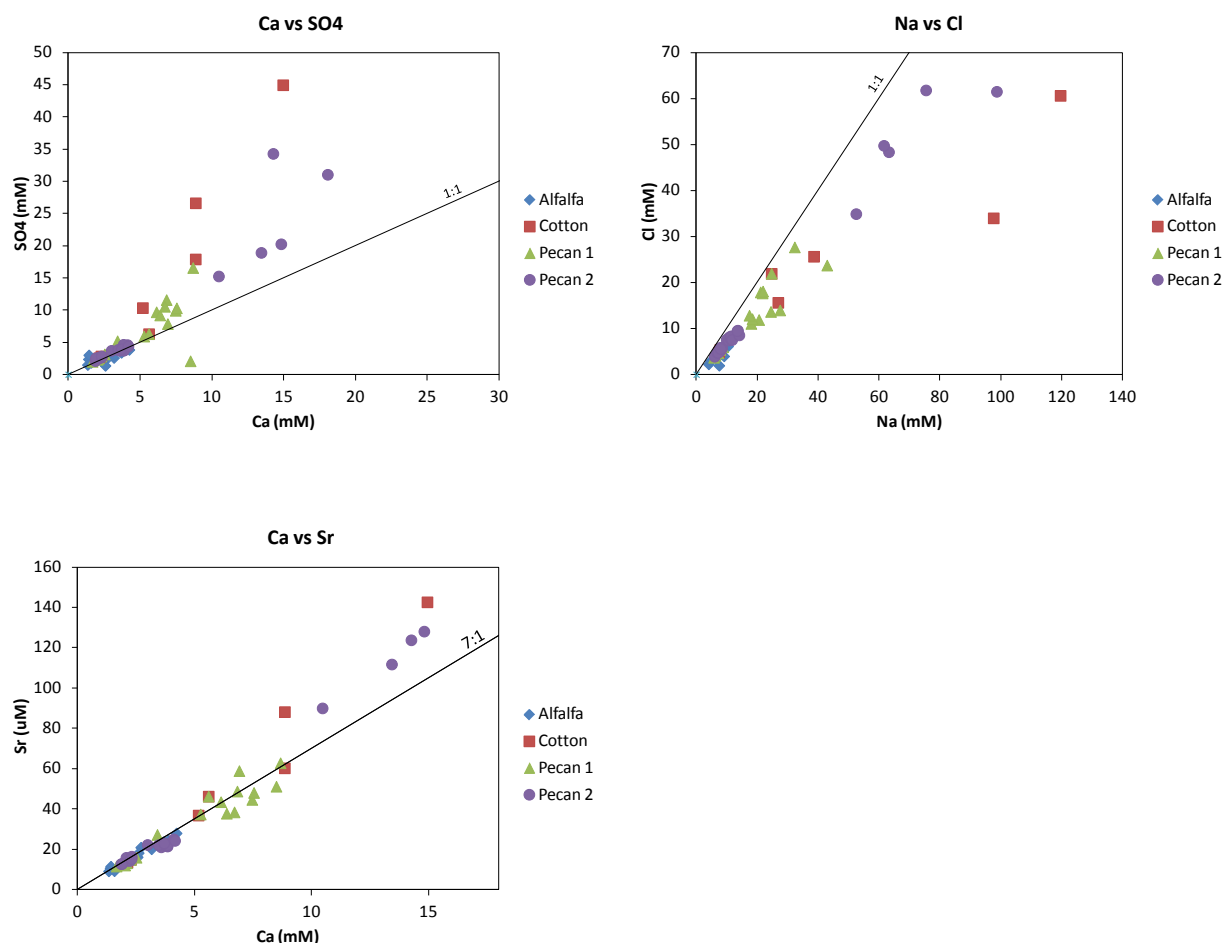
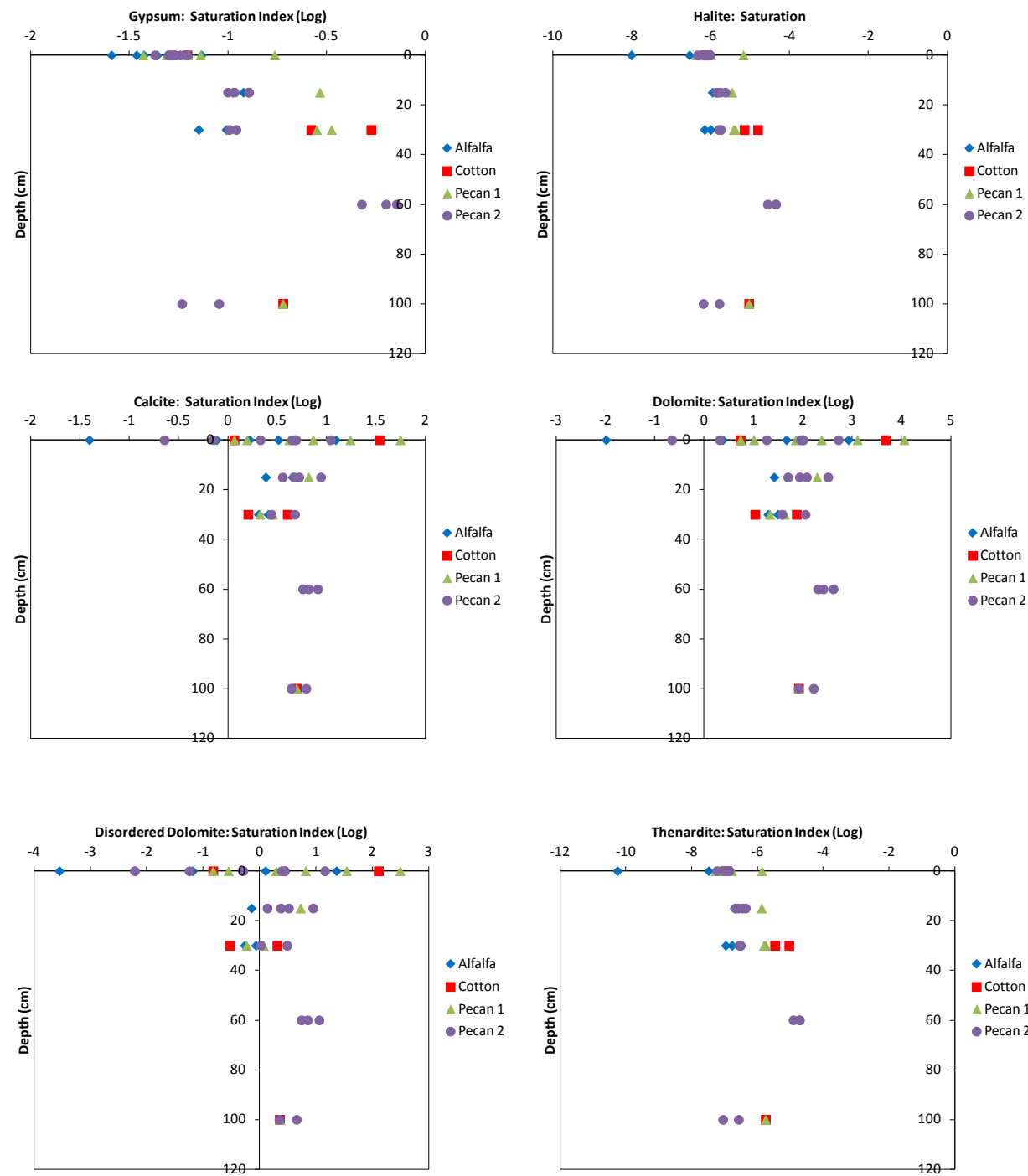


Figure 18: Correlations of Ca and SO₄ (A), Na and Cl (B), and Ca and Sr (C) in all types of water samples (IRW, soil water, DRW).

SATURATION INDICES

Saturation index (SI) values increase with depth for all minerals examined. Soil waters and DRW remain unsaturated with respect to minerals such as gypsum and halite (Figure 19 A and B). Calcite and dolomite are oversaturated with SI ranging from 0.25 to 1 for all soil solutions and ranging from 0.5 to 0.75 for DRW. The irrigation waters are mostly oversaturated with a few exceptions (SI = -1.5 to 1.75) as seen in Figures 19C and 19D respectively. Disordered dolomite is only oversaturated in soils at 60 cm and in DRW. The saturation index of disordered dolomite ranges from of -3.5 to 2.5 in IRW, and ranges from -0.5 to 1 in soil waters at depths of 15 and 30 cm (Figure 19E). Other salts such as

thenardite and nacholite were both undersaturated in IRW, DRW and soil waters. Thenardite ranges from -10 to -4 and nacholite ranges from -6 to -3 (Figures 19 F and G).



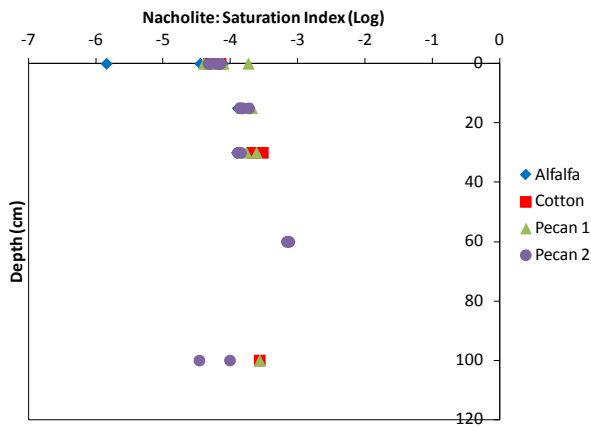


Figure 19: Saturation indices for waters versus depth for gypsum (A), halite (B), calcite (C), dolomite (D), disordered dolomite (E), thenardite (F), and nacholite (G).

IRRIGATION LOADS

Amounts of water used for irrigation vary based on crop type, and of all the crops grown in the El Paso area, pecan requires the most water. Reports from farmers indicate that pecan orchards use an average of 3.7 ft per year, cotton fields use 3.0 ft per year, and alfalfa fields use 4.5 ft per year. Calculations based on irrigation water chemistry and amounts of water have roughly estimated annual Na loading of 1.0 ton/acre for pecan, 0.7 ton/acre for cotton, and 0.9 ton/acre for alfalfa (Table 3). The annual irrigation loading for other ions such as Cl, SO₄, Ca, Mg, and bicarbonate were also calculated per acrefoot/acre: 0.7-1.1 tons for Cl, and 1.1-1.3 tons for SO₄, 0.4-0.5 tons for Ca, ~ 0.1 tons for Mg, and 0.9-1.2 tons for bicarbonate. Types of irrigation waters vary among irrigation events based on availability of ground water, river water, waste water and return flow (drainage water from other farms). Calculations were made based on volume of water used for each irrigation and average concentrations measure from these irrigation waters.

Table 3. Estimated annual irrigation loading for water (ft) and major elements for year 2011 (Tons/acre).

Location	Water added	Cl	SO ₄	Ca	Mg	Na	HCO ₃
Site	Feet	tons/acre	tons/acre	tons/acre	tons/acre	tons/acre	tons/acre
Alfalfa	4.5	0.8	1.3	0.4	0.1	0.9	1.2
Cotton	3.0	0.7	1.1	0.4	0.1	0.7	0.9
Pecan	3.7	1.1	1.4	0.5	0.1	1.0	1.2

DOC AND DIC:

Water samples were characterized for dissolved organic carbon (DOC) along with carbonate alkalinity. Given the pH measured in these waters, the dominant dissolved inorganic carbon (DIC) species is bicarbonate so carbonate alkalinity can be converted to DIC. DOC and DIC concentrations show similar trends as other major ions. DOC in IRW and DRW ranges from 0 to 1.3 mM, while that of soil waters ranges from 1.2 to 3.3 mM with highest concentrations observed at 30 and 60 cm below surface (Figure 20A). DIC in IRW and DRW ranges from 2 to 4 mM, and that of soil waters ranges from 3.6 to 9 mM with highest concentrations also observed at 30 and 60 cm of depth (Figure 20B).

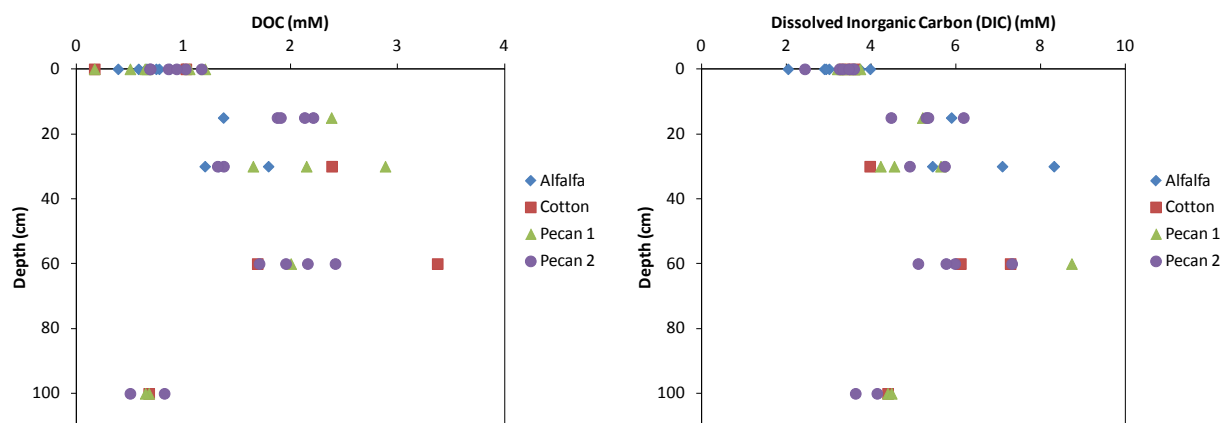


Figure 20: Dissolved carbon in waters: dissolved organic carbon (DIC) (A) and dissolved inorganic carbon (DIC) (B).

SENSOR DATA

Spiked soil moisture content and bulk soil EC are observed at the onset of every irrigation at all three depths (Figures 21 A and B). With water infiltration, uptake by plants and evapotranspiration, soil moisture content decreases with time until the next irrigation. When irrigation periods had a prolonged gap, the moisture in the soils was sometimes below the calibration range and sensors stopped responding accurately (Hilhorst, 2000). The maximum soil moisture observed at each depth was different: generally highest at 30 cm depth and lowest at 60 cm depth with 15 cm soil moisture in between. If we assume that the saturation was reached at each depth during the flood irrigation, then the maximum soil moisture content approximately is equivalent to the porosity of the soil at that depth. Soils at all four sites behave similarly to the onset of irrigation. Bulk soil EC shows similar trends as the changes in moisture with the irrigation cycles. Consistent with lower moisture values, bulk EC values are also significantly lower at 60 cm than other depths and also decrease with time after irrigation. Soil temperature decrease with

the onset of irrigation and after the initial decrease, soil temperature begins to increase as soils lose moisture (Figure 21C). Overall, soil temperature ranges from 17 to 29 °C. Moving into summer, the temperature fluctuation during and between irrigations were small.

The bulk soil EC from the sensor can be converted to fluid EC through the following equation (Hilhorst, 2000):

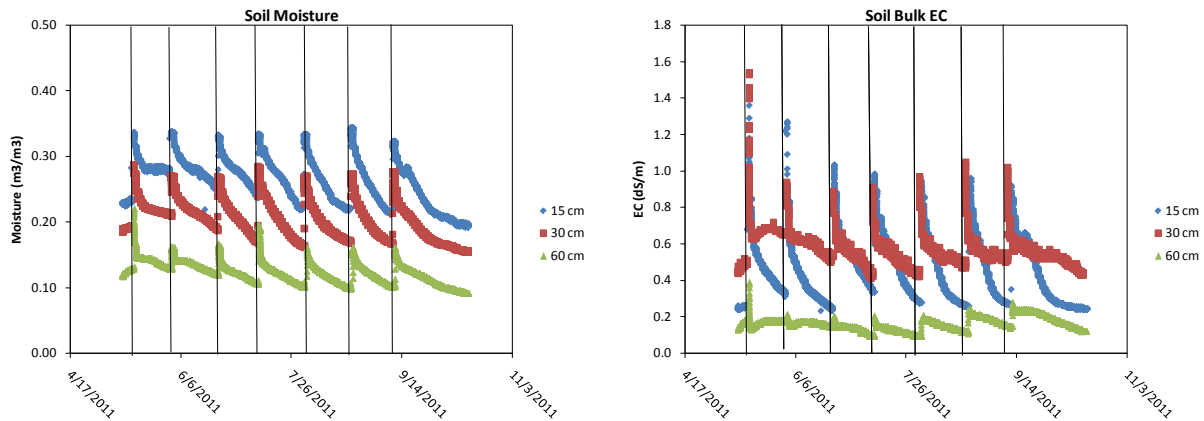
ϵ'_p is the dielectric permittivity of substrate pore water (unitless),

σ_b is the bulk electrical conductivity (dS m^{-1}),

ϵ'_b is the real portion of the bulk dielectric permittivity (unitless), and

$$\sigma_p = \frac{\epsilon'_p * \sigma_b}{\epsilon'_b - \epsilon'_{\sigma_b=0}} \quad \epsilon'_{\sigma_b=0} \text{ is an offset value for } \epsilon'_b.$$

Since this is an empirical equation and some physical properties were not measured for our soils, we used EC data from the soil waters to calibrate. This exercise reveals that fluid EC decreases after the onset of irrigation at all depths (Figure 21D). After that, the EC increases with time until the next irrigation event, probably due to the loss of water by evapotranspiration and plant uptake, which concentrates the fluid concentrations. Furthermore, fluid EC increases with depth from 15 to 30 and 60 cm, in agreement with the concentration and EC trends observed in soil waters.



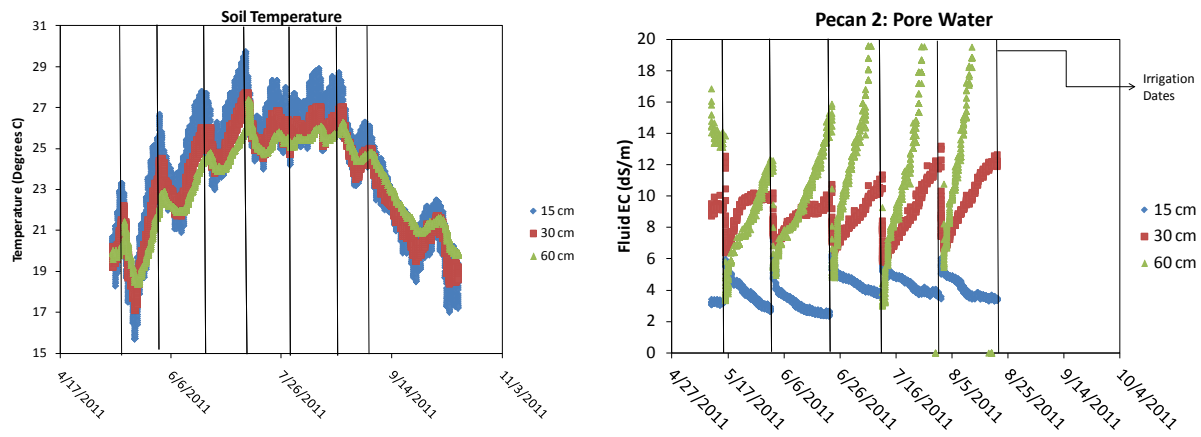


Figure 21: Representative sensor data from Pecan 2, showing soil moisture (A), soil bulk EC (B), soil temperature (C), and pore water calculations of fluid EC (D) with time in irrigation season of 2011. The vertical bold lines in these graphs indicate onset of each flood irrigation. On average, each irrigation had about 2 days of standing water.

DISCUSSION

Soil texture controls on soil chemistry

As shown in Table 2 according to WebSoil Survey, different textures occur at different depths within the soil profile and overall, soils in the southwestern TX are fine-grained. Alfalfa and Pecan 2 both have textural changes from a silty clay loam to a silty loam at 12 cm to 60 cm. Pecan 1 has two textural changes, one at 10 to 50 from a silty clay to a clay, then the other at 50 to 60 cm to become a silt loam. The most significant change in texture is observed in Cotton soils, where it changed from a silty clay loam to loamy fine sand at 32 to 60 cm. During sample collection texture changes were visually observed in Pecan 2 and Alfalfa at 50 cm from more clay rich to a more sandy texture.

As summarized below, soil texture places important controls over physical and chemical properties of soils. Both soil CEC and exchangeable cation concentrations vary with soil textures. For example, the higher percentages of clay in soils correlate with elevated exchange capacity of cations at shallow soils, but CEC is lowered when soils change to sandy texture at depths of 40 cm in Alfalfa and 50 cm in Pecan 2 (Figure 4). Similarly, the dependency of exchangeable cation concentrations on soil texture is observed in soils. Alfalfa and Pecan 2's exchangeable concentrations are lower than those at Cotton and Pecan 1 sites (Figures 5 A-D). Both Alfalfa and Pecan 2 are comprised of the same soil texture and composition, resulting in soil exchangeable cations and CEC to behave similarly. Pecan 1 is higher in EC and exchangeable concentrations in areas that have a larger clay percentage.

Saturation percentage (SP) also depends on soil texture with higher SP values observed in more clayey soils (Table 4 Figure 8). Soil EC also increases with clay content (Figure 7B).

Evaluation of soil alkalinity, sodicity and salinity

Our soil analyses provided a basis for understanding the soil's current health conditions before the 2011 irrigation season. Soil properties such as alkalinity, salinity and sodicity greatly impact water infiltration and availability of water and nutrients to crops (Miyamoto and Storey, 1995). Soil pH ranges from 7.2 to 8.2, indicative of alkaline soils (Figure 7A). Studies have shown that some macronutrients may not be easily available to crops at high pH (Doran et al, 1996; Larson and Pierce, 1994; and Seybold et al, 1997). Calcite concentrations in soil initially show higher concentrations in topsoil with decreasing concentrations with depth (Figure 12A). Calcite saturation indices of irrigation waters vary significantly, suggesting that chemistry of these waters is quite variable, ranging from unsaturated to

highly supersaturated with respect to calcite (Figure 19C). In contrast, all the soil waters and drainage waters are oversaturated for calcite, probably suggesting precipitation of calcite at all depths. This is in agreement with the high TIC contents (carbonate minerals) observed in these soils. The transition of unsaturation in irrigation water to oversaturation of calcite in soil water is probably due to the leaching of gypsum and thus the higher Ca concentrations.

Soil EC from the saturation paste extraction shows that soils are relatively high in salinity, especially those soils with clayey texture (Figure 7B). Furthermore, soils of high salinity are also coupled with high sodicity (soils with SAR of greater than 13 are considered sodic as shown in Figure 9). Increasing Na concentrations in soils, increases sodicity by replacing Ca and Mg with Na, this makes these divalent cations unavailable to plants. With the replacement of Ca with Na, the pH of soils increases which affects the availability of micronutrients. The higher sodicity also yields a dispersion of clay and the breakdown of the soil structure, decreasing permeability and water drainage. Along with salinity and sodicity these areas have a high clay percentage. As previously mentioned, crop types have different salinity and sodicity tolerances: Alfalfa, pecan and cotton are affected by soil salinities with EC's greater than 2.0, 2.6, and 7.7 dS/m, respectively (Maas and Grattan, 1999; Picchioni et al., 2000). The soils with SAR values greater than 13 are considered sodic and thus associated with poor air aeration and water infiltration. Soil salinity exceeds the tolerance levels of crops at three out of four studied sites (Figures 7B). Similarly, soils are sodic in three out of four sites (Figure 9). Alfalfa is considered the healthiest field among the four sites.

Irrigation also greatly increases soil salinity and sodicity. Our rough estimates show that every year about one ton of Na, Cl and SO₄ each are added to the soils just from irrigation loading (Table 3). Addition of Na at one ton per year rate can greatly elevate the soil sodicity over time. As previously mentioned Miyamoto (2010) suggested average salt accumulation of 20 to 50 tons/acre over a 10-year period if there is no drainage. Irrigation loads from the 2011 irrigation season indicate an average salt loading of 1 ton/acre. As discussed below, most of the salts loaded during irrigation are retained in the shallow soils.

The organic nutrient levels

Majority of carbon in soils is present as organic carbon. Top soils at Pecan 1 and Pecan 2 have the highest concentrations, possibly due to fall and degradation of pecan leaves. Once below the surface, organic carbon content at Pecan 1 and 2 lowers significantly. DOC levels of soil water are higher than irrigation waters, as soil organic material was continuously being leached (Figure 20A).

Dissolved K concentrations in irrigation and soil waters are high, so they are not the limiting nutrients. Concentrations of P in irrigation waters vary significantly, probably because of application of P-rich fertilizers. Soil waters however have much lower P levels than the irrigation waters, suggesting uptake of P by crops (Figure 17D). Thus we suggest P may be the limiting nutrient in the soils.

The downslope transport of salt during irrigation

Concentrations of all major ions increase with depth: the highest levels are observed at 60 cm of depth (deepest soil water sampled). This depth trend indicates the salts in the soils are dissolving in the irrigation water. It is unknown, however, where this salt will be eventually deposited at deeper soils or will be recharged to shallow groundwater systems. High levels of Na, Cl, Ca, and SO_4 measured in deeper soil waters, the good correlations between Na and Cl, and between Ca and SO_4 , and changes in saturation indices (Figures 15A and B; Figures 16A and C; Figures 18A,B; 19A and B) indicate dissolution of halite and gypsum phases from shallow soils.

All major salts such as gypsum, halite, thenardite and nacholite (Figures 19 A, B, F, and G) are undersaturated in irrigation waters, drainage waters and soil waters, although SI increases with depth towards 0. Exchangeable Na concentrations extracted from soils (Figure 5D) also show increasing concentrations with depth, indicating higher salt content at depth. This increase in concentrations within the soil coupled with high salinity irrigation can cause movement and leaching of Na to deeper depths (Figure 15 A). The conversion from bulk soil EC to fluid EC also supports the leaching of salts as water moves to deeper soils, as fluid EC continues to increase with depth (Figure 21D).

The salt loading between irrigation events

At the onset of irrigation, water is flowing through the soil dissolving salts and transporting them with flow either to the drainage canals or deeper into the soils. Once the standing water on the soil has infiltrated, water flow stops and evapotranspiration dominates causing decreases in water and increases ion concentration. Consistent with this, fluid EC calculated from sensor data (Figure 21 D) shows the concentration of ions in soils between irrigations increase with time. This observation suggests that between irrigations, salts are loaded on the soils,

Negative feedback between irrigation and salt loading

The addition of fertilizers and application of irrigation increase the soil salinity over time. Analysis of soils coupled with water analysis indicates ion dissolution from the top 30 cm of the soils and accumulation at deeper depths within the soils. Of soils analyzed, 60 cm has the highest concentrations of ions indicating migration of salts. Irrigation waters are low in concentrations in comparison to soil waters. Multiple irrigations per season year after year have led to accumulation of salts and ions in soils. Ion loading from irrigation waters increase ion loads at the surface, while the continual use of flood irrigation leaches the ion concentrations from the surface to greater depths within the soil profile as seen in Figures 15 A-E and 16 A-C. High amounts of Na in soils due to irrigation with saline waters and high amounts of evaporation cause a decrease in soil permeability as seen with an SAR greater than 13. When soils are coupled with poor permeability and high salinity, crop yields will be lower due to water flow and decreased nutrient availability.

As farmers cultivate the land and add fertilizers to increase soil performance, drainage waters inadvertently being increased in salinity, especially sulfate concentrations (Szynkiewicz et al., 2011). These drainage waters are then being reintroduced into the Rio Grande where farmers then use it for irrigation. Increases in salinity in irrigation waters have negative impacts on soil health, vegetation health and productivity. Yearly irrigation cycles add an average of one ton Na/acre/year to the fields (Table 3) due to degradation of water quality (Szynkiewicz et al., 2011). Additionally, anthropogenic inputs of gypsum by farmers to help remediate problems caused by sodicity in soils can also causes increases in concentrations due to leaching from irrigation waters.

Recommendations

Soil moisture data indicates only small amounts of water infiltration reaches 60 cm of depth as compared to 15 and 30 cm (Figure 21A). This information combined with drainage water concentrations of major ions (Figures 15 A-E and 16 A-C) supports the hypothesis that the majority of the irrigation water does not infiltrate beyond 60 cm at each soil profile, but instead it takes a shallow flowpath and quickly recharges to the drainage canals. Drainage water concentrations tend to be in the range of irrigation waters and the top 30 cm of soil waters. Increasing infiltration by surpassing impermeable layers with usage of below surface drip systems would increase water availability and decrease amount of water lost by evaporation.

Ion concentrations, nutrient loads, salinity, and sodicity values indicate poor soil health at almost all depths in all locations, especially deeper soils. If current practices are maintained without remedial

help to maintain adequate soil health, soil conditions will continue to diminish. SAR values will increase making water infiltration near impossible and salinity values will increase in soils rendering them uninhabitable for plants with low salt tolerance such as alfalfa and pecan. Remedial actions such as addition of gypsum to soils to increase Ca concentrations, and cultivation work to soils such as tilling, and chiseling will help prolong soil life. Usage of flood irrigation does leach salts and other ions away from the surface and out of the soil profile however, it also increases salinity between irrigation by evapotranspiration and decreases soil permeability by increasing weathering and formation of secondary minerals such as clays. To minimize evaporation the implementation of below ground drip systems would increase water availability to plants while helping to decrease the addition of salts to soils.

Future Work

The upcoming 2012 irrigation season will pose problems on many levels. Firstly due to extremely low storage levels in Elephant Butte Lake reservoir, irrigation allotments have been decreased from 4 ft to 18 inch of water for the entire season. Because of this, many farmers in the El Paso County have been drilling and reopening existing wells. Ground water in this region is much higher in total dissolved solids (TDS) than the Rio Grande river water. Irrigation with ground water with higher salinity water will impact the soils more seriously than river water. Now more than ever, water availability in soils to vegetation, water flow paths through the soil profile, soil quality and water quality need to be assessed.

This research suggests that the majority of water loaded to the soils during each flood irrigation does not penetrate to 60 cm of depth before flowing to the drainage canal. To quantify water flow paths, multiple test wells at multiple depths should be installed around the field towards the canal. In addition, tracers could be applied to the irrigation waters in the field to track water flow through the soil profile. Determination of root depth with crop type should be obtained to measure water availability at those depths. Furthermore, isotope analysis of hydrogen and oxygen from soil waters, irrigation and drainage waters will give a better understanding of water residence time and flowpaths within the soil.

2011 irrigation and soil collection data indicate maximum depths observed (60 cm) yielded the highest concentrations of ions. Chemistry of soils and soil waters below 60 cm should be determined to fully understand ion leaching and migration beyond the root zones and to investigate the quality of water that recharges to the shallow ground waters. Analysis of soils should reveal a different composition and possibly texture in the layer of maximum accumulation. This new analysis will also allow the

comparison with data collected in 2011, to evaluate the changes in soil properties from agricultural practices after the growth season (e.g., chiseling, application of gypsum, leaching of salts using flood irrigation).

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APPENDIX

APPENDIX A

SATURATION PASTE PROCEDURES

- Label Plastic cups with sample ID
- Zero scale,
- Weigh clean dry empty plastic cup, record results in “cup wt.” column
- Fill cup to designated mark (about 4 or 5 lines up from bottom on current cups) with DI Water.
- Place about 3 spoons of dry, ground sample in the cup. Mix and add more sample until a saturated paste is achieved, should be glistening, smooth, but not free flowing. (Slightly more liquid than pudding)
- Allow to set overnight.
- Next day check consistency add more water if needed and let set for several hours.
- Take small aluminum cup, record its id or give it one. Record the id in “box No”
- Zero the scale, (Ensure you do not use a number more than once)
- Record the aluminum cup weight in “box wt”
- Take a scoop of paste place in Al cup, Weigh and record weight
- Take Al cup with saturated soil and place in 105C oven for 8 hours,
 - The next day: Remove from oven; Zero Scale, Record dry weight.
- Prepare Vacuum Manifold.
- In Filter Flask place flat bottomed test tube. Place stopper with tubing inside the test tube. Attach vacuum line.
- Place filter in bottom of filter cup,
- Record the # of the spatula, record clean spatula weight
- Weigh plastic cup with the remaining saturation paste record under “cup+sat soil”
- Transfer saturated paste from plastic cup to the suction cups with spatula
- Weigh plastic cup, residue, spatula, and record in “cup + residues”
- Turn on vacuum pump
- Vacuum for 2 hours then monitor often until soil surface starts to crack.
- If allowed to run too long the water will evaporate and you will lose the sample.
- When one sample is done turn off the vacuum to that sample so the others may continue
- Transfer the saturated paste extract to a centrifuge tube and label with study name, sat paste and sample id.
- Measure and record the EC and pH of each sample.
- Prepare samples for use in ICP and IC. Place 1 ml in test tube and add 9 ml of di water.

- Prepare second set of test tubes and place 10 ml in it. Label the dilution factor on each test tube.
- Refrigerate the centrifuge tubes and the ICP test tubes.
- The goal is to extract about 25 ml from each cup. It needs to be consistent so it is actually possible to compare the results. If you get a lot of extract the sample was too wet, and the results are diluted.
- When measuring the EC and pH, the depth of the probe affects the results, it is best to half fill a glass test tube and then insert the probe, that way the results are consistent.

Appendix B

EXCHANGEABLE CATIONS

Reagents:

1 M NH₄OAC Ammonium Acetate, 154.16 g in 2 L DI water. Adjust to pH of 7 using 0.1 M NaOH or 1:1 Acetic Acid

Procedure:

1. Weigh 5 g of soil into 50 ml centrifuge tubes.
2. Add 33 ml of Ammonium acetate to each tube. Cap tubes tightly
3. Using vortex mixer, mix each centrifuge tube.
4. Centrifuge for 10 minutes at 4000 rpm. Ensure that the load is balanced; you may need to fill some blank tubes with water.
5. **Filter the supernatant with a Whatman 42 filter or equivalent, collecting it into a 100 ml volumetric flask.**
6. Repeat steps 2 to 5 twice more. You will have added a total of 99 ml Ammonium Acetate to each centrifuge tube.
7. Make up the volume in the volumetric flasks to 100 ml (the line on the neck of the flask) with 1M Ammonium Acetate.
8. Save 50 ml into a properly labeled centrifuge tube. IF time prepare samples right away with the remaining volume then dispose of it with the other supernatants.

Appendix C

CATION EXCHANGE CAPACITY

Reagents:

1 M NaOAc Sodium Acetate, 164 g in 2 L DI water. Adjust to pH of 8.2 using acetic acid or NaOH.

Ethanol

1 M NH₄OAc Ammonium Acetate, 154.16 g in 2 L DI water. Adjust to pH of 7 using 0.1 M NaOH or 1:1 Acetic Acid.

Procedure:

1. Weigh 5 g of soil into 50 ml centrifuge tubes.
2. Add 33 ml of Sodium Acetate Solution to each tube using dispenser. Cap tubes tightly.
3. Using vortex mixer, mix each centrifuge tube.
4. Shake on end to end shaker for 10 minutes on low speed.
5. Centrifuge for 10 minutes at 4000 rpm. Ensure that the load is balanced; you may need to fill some blank tubes with water.
6. Discard the supernatant (pour off the liquid)
7. **Repeat** steps 2 to 6 twice more. You will have added a total of 99 ml 1 M Sodium Acetate to each centrifuge tube.
8. Add 33 ml of Ethanol to each tube. Cap tubes tightly
9. Using vortex mixer, mix each centrifuge tube.
10. Shake on end to end shaker for 10 minutes on low speed.
11. Centrifuge for 10 minutes at 4000 rpm. Ensure that the load is balanced; you may need to fill some blank tubes with water.
12. Discard the supernatant (pour off the liquid)
13. **Repeat** steps 8 to 12 twice more. You will have added a total of 99 ml Ethanol to each centrifuge tube.
14. Add 33 ml of Ammonium acetate to each tube. Cap tubes tightly
15. Using vortex mixer, mix each centrifuge tube.
16. Centrifuge for 10 minutes at 4000 rpm. Ensure that the load is balanced; you may need to fill some blank tubes with water.
17. **This step is now different then before**

18. **Filter the supernatant with a Whatman 42 filter or equivalent, collecting it into a 100 ml volumetric flask.**
19. **Repeat** steps 14 to 18 twice more. You will have added a total of 99 ml Ammonium Acetate to each centrifuge tube.
20. Make up the volume in the volumetric flasks to 100 ml (the line on the neck of the flask) with 1M Ammonium Acetate.
21. Save 50 ml into a properly labeled centrifuge tube. IF time prepare samples right away with the remaining volume then dispose of it with the other supernatants.

Appendix D

CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS

TO PREPARE STANDARDS, STOCK AND SAMPLES

Sample Prep:

20x Dilution: Take 500 uL (.5 mL) of sample + 500 uL (.5 mL) of 1M Ammonium Acetate + 9mL of DI water into a 10 ml test tube.

10 x dilutions: Take 1 mL of sample + 9 mL of DI water into a 10 ml test tube.

Stock solution and STDs:

Stock (1000 ppm): Combine 25 mL of each 1000 ppm standard solution (Ca, Na, Mg, K) in a 250 ml volumetric flask and bring to volume with 1M Ammonium Acetate.

Ca 25 mL

Na 25 mL

Mg 25 mL

K 25 mL

Std: 100 ml volumetric Flasks	Stock (1000 ppm)	1N Ammonium Acetate
1	10 ml	90 ml
2	25 ml	75 ml
3	50 ml	50 ml
ICV	35 ml	65 ml
CCV	25 ml	75 ml
Blank/ICBV	0 ml	100ml

It is advised that any remaining stock solution be used to prepare extra CCV as you use that faster then you do any other standards.

Cation Exchange Capacity (CEC) is generally done at a 20x dilution.

Exchangeable Cations (EC) are generally done at a 10x dilution.

Make note of any and all dilutions that are performed.

Table 4: Soil Characterization

Soil Characterization																				
Study Site	Depth	CEC	Exchange Ca	Exchange K	Exchange Mg	Exchange Na	ESP	Soil pH	Soil EC	%H2O at Saturation	SAR	Water Soluble Na	Water Soluble Ca	Water Soluble K	Water Soluble Mg	ESP from SAR	CaCO3	CaCO3	TC	TOC
	cm	(meq/100g)	(meq/100g)	(meq/100g)	(meq/100g)	(meq/100g)	%	ds/m	%		%	(meq/100g)	(meq/100g)	(meq/100g)	(meq/100g)		Wt %	Wt %	Wt %	Wt %
Alfalfa	0	12.37	35.90	1.50	4.58	2.12	17.1	8.21	2.59	58	5	0.793	0.546	0.076	0.267	6.0	1.12	1.06	0.06	0.23
Alfalfa	10	11.84	35.77	1.38	4.44	1.77	14.9	8.15	0.97	92	5	0.504	0.177	0.056	0.057	5.6	1.07	0.05	0.05	0.05
Alfalfa	20	11.77	35.79	1.32	4.47	1.75	14.9	8.23	1.76	54	5	0.469	0.285	0.040	0.109	5.2	1.09	0.03	0.09	0.09
Alfalfa	30	12.21	36.38	1.29	4.69	1.76	14.4	8.13	1.15	75	5	0.492	0.174	0.044	0.073	5.9	1.08	0.04	0.06	0.06
Alfalfa	40	11.11	35.79	1.14	5.32	2.73	24.6	8.05	2.51	88	9	1.466	0.384	0.052	0.245	10.5	1.07	0.04	0.21	0.21
Alfalfa	50	3.00	31.11	1.00	4.16	1.91	63.5	8.05	1.57	54	8	0.543	0.117	0.027	0.071	9.1	1.16	0.02	0.06	0.06
Alfalfa	60	4.76	24.93	0.87	2.67	1.77	37.3	8.07	1.42	51	10	0.531	0.087	0.022	0.026	11.7	1.05	0.02	0.02	0.02
Cotton	0	17.69	40.55	1.72	5.52	3.24	18.3	8.05	2.76	69	10	1.241	0.370	0.067	0.126	11.3	9.4	1.69	0.06	0.11
Cotton	10	18.80	41.15	1.83	5.72	2.30	12.2	8.05	1.87	75	6	0.832	0.368	0.071	0.121	7.2	6.0	1.24	0.06	0.10
Cotton	20	17.19	39.89	1.72	5.77	3.11	18.1	8.22	3.13	75	9	1.570	0.631	0.081	0.210	10.5	8.8	1.30	0.07	0.18
Cotton	30	20.52	43.98	1.76	6.70	4.49	21.9	7.98	7.43	77	11	4.105	2.403	0.145	0.984	13.4	11.2	0.33	0.12	0.83
Cotton	40	30.71	58.93	2.10	10.28	8.42	27.4	7.92	8.03	105	14	6.752	2.875	0.164	1.333	16.6	13.8	1.41	0.14	1.13
Cotton	50	29.90	62.82	2.15	10.91	9.83	32.9	7.19	8.79	101	17	7.632	2.637	0.164	1.351	19.2	16.0	1.86	0.14	1.15
Pecan 1	0	21.66	38.77	2.06	6.22	2.42	11.2	8.08	3.06	74	5	1.118	0.830	0.124	0.315	6.3	1.11	1.11	0.10	0.27
Pecan 1	10	21.81	40.54	2.09	7.33	1.90	8.7	8.25	1.96	75	4	0.693	0.470	0.098	0.201	4.9	1.03	1.03	0.08	0.17
Pecan 1	20	22.96	41.09	2.17	7.98	2.28	9.9	8.17	2.10	76	5	0.769	0.456	0.098	0.207	5.6	1.28	1.28	0.08	0.18
Pecan 1	30	21.71	40.42	1.99	6.85	3.22	14.8	8.18	2.95	76	8	1.400	0.514	0.094	0.214	10.0	1.54	1.54	0.08	0.18
Pecan 1	40	24.49	40.86	1.94	6.91	3.88	15.8	8.07	4.59	86	9	2.574	1.380	0.134	0.545	10.6	1.10	1.10	0.11	0.46
Pecan 1	50	21.25	44.12	1.84	7.10	4.88	23.0	7.94	6.27	84	10	3.452	2.205	0.139	0.808	11.5	1.21	1.21	0.12	0.69
Pecan 1	60	18.63	40.60	1.69	6.50	4.76	25.5	7.99	7.36	72	11	3.138	1.599	0.111	0.634	13.1	1.37	1.37	0.09	0.54
Pecan 1	70	27.04	55.75	1.87	8.79	7.13	26.4	7.88	7.79	96	13	5.643	2.637	0.142	1.078	15.6	1.26	1.26	0.12	0.91
Pecan 2	0	3.26	34.48	1.68	4.75	1.82	55.7	8.18	3.14	56	5	0.827	0.699	0.110	0.305	5.6	0.84	0.84	0.09	0.26
Pecan 2	10	11.51	34.04	1.36	3.61	1.38	12.0	8.12	1.47	62	4	0.392	0.295	0.054	0.094	3.9	0.83	0.83	0.05	0.08
Pecan 2	20	10.72	34.43	1.32	3.79	1.50	14.0	8.15	1.91	70	9	0.858	0.212	0.052	0.076	10.2	0.54	0.54	0.04	0.06
Pecan 2	30	10.77	34.11	1.32	3.98	2.41	22.3	8.18	1.89	48	5	0.489	0.248	0.047	0.086	6.3	1.63	1.63	0.04	0.07
Pecan 2	40	6.56	32.39	1.15	3.19	2.32	35.3	7.96	3.07	77	12	1.693	0.339	0.070	0.151	14.5	0.53	0.53	0.06	0.13
Pecan 2	50	13.13	39.63	1.54	5.84	4.51	34.4	7.78	8.16	60	12	3.485	1.861	0.112	0.788	14.5	0.87	0.87	0.10	0.67
Pecan 2	60	11.90	34.97	1.26	4.21	2.90	24.4	7.90	7.26	48	13	2.426	1.062	0.082	0.458	14.9	0.41	0.41	0.07	0.39

Table 5: Water Characterization

Water Characterization																							
DATE	LOCATION	DEPTH	COLLECTION	pH	EC	Br	F	PO4	Al	Fe	Mn	P	Pb	Sr	Cl	NO3	SO4	Ca	K	Mg	Na	Si	HCO3
		cm	#		(ds/m)	(uM)	(uM)	(uM)	(uM)	(uM)	(uM)	(uM)	(uM)	(uM)	(mM)	(mM)	(mM)	(mM)	(mM)	(mM)	(mM)	(mM)	(meq/kg)
6/12/2011	ALFALFA	0	14	7.80	1.13	0.00	23.02	0.00	0.00	0.00	0.22	1.50	0.00	10.60	3.54	0.02	2.38	1.40	0.26	0.75	6.24	0.07	3.212
6/26/2011	ALFALFA	0	20	8.68	0.77	0.00	32.59	0.00	0.00	0.00	0.01	1.45	0.00	9.10	2.26	0.01	1.51	1.34	0.25	0.55	4.02	0.17	3.355
7/1/2011	ALFALFA	30	23	7.07	1.58	4.82	55.54	0.00	0.00	0.00	0.03	0.46	0.00	20.90	3.99	0.03	2.53	2.71	0.56	1.34	9.06	1.05	
7/18/2011	ALFALFA	0	28	8.04		1.24	57.02	0.00	0.00	0.00	1.79	0.00	0.00	16.09	1.96	0.02	1.38	2.57	0.20	0.85	7.46	0.30	
7/25/2011	ALFALFA	15	34	7.58		3.84	84.53	8.68	0.00	0.00	0.00	0.00	0.00	23.24	6.17	0.13	3.73	3.75	0.49	1.44	9.45	0.79	6.602
7/25/2011	ALFALFA	30	35	7.24		6.07	50.04	5.20	0.00	15.62	0.28	0.00	0.00	27.95	6.14	0.20	3.85	4.23	0.52	1.87	10.34	1.11	
7/27/2011	ALFALFA	0	36	6.30	1.02	3.62	20.97	0.00	0.00	0.00	0.00	0.00	0.00	11.47	5.33	0.03	3.02	1.43	0.20	0.85	7.70	0.31	2.464
8/2/2011	ALFALFA	15	38	7.34	1.97	3.33	62.92	0.00	0.00	0.00	0.00	0.00	2.17	24.43	7.45	0.41	4.18	3.88	0.48	1.49	10.72	0.75	6.042
8/2/2011	ALFALFA	30	39	7.22	1.88	4.64	54.06	7.62	0.00	0.00	0.00	0.00	0.00	23.68	5.83	0.52	3.40	3.69	0.46	1.50	9.07	0.88	6.726
8/25/2011	ALFALFA	0	43	7.11	1.16	9.97	38.98	0.00	0.00	0.00	0.00	0.00	0.00	18.15	6.08	0.05	3.07	2.61	0.22	0.94	8.38	0.39	4.278
9/13/2011	ALFALFA	0	51	7.99	0.94	3.87	60.57	0.00	0.00	0.00	0.00	0.00	0.00	9.17	2.98	0.06	1.84	1.58	0.18	0.56	4.67	0.22	3.375
9/19/2011	ALFALFA	30	52	7.32	1.60	7.49	54.07	3.18	0.00	0.00	0.00	0.00	0.00	20.05	4.50	0.78	2.60	3.17	0.39	1.31	8.11	0.91	7.257
6/17/2011	COTTON	30	15	7.55	5.34	10.81	75.65	0.00	0.00	0.00	0.06	3.82	0.00	60.26	25.65	0.71	17.90	8.85	1.55	3.56	38.56	1.25	4.579
6/17/2011	COTTON	60	16	7.44	12.84	43.07	66.88	1.83	0.00	0.00	0.36	5.40	0.00	142.63	60.61	0.87	44.95	14.95	2.58	10.39	119.57	0.84	
7/25/2011	COTTON	0	33	9.03		4.09	43.84	12.44	0.00	0.00	0.00	0.00	0.00	13.37	4.81	0.14	2.57	2.13	0.26	0.74	7.35	0.20	3.756
8/2/2011	COTTON	30	40	7.31	3.51	14.07	111.60	0.00	0.00	0.00	0.00	0.00	0.00	36.82	15.64	0.33	10.35	5.17	0.82	1.92	26.83	0.59	4.264
8/2/2011	COTTON	60	41	7.28	7.26	23.76	128.30	0.00	0.00	0.00	6.71	0.00	0.00	88.15	34.00	0.06	26.62	8.86	1.81	7.14	97.60	0.68	
8/26/2011	COTTON	0	44	7.34	1.08	5.08	54.77	16.12	0.00	0.00	0.00	0.00	0.00	14.85	5.41	0.17	2.84	2.28	0.24	0.76	7.78	0.31	4.245
8/29/2011	COTTON	100	47	7.59	3.78	10.82	67.34	1.79	0.00	0.00	0.00	0.00	2.07	46.21	21.95	0.13	6.31	5.60	0.31	1.58	24.65	0.46	5.912
5/18/2011	PECAN 1	0	1	8.79	1.35	11.38	39.33	13.44	0.00	0.00	0.78	12.95	0.00	37.32	17.68	0.14	5.93	5.26	0.41	1.62	21.68	0.45	5.624
5/18/2011	PECAN 1	30	2	7.49		6.13	32.99	13.46	0.00	0.00	0.00	22.90	0.00	51.14	13.98	2.68	2.10	8.50	2.59	4.02	27.46	0.96	
6/10/2011	PECAN 1	0	10	8.21	1.38	0.00	38.57	0.00	0.00	0.00	0.19	17.29	0.00	13.12	4.66	0.11	2.52	2.11	0.34	0.77	7.15	0.23	3.994
6/17/2011	PECAN 1	30	17	8.14	4.08	10.95	46.85	0.00	2.52	2.52	0.15	25.71	0.00	48.73	13.66	2.86	11.59	6.83	2.48	3.27	24.44	0.64	
6/17/2011	PECAN 1	60	18	7.57	6.04	12.41	37.84	0.00	0.00	0.00	0.02	50.30	0.00	62.77	23.73	4.28	16.58	8.68	2.39	4.48	42.91	0.83	
6/28/2011	PECAN 1	0	21	8.75	1.04	2.72	36.92	6.98	0.00	0.00	0.01	12.37	0.00	11.53	3.69	0.10	2.01	1.67	0.29	0.62	5.72	0.21	3.595
7/11/2011	PECAN 1	30	25	7.31	3.64	7.08	43.15	0.00	0.00	0.00	0.05	28.24	0.00	43.45	11.91	3.83	9.70	6.13	2.38	2.84	20.53	0.58	6.400
7/15/2011	PECAN 1	0	26	8.01		3.94	64.99	17.41	0.00	0.00	0.00	0.00	0.00	12.03	4.15	0.19	2.33	2.03	0.23	0.67	6.21	0.23	3.639
8/26/2011	PECAN 1	0	44	7.34	1.08	5.08	54.77	16.12	0.00	0.00	0.00	0.00	0.00	14.85	5.41	0.17	2.84	2.28	0.24	0.76	7.78	0.31	4.245
8/29/2011	PECAN 1	15	45	7.66	3.21	12.42	64.55	14.23	0.00	0.00	0.00	0.00	0.00	37.74	11.06	1.57	9.21	6.38	1.57	2.48	17.98	0.72	6.214
8/29/2011	PECAN 1	30	46	7.25	3.43	10.95	32.45	11.10	0.00	0.00	0.00	0.00	0.00	38.39	12.09	0.94	10.56	6.71	1.70	2.77	18.35	0.79	5.040
8/29/2011	PECAN 1	100	47	7.59	3.78	10.82	67.34	1.79	0.00	0.00	0.00	0.00	2.07	46.21	21.95	0.13	6.31	5.60	0.31	1.58	24.65	0.46	5.912
9/10/2011	PECAN 1	0	49	7.45	1.23	11.93	63.09	3.29	0.00	0.00	0.00	0.00	0.00	15.90	6.00	0.21	3.16	2.52	0.24	0.88	8.72	0.32	4.154
10/7/2011	PECAN 1	0	54	8.25	2.62	11.27	51.90	26.27	0.00	0.00	0.00	0.00	0.00	27.20	12.84	0.33	5.20	3.41	0.38	1.21	17.38	0.44	
10/14/2011	PECAN 1	15	55	7.60	2.80	11.95	39.46	13.31	0.00	0.00	0.00	0.00	0.00	44.60	17.90	4.88	9.93	7.46	1.61	3.05	21.05	0.86	
10/14/2011	PECAN 1	30	56	7.46	4.01	8.97	44.90	27.05	0.00	0.00	0.00	0.00	0.00	48.04	18.09	4.11	10.32	7.54	1.84	3.33	21.83	0.49	
10/14/2011	PECAN 1	100	57	7.95	4.57	16.29	60.97	0.00	0.00	0.00	0.00	0.00	0.00	58.88	27.68	0.15	7.87	6.91	0.33	1.97	32.27	0.53	
5/18/2011	PECAN 2	0	3	7.98	3.39	2.43	35.01	0.00	0.00	0.00	0.98	14.85	0.00	14.36	5.21	0.15	2.54	2.12	0.31	0.77	7.84	0.27	4.120
6/2/2011	PECAN 2	0	4	8.03	1.55	4.61	36.95	28.02	0.00	0.00	1.08	32.67	0.00	15.08	5.78	0.32	2.70	2.19	0.36	0.81	8.41	0.27	3.868
6/2/2011	PECAN 2	100	5	7.98	1.85	5.96	34.12	0.00	0.00	0.00	1.43	1.00	0.00	22.22	8.09	0.02	3.72	2.99	0.32	1.11	10.69	0.26	4.545
6/2/2011	PECAN 2	30	6	7.43	2.24	1.85	68.78	0.00	0.00	0.00	0.03	17.92	0.00	24.98	9.59	2.75	4.60	4.11	1.03	1.71	13.57	1.68	
6/2/2011	PECAN 2	60	7	7.38	8.71	24.37	89.46	0.00	0.00	0.00	0.04	5.55	0.00	111.76	48.37	12.62	18.92	13.43	1.74	6.89	63.19	1.59	7.181
6/2/2011	PECAN 2	15	8	7.83	2.12	6.57	57.47	0.00	0.00	0.00	0.30	20.03	0.00	21.05	7.62	0.73	3.73	3.58	1.07	1.33	9.88	0.88	7.650
6/2/2011	PECAN 2	30	9	7.69	2.34	0.00	65.89	6.12	0.00	0.00	0.04	8.39	0.00	22.66	8.31	1.16	4.02	3.77	1.28	1.61	11.61	1.05	5.542
6/10/2011	PECAN 2	15	11	7.66	1.99	5.89	55.80	10.92	0.00	0.00	0.05	19.09	0.00	21.46	7.45	0.10	3.77	3.85	1.16	1.41	10.58	1.06	6.423
6/10/2011	PECAN 2	30	12	7.42	2.18	4.89	69.20	0.00	0.00	0.00	0.02	6.87	0.00	22.10	7.80	0.93	3.87	3.46	1.13	1.47	11.13	1.14	6.300
6/10/2011	PECAN 2	60	13	7.51	7.02	17.70	99.99	0.00	0.00	0.00	0.03	4.43	0.00	89.99	34.91	8.31	15.26	10.47	1.52	5.56	52.45	1.59	8.836
6/23/2011	PECAN 2	0	19	8.45	1.11	12.60	32.00	0.00	0.00	0.00	0.01	12.02	0.00	12.70	3.92	0.11	2.12	1.87	0.29	0.68	5.96	0.23	3.818
6/28/2011	PECAN 2	60	22	7.40	8.58	25.37	93.75	0.00	0.00	0.00	0.02	3.97	0.00	128.08	49.75	12.41	20.26	14.81	1.91	7.47	61.58	1.54	7.251
7/11/2011	PECAN 2	0	24	8.02	1.43	1.93	39.73	7.56	0.00	0.00	0.69	17.89	0.00	15.84	5.14	0.57	2.63	2.08	0.31	0.77	7.36	0.30	3.978
7/15/2011	PECAN 2	15	27	7.64		8.31	78.55	16.49	0.00	0.00	0.00	0.00	0.00	21.61	8.34	0.48	4.66	3.83	0.87	1.32	11.30	0.89	6.209
7/18/2011	PECAN 2	15	29	7.84		11.68	106.74	7.48	0.00	0.00	0.00	0.00	0.00	22.08	7.54	0.08	3.75	3.84	0.87	1.37	11.67	1.05	
7/18/2011	PECAN 2	30	30	7.91		11.34	81.86	8.92	0.00	0.00	0.00	0.00	0.00	22.97	8.56	0.49	3.96	3.70	0.97	1.46	14.03	1.12	
7/18/2011	PECAN 2	60	31	7.64		20.60	127.37	0.00	0.00	0.00	0.00	0.00	2.10	123.78	61.79	14.11	34.						

Table 6: Water Saturation Indices

Water Saturation Indices										
DATE	LOCATION	DEPTH	COLLECTION	Calcite	Nacholit	Dolomite	Dolo. Disord.	Gypsum	Halite	Thenardite
		cm	#	LOG(AP/KT)	LOG(AP/KT)	LOG(AP/KT)	LOG(AP/KT)	LOG(AP/KT)	LOG(AP/KT)	LOG(AP/KT)
6/12/2011	ALFALFA	0	14	0.2	-4.4	1.3	-0.3	-1.4	-6.4	-7.1
6/26/2011	ALFALFA	0	20	1.1	-5.8	2.9	1.4	-1.6	-8.0	-10.3
7/18/2011	ALFALFA	0	28							
7/27/2011	ALFALFA	0	36	-1.4	-4.4	-2.0	-3.5	-1.4	-6.1	-6.9
8/25/2011	ALFALFA	0	43	-0.1	-4.1	0.4	-1.2	-1.1	-6.0	-6.8
9/13/2011	ALFALFA	0	51	0.5	-4.5	1.7	0.1	-1.5	-6.5	-7.5
7/25/2011	ALFALFA	15	34	0.7	-3.9	2.0	0.4	-1.0	-6.0	-6.7
8/2/2011	ALFALFA	15	38	0.4	-3.9	1.4	-0.1	-0.9	-5.9	-6.6
7/1/2011	ALFALFA	30	23							
7/25/2011	ALFALFA	30	35							
8/2/2011	ALFALFA	30	39	0.3	-3.9	1.3	-0.3	-1.0	-6.0	-6.8
9/19/2011	ALFALFA	30	52	0.4	-3.9	1.5	-0.1	-1.1	-6.2	-7.0
7/25/2011	COTTON	0	33	1.5	-4.3	3.7	2.1	-1.3	-6.1	-7.0
8/26/2011	COTTON	0	44	0.1	-4.2	0.7	-0.8	-1.2	-6.1	-6.9
6/17/2011	COTTON	30	15	0.6	-3.5	1.9	0.3	-0.3	-4.8	-5.0
8/2/2011	COTTON	30	40	0.2	-3.7	1.0	-0.5	-0.6	-5.1	-5.5
6/17/2011	COTTON	60	16							
8/2/2011	COTTON	60	41							
8/29/2011	COTTON	100	47	0.7	-3.6	1.9	0.4	-0.7	-5.0	-5.8
5/18/2011	PECAN 1	0	1	1.7	-3.7	4.1	2.5	-0.8	-5.2	-5.9
6/10/2011	PECAN 1	0	10	0.9	-4.2	2.4	0.8	-1.3	-6.2	-7.0
6/28/2011	PECAN 1	0	21	1.2	-4.4	3.1	1.5	-1.4	-6.4	-7.3
7/15/2011	PECAN 1	0	26	0.6	-4.3	1.9	0.3	-1.3	-6.3	-7.2
8/26/2011	PECAN 1	0	44	0.1	-4.2	0.7	-0.8	-1.2	-6.1	-6.9
9/10/2011	PECAN 1	0	49	0.2	-4.1	1.0	-0.6	-1.1	-6.0	-6.8
10/7/2011	PECAN 1	0	54							
8/29/2011	PECAN 1	15	45	0.8	-3.7	2.3	0.7	-0.5	-5.5	-5.9
10/14/2011	PECAN 1	15	55							
5/18/2011	PECAN 1	30	2							
6/17/2011	PECAN 1	30	17							
7/11/2011	PECAN 1	30	25	0.5	-3.6	1.6	0.1	-0.6	-5.4	-5.8
8/29/2011	PECAN 1	30	46	0.3	-3.8	1.3	-0.2	-0.5	-5.4	-5.8
10/14/2011	PECAN 1	30	56							
6/17/2011	PECAN 1	60	18							
8/29/2011	PECAN 1	100	47	0.7	-3.6	1.9	0.4	-0.7	-5.0	-5.8
10/14/2011	PECAN 1	100	57							
5/18/2011	PECAN 2	0	3	0.7	-4.2	2.0	0.4	-1.3	-6.1	-7.0
6/2/2011	PECAN 2	0	4	0.7	-4.2	2.0	0.4	-1.2	-6.0	-6.9
6/23/2011	PECAN 2	0	19	1.0	-4.3	2.7	1.2	-1.4	-6.3	-7.2
7/11/2011	PECAN 2	0	24	0.7	-4.2	2.0	0.4	-1.3	-6.1	-7.0
7/30/2011	PECAN 2	0	37	-0.6	-4.3	-0.7	-2.2	-1.3	-6.2	-7.0
8/23/2011	PECAN 2	0	42	-0.1	-4.2	0.3	-1.2	-1.2	-6.0	-6.9
9/10/2011	PECAN 2	0	50	0.3	-4.2	1.3	-0.3	-1.2	-6.1	-6.9
6/2/2011	PECAN 2	15	8	0.9	-3.8	2.5	1.0	-1.0	-5.8	-6.7
6/10/2011	PECAN 2	15	11	0.7	-3.9	2.1	0.5	-1.0	-5.8	-6.6
7/15/2011	PECAN 2	15	27	0.7	-3.9	1.9	0.4	-0.9	-5.8	-6.5
7/18/2011	PECAN 2	15	29							
9/19/2011	PECAN 2	15	53	0.6	-3.7	1.7	0.1	-0.9	-5.6	-6.4
6/2/2011	PECAN 2	30	6							
6/2/2011	PECAN 2	30	9	0.7	-3.9	2.1	0.5	-1.0	-5.7	-6.5
6/10/2011	PECAN 2	30	12	0.4	-3.8	1.6	0.0	-1.0	-5.8	-6.6
7/18/2011	PECAN 2	30	30							
6/2/2011	PECAN 2	60	7	0.8	-3.2	2.3	0.7	-0.2	-4.3	-4.7
6/10/2011	PECAN 2	60	13	0.9	-3.1	2.6	1.1	-0.3	-4.6	-4.9
6/28/2011	PECAN 2	60	22	0.8	-3.2	2.4	0.9	-0.1	-4.4	-4.7
7/18/2011	PECAN 2	60	31							
8/29/2011	PECAN 2	60	48							
6/2/2011	PECAN 2	100	5	0.8	-4.0	2.2	0.7	-1.0	-5.8	-6.6
7/18/2011	PECAN 2	100	32	0.6	-4.5	1.9	0.4	-1.2	-6.2	-7.0

VITA

I was born in November of 1987, and have lived in El Paso, Texas my whole life. I graduated from Franklin High School in 2006 in the top 10% of my class. After high school I then attended Texas Tech University in Lubbock, Texas where I obtained a Bachelors Degree in Business Marketing in 2009 with a 3.3 GPA and received numerous Dean's List Awards (3.5 or greater). With my Marketing degree I moved back to El Paso and worked with the family business for a year before deciding to go back to school for my Masters in Environmental Science. In June 2010, I started working on my MS at University of Texas at El Paso. During the spring semester of 2011 I met my advisor, Lixin Jin, and started working on my thesis. While working on my thesis I attended the American Geophysical Union (AGU) conference in 2011 where I was awarded a travel grant by AGU. I attended the 2012 Colloquium hosted by the Geology department and received 1st place in the oral presentations. I graduated from UTEP on the 12th of May, 2012 with a Masters in Environmental Science and a 4.0 GPA.

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