2019-01-01

A Quantitative Assessment Of Trace Metals In Subsurface Soils And Groundwater In Agricultural Fields Of El Paso, Texas

Emmanuel Sosa
University of Texas at El Paso

A QUANTITATIVE ASSESSMENT OF TRACE METALS IN SUBSURFACE SOILS AND GROUNDWATER IN AGRICULTURAL FIELDS OF EL PASO, TEXAS

EMMANUEL SOSA

Master's Program in Environmental Science

APPROVED:

Lixin Jin, Ph.D., Chair

Lin Ma, Ph.D.

Hugo Gutierrez, Ph.D.

Mark Engle, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

A QUANTITATIVE ASSESSMENT OF TRACE METALS IN SUBSURFACE SOILS AND GROUNDWATER IN AGRICULTURAL FIELDS OF EL PASO, TEXAS

by

EMMANUEL SOSA

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Geological Sciences

THE UNIVERSITY OF TEXAS AT EL PASO

August 2019

Acknowledgements

The research conducted in this thesis could not have been made without the help and guidance of various people. I would like to express my gratitude to Galen Kaip and his team for the help with the seismic survey, to Dr. Hugo Gutierrez and his team for allowing us to conduct a resistivity survey with his equipment, to the Ivey Family for permission to use their pecan orchard to conduct this study and for notifying me of upcoming irrigation events. I would also like to thank Julietta Saucedo for helping with lab work, Dr. Anna Ortiz for assistance with the data collected at this location, and my employer Wood E&IS for allowing me to use equipment during fieldwork. Furthermore, I would like to thank my committee members for the great feedback and support during this project. Each one of them has provided an enormous amount of knowledge and advice through courses or in person that I have been able to use during my time at UTEP and with my current position with my employer.

Abstract

Intensive agricultural practices such as irrigation, application of pesticides and the use of fertilizers, as well as contamination from urban settings and industrial activities contribute to the input of trace metals onto soils and groundwater. Consequentially, biological uptake and accumulation concentrate these toxic metals in fruits, vegetables, and grains that will be used for human consumption. In southern New Mexico and western Texas, cropland is developed along the Rio Grande valley. These farmers are concerned about the quality of their irrigation water and soils in order to produce adequate crops and maintain healthy soils to maximize revenue. To evaluate loading and mobility of trace metals through agricultural practices, irrigation water (from the Rio Grande River and a local well), groundwater, soil water, agricultural soils, and soil amendments were sampled and analyzed for As, Pb, P, Zn, V, B, and Fe concentrations at a pecan orchard in Tornillo, Texas. In addition, soils were collected at a natural site near Fabens, Texas for comparison. The emphasis was placed on sources and sinks of these trace metals and different fluxes that added to or removed them from soils.

A mass balance approach spanning 90 years estimated the loading of trace metals onto soils during the lifetime of the pecan orchard situated in the study area, through irrigation, and soil amendments. Soluble As, Pb, P, Zn, V, B, and Fe were predominantly loaded onto soils through irrigation water with some addition from soil amendments. Irrigation water sourced from the river water and from the local well were observed to have different trace metal concentrations; indeed, concentrations of B (504 +/- 7 μg/L; n=2) Fe (14 +/- 0.5 μg/L; n=2), and Pb (7 +/- 1 μg/L; n=2) were higher in groundwater while those of P (923 +/- 709 μg/L; n=8), V (10 +/- 2 μg/L; n=8), Zn (8 +/-6 μg/L; n=8), and As (6 +/- 1 μg/L; n=8) were higher in Rio Grande water. Soil amendments added a smaller amount of trace metals to soils than irrigation,

but continuous application of fertilizers and others would load trace metals to soils over long-term. This is especially true for Zn and P that were added as nutrients.

Soils were characterized for both water leachable fraction (salt phases) and acetic acid leachable fraction (pedogenic carbonate and Fe-oxyhydroxide) to understand trace metals that have been sequestered in soils at different mobility. The acid leachable fractions had much higher trace metal concentrations than water leachable fractions. For example, almost all P and Fe that were loaded through irrigation and soil amendments were estimated to be present in the acid leachable fractions, at almost 390 g/m^2. The trace metal concentrations in groundwaters were variable, but generally much lower for P and much higher for Zn than those in irrigation waters or soil waters.

The depth variation of these trace metals in the natural waters (soil waters and groundwaters) are in the acid leachable fractions was controlled by their geochemical properties and gradients of soil conditions. For example, V and Fe concentrations were controlled by redox conditions, and dictated by fluctuations in groundwater table. Clayey soils, where salts and pedogenic carbonates accumulate, have limited the mobility of trace metals to pecan trees and to drainage canals that lead to nearby orchards and back to the Rio Grande River. Assessing the presence of trace metals in agricultural fields provides a better understanding of the quality of irrigation water that can affect crop quality, crop production, soil health, and the need for soil management by farmers.

Table of Contents

List of Tables

List of Figures

Introduction

Freshwater quantity and quality are major growing concerns globally (Tay and Hayford, 2016). With a growing population worldwide and increasing industrial activities, larger amounts of trace metals can potentially enter surface environments and contaminate water resources and soils (Olajire et al., 2005; Satterthwaite, 2009). One important land use change, from a natural ecosystem to an agricultural system, impacts both water quantity and quality through irrigation, fertilizers, and pesticide use (Böhlke, 2002). Trace metals in irrigation water, fertilizers, and pesticides have the potential to become mobile depending on different variables such as pH, redox, and mineral solubility (Kumar Sharma et al., 2007; Lucho-Constantino et al., 2005). Once trace metals become mobile, they can be transported to groundwater in aquifers and other water systems (Böhlke, 2002; Lucho-Constantino et al., 2005). Thus, high concentrations of trace metals are of major concern to human health in drinking water (Ayotte et al., 2011; Kumar Sharma et al., 2007; Lal, 2016; Reddy et al., 2017; Tay and Hayford, 2016). In addition, toxic metals reside in the soils and can be taken up by crops, and consumed by humans (Huang et al., 2018; Komorowski and Szulc, 2017; Loska et al., 2004; Wong et al., 2007; Zimmerman and Weindorf, 2010).

Significance for agriculture along Rio Grande valley in the American Southwest

In the southwestern United States, the Rio Grande is a major source of surface freshwater. The Rio Grande receives snowmelt from the Rocky Mountains in Colorado and flows south; along the way, the Rio Grande flows through U.S. towns and cities (e.g., Albuquerque and Las Cruces in New Mexico, and El Paso in Texas) that depend on this freshwater resource to support industry, agriculture, and municipal use. The Rio Grande

eventually makes its way down to far west Texas after flowing along its approximately 640-mile path from its point of origin in Colorado to the Texas/New Mexico border (Lowe and Lowe, 1952). The utilization of this river water continues along the United States and Mexican border as the Rio Grande flows approximately 1,245 miles through various towns, mining districts, and more agricultural fields in Mexico until its end in the Gulf of Mexico (Lambert et al., 2008; Lowe and Lowe, 1952).

Hydrocarbons and trace metals from mining activity, refineries, wastewater treatment in urban areas, and other small industrial activities contribute to the changes of the chemical composition and quality of the water in the Rio Grande (Borrok and Engle, 2014; Lucho-Constantino et al., 2005) . Additionally, agricultural irrigation is another use of river water and has modified water chemistry through return flow (Cox et al., 2018; Szynkiewicz et al., 2011) For example, in the state of New Mexico, approximately 155,000 acres of land depend on the use of river water that is stored in the Elephant Butte dam in central New Mexico and released for irrigation during growing seasons (Lowe and Lowe, 1952). This soil-water interaction changes the chemical composition of the Rio Grande water, due to soil amendments and fertilizers. Along the Rio Grande, sulfur isotopic ratios indicate that sulfate (SO_4^{2-}) is dominated by inputs from agricultural activities, i.e., fertilizers (Szynkiewicz et al., 2011). In addition, Szynkiewicz et al. (2011) observed higher sulfate concentrations near irrigation canals and drains in the Rio Grande, indicating a close connection between agricultural fields and the river. Furthermore, Miyamoto et al. (1995) observed an increase in salinity, sodicity, and sulfate concentrations during the irrigation off-season where the main source of water to the Rio Grande is irrigation return flow and sewage water. The non-irrigation season for the El Paso region in Texas lasts roughly six months when much higher concentrations of sulfate, chloride, bromide, calcium,

magnesium, and sodium are observed in the Rio Grande. Various geochemical studies of the Rio Grande waters focus on salinity and major elements, but trace metal research is limited to these waters (Rios-arana et al., 2003). Additional research on trace metals coupled with existing data on Rio Grande water can provide a better understanding of water quality and its use for urban, industrial, and agricultural activity.

STUDY SITE

The Rio Bravo Farm, as are many other farms in the vicinity, is situated in the flood plain sediments of the Rio Grande alluvium aquifer along the Rio Grande valley near El Paso, Texas (Figure 1). The aquifer system underlying the farm is composed of poorly sorted sediments with a mixture of sand, silt, clay, and gravel. The groundwater level is shallow, just a few feet below the surface near the Rio Grande (Ashworth, 1990). Water withdrawn from this aquifer is used for irrigation during times of low river water and is known to range from slightly to moderately saline (1,000 to 10,000 milligrams per liter dissolved-solids concentrations) (Ashworth, 1990; Carter et al., 1963). The application of these alluvium waters to agricultural fields increases the salt content of soils due to regionally high evaporation rates (1,000 – 1,460 mm per year) (Cox et al., 2018; Ganjegunte et al., 2017; Sheng and Liu, 2015). The dominant soils in the study area belong to the Glendale (Ge), the Tigua (Tg), and the Saneli (Sa) series, as characterized by the Soil Conservation Service and the Texas Agricultural Experiment Station (Figure 2; Jaco, 1971). Glendale (Ge) is a calcareous silty clay loam followed by a silty clay loam with thin silt loam lenses and is underlaid by clay and sand sediments. Tigua (Tg) is calcareous silty clay followed by a clay layer and underlaid by a very fine sandy loam. Saneli (Sa) is a calcareous silty clay loam above a calcareous hard clay and underlaid by loamy fine sand.

The Rio Bravo Farm initially cultivated cotton for about 60 years before transitioning into a pecan orchard 30 years ago. Soils are typically tilled prior to the growing season and are treated with fertilizers to enhance crop growth. Foliar and soil fertilizer application rates vary with each growing season and are applied as needed by the operators of the Rio Bravo Farm. The

main source of irrigation is sourced from Rio Grande water via flood irrigation. On average, four inches of water are applied to soil surface during each of the nine or ten irrigation events per growing season (April to October). Irrigation water then seeps into the soils and drains into a drainage canal adjacent to the pecan orchard. When Rio Grande river water is not available, groundwater from local wells is used for irrigation.

Cox et al. (2018) and Ortiz et al. (2018) discussed dynamics and magnitude of salt buildup from irrigation at the Rio Bravo Farm. These studies identified that different canopy sizes of pecan trees are due to different levels of soil salinity, and ultimately controlled by soil texture and water infiltration rates: the “Pecan Fine” site is characterized by relatively smaller pecan trees and soils with finer particles (Tg soil series), whereas the “Pecan Coarse” site with pecan trees of larger canopies has soils with coarser sediments (Ge soil series) (Figure 1D). As a consequence of irrigation, soil salinity at Pecan Fine site exceeds the tolerance level of pecans and stunts their growth (Cox et al., 2018; Ortiz et al., 2018). Agricultural practices including irrigation, fertilizer, and pesticide application not only load nutrients and salts into the soils, but also load trace metals. These metals then have the potential to mobilize from ground surface to deeper soils and underlying aquifers, and to the Rio Grande through return flow, or alternatively remain in the soils, or are taken up by pecan roots.

Mobility of salts and nutrients has been well studied, but our knowledge of trace metals in the agricultural settings is limited. This project aims to use a mass balance approach to:

(1) Investigate the loading of trace metals from different sources (irrigation, fertilizers, and other soil amendments);

(2) Evaluate the retention of trace metals in agricultural soils of different texture; and

(3) Study the mobility of trace metals from soils to groundwater and drainage canals.

In addition to agricultural soils, an undisturbed natural location in Fabens, Texas, was utilized to collect samples that would serve as a comparison between soils that have been exposed to agricultural activity for over 90 years and soils that have not been disturbed by human

activity. This location is situated approximately 15 kilometers northwest of the pecan orchard and is of a sandy texture (Figure 1B).

The monitoring of trace metal concentrations in soils and freshwater is beneficial to provide the quality assurance of safe agricultural products, and water resources. Additionally, intensive irrigation and soil salinization are not uncommon in other parts of the world, especially in drylands where agricultural farms are irrigated with wastewater, reclaimed water or river water of high total dissolved solids, use pesticides, and/or are located near an urban setting (Kumar Sharma et al., 2007; Lucho-Constantino et al., 2005; Nicolli et al., 1989; Reddy et al., 2017; Tay and Hayford, 2016). For this study, arsenic (As), lead (Pb), phosphorus (P), zinc (Zn), vanadium (V), boron (B), and iron (Fe) will be the trace metals of interest.

Methods

Sample Collection

Soil Sampling

Two boreholes of approximately 3 meters (m) were previously dug using a hand auger at the Pecan Fine and Pecan Coarse sites and soil samples collected at approximately 10-centimeter (cm) intervals and characterized for soil particle size and salinity (Ortiz et al., 2018). Additionally, a set of soil samples from an undisturbed region in Fabens, Texas, were collected by a sand auger at 20 cm intervals to a depth of approximately 1.1 m to use as a natural site.

Water Sampling

Irrigation Water Sampling

Two sources of freshwater were used for irrigation in the pecan orchard: the Rio Grande and local groundwater. Rio Grande water is diverted, channeled through canals, and applied to agricultural fields via flood irrigation during the growing season. Water samples were collected at the irrigation canals with a water bailer approximately one to two days before irrigation. At each sampling event, the bailer was rinsed three times with the river water prior to sampling. Samples were then stored in a refrigerator after filtration with the use of a 0.45-micron filter.

The second set of irrigation water samples were collected from the industrial water well that was adjacent to the pecan orchard and drilled to a depth of approximately 200 ft. (66 m) (Texas Water Development Board, 1973). The groundwater is only used during the end of the irrigation season and the winter months when river water is not available. Groundwater was pumped into a cement-lined canal and channeled to the pecan orchards and samples were collected using trace metal-grade acid washed containers, filtered with a 0.45 micron filter, and stored in a refrigerator at about 4 ^{o}C.

Soil waters through Lysimeters

Soil water was collected from 1900-series tension lysimeters (SoilMoisture Ltc, Barbara, CA) installed at depths of 15 cm, 30 cm, 60 cm, and 120 cm below ground surface at the Pecan Coarse location only (Figure 3). Vacuum was pulled to 50 centibars one or two days before irrigation water reached the pecan orchard. Samples were retrieved using a syringe and plastic tubing approximately one week after irrigation when the orchard was accessible. The syringe and tubing were rinsed thoroughly using distilled water between lysimeters. Samples were collected into trace metal-grade acid washed bottles, filtered with a 0.45 micron syringe filter and stored in a refrigerator at about 4 ^{o}C.

Groundwater through monitoring wells

During this study, three water wells were installed near Pecan Coarse to sample shallow groundwater. The wells were advanced to depths of 11.5 ft. (WW1), 9.5 ft. (WW2), and 7.5 ft. (WW3) below ground surface (Figure 1D; Figure 3). The WW1 well was made of stainless steel piping and a stainless steel well point with a 0.01 inch slotted screen and was driven into the ground. The parts comprising WW1 were cleaned with water and Alcanox (phosphate free soap) followed by a rinse with distilled water. Groundwater at WW1 well was sampled with a bailer until fine sediments were no longer visible and purge water was clear. WW2 and WW3 wells were made up of schedule 40 PVC, with a 5ft casing section with a 0.01-inch slotted screen to keep fine sediments from entering the well. WW2 and WW3 were installed using a hand auger to remove soils and set the well. Bentonite was used in the upper 6 inches to seal the annulus between the well and soils. The well was developed until fine sediments were no longer observed in the purged water.

All three wells were capped with a J-plug locking cap and a padlock to limit well access. Groundwater samples were collected at the same time as soil water samples approximately one week after an irrigation event. Three well volumes are typically purged and

that would be approximately 1.8 gallons for WW1, 1.1 gallons for WW2, and 0.8 gallons for WW3. For this study, three gallons of water were purged prior to sampling to allow the collection of a representative sample from each well. Groundwater samples were collected in trace metal-grade acid washed containers, filtered with 0.45-micron filters and stored in a refrigerator for chemical analysis. Water quality parameters including pH, electrical conductivity and temperature were measured along with sample collection with bailers.

Additional well water samples were collected using low flow sampling guidelines (Puls and Barcelona, 1996). The use of low flow purging limits the mobilization of colloidal material and enables the collection of elemental concentrations of water samples in their dissolved forms. A peristaltic pump with silicon tubing rinsed with DI water in the field was used to purge and collect water samples. Depth to water was monitored using a Geotech water level meter to ensure that drawdown of the water table was limited during purging. Water quality parameters were collected at five-minute intervals and included pH, electrical conductivity (EC), temperature, and totally dissolve solids (TDS) using a YSI Pro instrument and an Orion 3 star conductivity probe. After these parameters stabilized, a sample was obtained from the well, filtered and stored in a refrigerator for further analysis.

Soil amendment samples

Eight soil amendment samples (i.e. fertilizers) were obtained from the owners of the pecan orchard to examine the trace metal concentrations in each fertilizer that is applied to soils (Table 1; Table 2). Samples were collected and stored in zip lock bags.

SAMPLE ANALYSES

Soil Texture Data

Soil samples collected from previous field work at the Pecan Fine and Pecan Coarse locations were analyzed for particle size distribution. The soil samples were grounded gently with a mortar and pestle to break any present soil aggregates. Particle size analysis was first

carried out using a wet sieving method to separate the sand particles from silt and clay portions, by a 0.063 mm sieve (#230). All finer silt and clay particles in the slurry were centrifuged at 3500 rpm for ten minutes in a 50 ml centrifuge tube. The resulting supernatant contained the clay portions of the soil sample and the pellet at the bottom of the centrifuge was the silt portion. All three portions were air dried and then weighed to calculate relative percentages and thus determine soil texture.

Sequential soil leachates

Soil samples were leached sequentially, first with deionized water for water soluble metals, then 0.1M NH_4Cl-$BaCl_2$ for exchangeable cations, and then by dilute acetic acids for carbonate fraction. Specifically, 30 milliliters (ml) of deionized water and 10 grams (g) of soil were mixed, and the leachates were centrifuged, filtered using 0.45 micron filters to remove particles, analyzed for concentrations of major cations, major anions, and trace metals using the Perkin Elmer DV5300 inductively coupled plasma optical emission spectrometer (ICP-OES) and the Dionex CS2100 ion chromatograph (IC), and the inductively coupled plasma mass spectrometry (ICP-MS), respectively. After this, soil residue was mixed with 25ml of 0.1M $BaCl_2$-0.1M NH_4Cl, shaken for 15 minutes, and then centrifuged at 3500rpm for five minutes. The resulting supernatant was filtered with 0.45μm paper filters and diluted for ICP-MS analysis. Finally, 20mL of 2M acetic acid was added to soil residue, shaken for 6 hours and centrifuged at 2500 rpm for 20 minutes. The supernatant was filtered with a 0.45μm paper filter, dried and re-dissolved in 2% HNO_3, before analysis of trace metal concentrations on the ICP-MS. Data from the ICP-MS analysis was converted from μg/L (dissolved phase) to mg/kg (solid phase) using the ratio of the weight of soil (10 g) and the volume of liquid used (30 ml for water, for example).

Water sample analysis

Water samples including irrigation water (both from the Rio Grande and local wells), soil water, and groundwater were analyzed for pH, EC, and elemental chemistry similar to the soil leachate samples after filtration. Water samples were analyzed using the ICP-MS, ICP-OES, and IC for trace metal, cation, and anion concentrations, respectively. For quality control and quality assurance, blanks and checks were analyzed with the standards and unknown samples for each instrument. Reported data was compared to the limit of detection (LOD) of the instruments to remove any values lower than the LOD. The USGS reference material (T-217) was used as a check standard and run every 30 samples. Results from multiple analyses were averaged and compared to the most probable values for different trace metals to estimate a bias in percentage. On average, for most of the elements analyzed, the difference is less than 13%; the largest error of all analysis was 39% for B (57% for Be, but with only one check standard).

A total of ten (10) irrigation samples were collected between May 2018 and May 2019. The first seven irrigation samples (IS 1-7) were collected from the Rio Grande, the eighth irrigation sample (IS-8) was a mix of Rio Grande water and local groundwater, and the last two samples (IS-9 and IS-10) were groundwater samples from a water supply well on the Rio Bravo Farm. Soil water samples were collected during four irrigation events. The first three sets of soil water samples were collected after irrigation using Rio Grande water, and the last set was collected after irrigation using local groundwater. Groundwater samples were collected approximately one week after the start of an irrigation event when majority of the irrigation water had infiltrated soils and the surface soils were dry enough to walk on. Water Well 1 (WW1) was the first well installed, thus more samples were collected from that well. The first sample (WW1S1) was obtained from a shallower depth (~189 cm bgs) than the following five samples (WW1S2 – WW1S6). WW1 samples were collected from an approximate depth range of 2.6 m to 3.5 m. Groundwater samples from Water Well 2 (WW2) were collected from an

approximate depth range of 2 m to 3 m. A total of four samples were collected from WW2. Water Well 3 (WW3) samples were collected from a depth of 1.7 m to 2.3 m (n=3).

Geophysical Surveys

Geophysical surveys were performed at the pecan orchard to collect general information about soils and groundwater. Prior to the surveys, depth to water had only been estimated and soil texture was known only at two locations within the orchard.

Resistivity survey

A resistivity survey was conducted in March 2018 in the pecan orchard beginning in the Pecan Coarse site and extending past the Pecan fine site (A-A' in Figure 4). A 110-meter transect was used for the survey utilizing the Super Sting instrument. 56 electrodes were inserted into the orchard soils and were spaced in 2-meter intervals. A Dipole-Dipole method was performed to produce an inverted conductivity cross section of soils.

Seismic survey

A seismic survey was conducted in April 2018 using a Geometrics StrataView seismograph. This survey was approximately 69 meters in length and conducted in the same location as the resistivity survey (B-B' in Figure 4). This seismic survey was used to locate the water table under the pecan coarse location to properly install groundwater monitoring wells.

Monitoring groundwater level

HOBO water level loggers were installed in water well 1 (WW1) to monitoring the fluctuation in groundwater levels during irrigation events. The pressure transducers were set up to record data every 5 minutes from June 26, 2018 to May 9, 2019. Two pressure transducers

were placed in the water well to collect different pressure information. The first pressure transducer was placed towards the bottom of the well at approximately 12 feet below the top of the well casing to ensure that it was submerged in groundwater. The second transducer was placed one foot under the top of the well casing to ensure that it was above groundwater to record surface air pressure. Pressure differences were then processed to obtain the change in the groundwater depth with time. A second set of pressure transducers was installed in water well 2 (WW2) to record additional data from January 26, 2019 to April 13, 2019.

MASS BALANCE APPROACH

The trace metals were loaded to agricultural soils at the pecan orchard through natural precipitation, irrigation and soil amendments, and processes that removed the trace metals were mainly through recharge to the groundwaters and potential lateral water flow to drains. These fluxes were quantified in order to determine the mobility of these trace metals in an agricultural system using a mass balance approach (Figure 5). Trace metals were monitored as irrigation water infiltrated soils, interacted with soil amendments, and flowed to become groundwater. The concentrations of trace metals obtained from water well samples provide insight into the mobile trace metals that can flow into drainage canals and into shallow water table. The differences in concentrations between well and soil water samples reflect the amount of trace metals that are deposited in soils or uptaken by crops.

Daily precipitation data for Tornillo, Texas, from June 2018 to March 2019 were downloaded from www.usclimatedata.com. Evapotranspiration (ET) data were previously estimated using an eddy covariance tower for a different pecan orchard in Tornillo, Texas (Sheng and Liu, 2015). The ET data were collected for year 2012 but generally in agreement with average ET rates in the Tornillo, Texas region (Scanlon et al., 2005; Sheng and Liu, 2015). These ET data were used for this study site to estimate the water loss to atmosphere in the mass balance calculation.

Results

SOIL SAMPLES

Chemistry of the water leachable and acid leachable fractions in all soil samples as well as soil texture are reported in Table 3.

Soil texture

At the natural site near Fabens, Texas, soils at the surface were characterized by fine sand texture, and became finer with depth (loamy fine sand, sandy loam, loam, and then silt loam) (Figure 6). The average sand percentage of the soil profile was approximately 57% while that of clays only averaged 5% (Figure 6A). The maximum percentage of sand particles (95%) was observed at the surface. Clay contents reached a maximum of 8% between 20 cm and 40 cm below ground surface (bgs) (Figure 6B). Sand particles dominated the shallow half of the soil profile while silt particles reached approximately 50% of the total soil texture in the deeper half of the soil profile (Table 3 and Figure 6).

Prior to a growing season, soils at the pecan orchard are tilled to a depth of approximately 6 inches (15 cm) to prepare soils for irrigation and application of soil amendments. Pecan Coarse samples revealed a higher percentage of sand particles throughout the soil profile than clay particles (Figure 6; Table 3). The average percentage of sand in the Pecan Coarse was 84%, while clays averaged ~5%. The maximum percentage of sand particles in the soil samples was 97% (at 160 – 210 cm bgs) while clays had a maximum of 28% (at 110 cm). Using USDA definitions, soil texture in the top half (0 - 130 cm bgs) of the soil profile consisted of loamy, sandy loam, loamy fine sand, and sandy clay loam soils while the lower half (140 – 250 cm bgs) of the soil profile was dominated by fine sand soils (Figure 6C).

Compared to Pecan Coarse, the Pecan Fine soil samples were finer and showed also large depth variation (Figure 6). The average percentage of sand particles throughout the soil profile was 48% while clays averaged out at 17%. The maximum sand was 94% (284 cm bgs) while

clay had a maximum percentage of 75% (102 cm bgs). Soils between 0 cm and 71 cm bgs contained less than 25% of clay particles and had a USDA soil texture class ranging from loam to silt loam. Soils between 71 cm and 142 cm bgs contained clay percentages between 25% and 75% that were assigned USDA soil textures of silty clay, clay, and silty clay loam (Figure 6C). These depths contained the highest percentage of clay particles in both Pecan Fine and Pecan Coarse sites. Soil samples below 142 cm contained lower clay contents and were typically coarser.

Water Leachable and acid leachable fractions

At the Fabens, Texas site, trace metals in the water leachable fraction were typically lower than 1 mg/kg for As, Pb, P, Zn, V, and Fe, except for B at 3.8 mg/kg (Figure 7G). Concentrations of these trace metals in the acid leachable fraction were also lower than 1 mg/kg for V and Pb, but higher for As (1.4 mg/kg), Zn 1.9 (mg/kg), Fe (2.4 mg/kg), B (5.9 mg/kg), and P (43.9 mg/kg). On average, B, V, Fe, As, and Pb concentrations were observed to be higher in the water leachable fraction at the natural site than those in Pecan Fine and Pecan Coarse soils. In the acid leachable fraction, only B and As were higher at the natural site than the average concentrations reported at both sites in the pecan orchard. Three depth trends were observed with trace metals at the Fabens site: As, Pb, Zn, and V increased with depth around 60 cm bgs, followed by a decrease where silty sediments were present and sandy particles ceased to dominate soil texture (Figure 6); P and Fe concentrations varied little with depth; B exhibited a sharp increase after 30 cm but generally higher concentrations throughout the soil profile.

Trace metals at the Pecan Coarse and Pecan Fine soils were lower in the water leachable fraction when compared to concentrations in the acid leachable fraction (Figure 6). Indeed, Pb, As, P, Zn, V, B, and Fe had average concentrations at 1 mg/kg or lower in the water leachable fraction. However, As, Pb, and V had concentrations lower than 1 mg/kg in the acid leachable fraction, while B (1.8 mg/kg), Zn (68 mg/kg), P (99.8 mg/kg), and Fe (101.6 mg/kg) had higher

concentrations at Pecan Coarse. At Pecan Fine site, As and V were the only trace metals with average concentrations lower than 1 mg/kg, but Pb (1.5 mg/kg), B (2.4 mg/kg), Zn (9.2 mg/kg), P (42.7 mg/kg), and Fe (51.5 mg/kg) were present in much higher concentrations in the acid leachable fraction.

Different trace elements had variable concentrations in soil leachates, but they also exhibited different depth profiles (Figure 7). For example, V in the water and acid leachable fraction was observed to increase in concentration with depth at the pecan orchard, especially around 180 cm bgs and was followed by a decrease in concentration at Pecan Coarse (Figure 7D). At Pecan Fine, similar trends were observed as with Pecan Coarse, as B had an increase in concentration in the shallower soils followed by a decrease in deeper soils.

B concentrations in the water and acid leachable fraction increased near the clayey soil layer (~60-130 cm bgs) at Pecan Coarse and Pecan Fine, while As and Pb were observed to increase at similar depths only in the acid leachable fraction (Figure 7). Concentrations of B, V, As, Pb, and Fe were noticeably higher in surface soils, and then proceeded to generally decrease with depth. Near depths of 200 cm bgs, B, V, and Fe were observed to increase in concentration followed by a decrease in the deepest soils. Concentrations of P and Zn were generally decreasing with depth with no increases at deeper depths.

AQUEOUS SAMPLES

Chemistry data of irrigation, soil water and groundwater samples are reported in Table 4. EC and pH data were only measured on samples with enough volume after elemental chemistry analyses. For irrigation water, EC values ranged from 1506 – 3100 µS/cm and pH values ranged from 6.68 – 7.95. For soil waters, EC data increased with depth from 15 cm to 60 cm bgs, followed by a slight decrease at 120 cm depth (1439 – 1690 µS/cm at 15 cm, 2600 – 2910 µS/cm at 30 cm, 4820 µS/cm at 60 cm, and 4310 – 46310 µS/cm at 120 cm). Soil water pH remained relatively constant throughout the profile ranging from 7.67 to 8.71. EC values decreased slightly

with depth with the shallowest water well (WW3, 2900 -3130 µS/cm), followed by WW2 (2260 – 3280 µS/cm), and then WW1 (1506 – 3100 µS/cm). Values of pH in the groundwaters were stable at WW3 from 7.49 – 7.61, and more variable at WW2 values (6.73 – 7.97) and WW3 (6.68 – 7.95).

Average trace metal concentrations and their standard deviations in irrigation water samples were plotted in Figure 8A. On average, trace metal concentrations in irrigation samples were dominated by P (764 µg/L) and B (301 µg/L), while Pb, As, V, Fe, and Zn concentrations were all lower than 12 µg/L. Irrigation water from the Rio Grande contained much higher P (923 µg/L) than the irrigation water from a local well (127 µg/L). In contrast, B concentrations were higher in groundwater of the local well (504 µg/L) than those in the Rio Grande (251 µg/L). Furthermore, Pb and Fe concentrations were slightly higher in groundwater while As, V and Zn were higher in Rio Grande water (Figure 14).

Average concentrations of trace metals in soil water samples were reported in Figure 8B. The highest Pb (2.4 µg/L), V (23 µg/L), As (38 µg/L), Fe (83 µg/L), B (1128 µg/L), and Zn (108 µg/L) concentrations were observed in soil water from 15 cm bgs compared to those in soil waters from 30, 60, or 120 cm. However, the highest P (3791 µg/L) concentration was observed at soil waters from 120 cm bgs. The lowest concentrations for Pb, As, Zn, and P were observed at 60 cm bgs and at 30 cm bgs for Fe and B.

Average concentrations of trace metals in groundwater samples were reported in Figure 8C. The groundwaters from WW3, the shallowest well contained higher B (592 µg/L) and V concentrations (9.1 µg/L), and lower concentrations of Pb (0.3 µg/L) and Zn (12 µg/L) than those from WW2 and WW1. WW2 situated in the intermediate depth contained the highest concentration of As (30 µg/L) and P (303 µg/L), while the lowest concentrations of Fe (20 µg/L) and B (429 µg/L). The deepest groundwater samples from WW1 had the highest concentrations for Pb (2.3 µg/L), Fe (871 µg/L), and Zn (33 mg/L). The lowest average concentrations for V (4.6 µg/L), As (11 µg/L), and P (108 µg/L) were also measured in groundwater from WW1.

For soil waters, average concentrations and standard deviations of trace metals from all four sampling events were calculated for each sampling depth (15, 30, 60, and 120 cm). Soil water samples collected from the 15 cm depth contained higher relative concentrations of B, V, As, P, and Fe than irrigation water samples (Figure 7), indicative of additions through soil amendments. A decrease in concentration of these trace metals was observed following the 15 cm depth samples. Following the decrease in concentrations after 15 cm, trace metal concentrations increased once again for B, V, As, P, and Fe at deeper soil water collection depths. The Zn and Pb showed little to no variability in concentrations in soil water with depth, and they were also lower in concentrations in soil water samples than groundwaters.

Analysis of groundwater samples revealed a trend where trace metals that had been previously observed to increase in concentration in soil water samples to begin to decrease once in contact with groundwater B, V, As, P, and Fe (Figure 7) have a relatively lower concentration in groundwater when compared to concentrations in soil water samples. In contrast, concentrations of Zn increase in groundwater with increasing depth. Concentrations of Pb did not show any major trends and remained relatively constant with those of soil water and irrigation water.

Soil Amendments

Trace metal concentrations of water soluble forms were reported for each soil amendment sample in mg/kg (Table 7). B, P, Fe, and Zn were present in the cumulative concentrations of fertilizers with a concentration of more than 10,000 mg/kg. V, As, and Pb were also present in concentrations ranging from 32 to 444 mg/kg (Figure 9). Trace metal data from fertilizers were converted to loading rates per year using application rates given by farmers at the Rio Bravo Farm. Data from the ICP-MS was converted to mg/kg using the volumes of fertilizer samples and DI water for sample preparation. 50 ml of DI water were used to dissolve 30 mg of the fertilizer samples. The mg/kg value was converted to g/kg followed by a conversion to $g/m^2/yr$.

by multiplying the g/kg value with the loading rate of fertilizers (kg/yr.) and dividing by the total area (259203 m^2). P had the highest concentration in fertilizers loaded to soils at approximately 131 mg/m^2/yr. Fe, Zn, and Pb had lower concentrations above 1000 µg/ m^2/yr., while B, V, and As were calculated to be below 1000 µg/ m^2/yr.

Groundwater level fluctuations

A total of 73,272 readings were collected from pressure transducers and data loggers between July 26, 2018 and May 9, 2019. Pressure readings were recorded every five minutes which allow the visualization of the overall changes in groundwater depth with each irrigation event, precipitation event (Figure 10A), and diurnal fluctuations (Figure 10B). During periods of no irrigation, groundwater levels dropped to the deepest (2.07 m bgs) on March 3rd, 2019. The shallowest recorded groundwater depth was recorded on August 8th, 2019 at 1.08 m bgs. Precipitation data for Tornillo, Texas, was obtained from usclimatedata.com. Precipitation events are responsible for small peaks on the overall curve of the groundwater fluctuation data. Periods of rain were followed by changes in water levels shortly after. Additionally, the amount of water used for each irrigation was obtained from the owners of the pecan orchard, at approximately 4 - 5 inches (10.16 – 12.7 cm) per irrigation, and the total water used per growing season was obtained for the pecan orchard, with 10 irrigation events (1270 mm; Figure 4).

GEOPHYSICAL SURVEYS

Resistivity Survey

The resistivity survey conducted in April 2018 produced a 2-dimensional inverted conductivity and inverted resistivity model of subsurface soils at the Pecan Coarse and Pecan Fine locations (Figure 11). Areas known to contain high amounts of clay exhibited high conductivities (155 – 402 mS/m) /low resistivity (2.5 – 6.4 Ohm-m). These areas of high conductivity correlate with the Pecan Fine location were tree growth is noticeably less than that

of the Pecan Coarse site. Regions known to have a more sandy soil texture are shown to have conductivity values ranging from 60 to 130 mS/m and resistivity values at approximately 12 Ohm-m.

Seismic Survey

A 2-dimensional model was produced using the seismic survey showing differences in velocities with changing depth (Figure 12). The 2-layer model shows a 372 m/s velocity approximately 1 m bgs, followed by a 476 m/s velocity at 5m bgs. An increase in velocity is observed approximately at 6 m bgs where the average velocity is shown to be at 1926 m/s. The initial predicted groundwater level was around 5 m bgs. Water levels were later measured to be approximately 2 m bgs.

Discussion

WATER FLUXES IN A MASS BALANCE MODEL

Evapotranspiration (ET), precipitation, and irrigation data allow us to assess the mobility and availability of water in soils (Figure 10). The fluctuation of groundwater levels at depth (panels A and B), soil moisture in unsaturated soils (panel D), and water input-ET cumulative fluxes at soil surface (panel C) all respond quickly to each irrigation event. Higher rates of ET were observed during summer months at rates of approximately 6 to 7 mm/day for year 2012 (Sheng and Liu, 2015). Soil moisture was observed to be higher at the 60 cm measurement depth than the 15 cm measurement depth, with the lowest soil moisture content (data from Cox et al. (2018)). The increase in soil moisture is correlated with irrigation events and the subsequent decrease is due to ET and mobility of irrigation water to groundwater. These rapid changes in shallow soil moisture result in the precipitation of evaporite minerals (salts and carbonates) and have the potential to sorb or co-precipitate certain trace metals (see discussion below). Indeed, trace metals like P and B are removed from solution and therefore resulted in high concentrations in soils during acid leaching and can be observed in Figure 7C.

Low precipitation rates coupled with high ET rates demonstrate how irrigation water is mostly removed from shallow soils by biological uptake and evaporation to atmosphere, increasing the concentrations of trace metals introduced via irrigation. The shallow groundwater level does not increase significantly after one year of monitoring, even though irrigation and natural precipitation exceed annual ET rates at the study site. This suggests that water is lost through lateral flow or/and vertical infiltration by approximately 500 mm/yr. to much deeper and regional groundwater aquifers.

GEOCHEMICAL CONTROLS ON ELEMENT MOBILITY

For the trace metals investigated in this study, their concentrations are modified as irrigation water infiltrates and interacts with soils before recharging to groundwater or moves laterals to the drainage canal. Different processes are observed that control their mobility, including adsorption/desorption, precipitation and dissolution of secondary mineral phases, and redox reactions. Most of time, the concentration of a given element in natural waters is modified by multiple processes at different soil depths.

Adsorption: Spatial heterogeneity in soil texture was visualized with a resistivity survey and it correlated well with particle size analysis on two soil cores (Figure 6A and Figure 11). A clayey layer is shown to adsorb trace metals. Indeed, concentrations of As, Pb, V, B, and Fe in water soluble fraction of soils showed a peak in clayey soils (approximately 80 cm – 130 cm bgs at Pecan fine and approximately 110 – 120 cm bgs at Pecan Coarse) (Figure 7). Furthermore, higher concentrations of trace metals were also observed in the acid leachable fraction in soils, more so at Pecan Fine which contained a higher amount of clayey soils.

Redox: V and Fe. Monitoring groundwater depth allows for the differentiation between the static water depths and fluctuating water levels during irrigation (Figure 10). Water depth fluctuated approximately between 1.1 m to 2.1 m bgs after an irrigation event. It is thus reasonable to assume that reducing condition prevails below 2.1 m bgs, and oxic condition above 1.1 m bgs, and a potential fluctuating redox zone in between. If so, redox sensitive trace metals would change concentrations cross this gradient due to the change in the groundwater level (Figure 13A). Indeed, trace metals V and Fe had low concentrations in irrigation water, increased noticeably at the depth of the static water table (Figure 7B). Furthermore, an increasing trend in both V and Fe concentration was observed in acid leachable fraction of deeper soil samples, probably due to coprecipitation of Fe^{2+} with pedogenic carbonate or/and iron oxyhydroxide.

Nutrients and soil amendments: P, B, and Zn. The primary inputs of B and P are soil amendments: B and P concentrations were high in soil amendments and also at shallow soils. In

addition, B and P were observed to be highly soluble and had high concentrations in natural waters, especially irrigation waters. Boron and P were observed to be soluble in groundwater, but decreased sharply with depth. Decreasing trends in concentrations in both the soil and aqueous phase depict a reduction in mobility of these trace metals limiting their flow to drainage canals. Zinc concentrations in irrigation water were low, increased slightly in soil waters, and sharply in groundwater samples attributed to soil amendments. Concentrations of Zn in soils follow a decreasing trend with depth, which could represent the leaching of these trace metals into river water via groundwater flowing into drainage canals.

BOX MODELS OF DIFFERENT ELEMENTS

Estimated irrigation and soil amendment fluxes for the past 90 years were collected for loading As, Pb, P, Zn, V, B, and Fe to soils in a mass balance model (Figure 5; Table 6). Sizes of water and acid leachable fractions in Pecan Coarse soils were included to visualize accumulation of these trace metals sequestered in different mobility. Finally, average concentrations from WW1-WW3 were used to quantify the flux of each trace metal that have the potential to be removed from the pecan orchard through groundwater or drainage canals (Table 6). Since the water flux was not quantified for the groundwater recharge, the difference between irrigation/precipitation and ET was used. In the box model, B and P were observed to enter soils in higher concentrations through irrigation water at 34.5 g/m^2 and 87 g/m^2 respectively (Figure 5, Table 6). Soil amendment concentrations were noticeably lower than irrigation water for almost all elements, with the highest loading rate observed for P at 11.8 g/m^2. Water leachable soils had rather small amounts of all these elements with the highest P at 4 g/m^2, while the acid leachable fraction of soils had 389 g/m^2 P. The losses through groundwater or drainage flow were low for As, Pb, P, V, B, and Fe from 0.3 to 23 g/m^2, but much higher for Zn at 521 g/m^2. The results obtained from this mass balance indicate that a large amount of trace metals may be associated with other sources acting as reservoirs such as vegetation or soils deeper than the ones assessed.

Furthermore, the low concentrations of trace metals, with the exception of Zn, in groundwater indicate that the application of fertilizers to soils at the pecan orchard are loaded with efficient amounts that are not leaching away to groundwater or to the Rio Grande. Unfortunately, liquid soil amendments and the loading rates for four of the eight solid fertilizers were not available to assess the complete total input of trace metals onto soils. Trace metal input values discussed in the mass balance table pertaining to soil amendments are thus assumed to be underestimated.

Conclusion

This project studied agricultural soils at a pecan orchard and a natural soil profile near El Paso, Texas, along the Rio Grande valley, and investigated the loading of trace metals (As, Pb, P, Zn, V, B, and Fe) through precipitation, irrigation and soil amendments, and their mobility in shallow soils and groundwater. Different hydrological, geochemical conditions and soil properties including redox, water mobility, and soil texture, play an important role in the adsorption or desorption of trace metals, and their co-precipitation and re-dissolution with salts and carbonate minerals in an agricultural system. The buildup of trace metals in soils and in crops can impact human health and soil quality. At the pecan orchard, various trace metals were observed to be adsorbed to soils, yet the mobility of these trace metals was limited by adsorption to clayey soils and sequestration in carbonates. Furthermore, transition from oxic to reducing conditions below the groundwater may affect the redox-sensitive metals and change their mobility in groundwaters.

The application of river water versus groundwater for irrigation resulted in a different loading of trace metals onto soils. Groundwater contained higher concentrations of Fe, B, and Pb than river water, but had less amounts of P, V, Zn, and As. The absence of river water in the beginning and towards the end of the growing season results in the great need for groundwater as a source for irrigation. Similarly, if Rio Grande flows are limited due to climate variability at the Colorado headwater regions, more groundwaters from local wells will be used. Furthermore, usage of river water may increase upstream due to more industrial and urban activities which also could lead to more use of groundwaters for irrigation. All these will lead to higher loading rates of trace metals and other salts, and can affect crop yields and quality. Ultimately, this will demand more soil amendments and make it more expensive and less competitive for the pecan orchard owners.

The trace metals discussed in this study were observed to enter soils at the pecan orchard through irrigation water and soil amendments. As trace metals infiltrate soils through water flow,

they come in contact with soils where they are adsorbed, mainly to clayey particles. Due to high evapotranspiration rates experienced in this region, soil moisture is removed from shallow soils resulting in salt and carbonate buildup which remove trace metals from water in soils. These sequestered trace metals require acidic conditions, which are not expected in agricultural soils, to be released. As trace metals move past clayey soils, their concentrations tend to decrease with depth as groundwater is encountered, with the exception of Zn. Vegetation uptake may act as a sink for some trace metals to be removed from soils and water, but further analysis would be required to assess that factor. Once in groundwater, high concentrations of dissolved Zn, and low concentrations of the other trace metals, may flow towards drainage canals which lead back into the Rio Grande where river water will be used in downstream locations carrying these trace metals encountered in groundwater at the pecan orchard.

Future work

During this study, the quantification of different fluxes is limited due to missing information such as an incomplete sample set of solid and aqueous amendments applied to the pecan orchard. Loading rates were only available for only four of the soil amendments resulting in an underestimation of trace metal concentrations in the mass balance. The soil profile was only advanced to a depth of 3 m which provides a small set of data that may not encompass the entire root zone of pecan trees. Deeper soil sampling can provide better insight into soil textures and the geochemical makeup of soils under the water table. Furthermore, analysis of vegetation was not performed which is an important sink for trace metals. Dust and precipitation sources were not accounted for in this study, but are also important variables to be assessed. During the resistivity survey, other zones with high conductivity were observed in the cross section which could be an important factor in characterizing soils across the pecan orchard in this study. Finally, groundwater beneath the pecan orchard seeps into drainage canals, but with the absence of a physical conduit such as a drainage pipe underneath the orchard, samples are hard to collect which would address the flux of groundwater leaving the pecan orchard and helping with the differentiation between groundwater recharge and lateral flow. Future studies involving these factors can provide a closer understanding to a complex system such as this agricultural field situated in the flood plain of a major river utilized for urban, industrial, and agricultural needs that is situated and shared between two nations, United States and Mexico, with different environmental laws, quality standards, and agricultural practices.

Table 1: Soil amendments: Solid

Solid Additions						
Sample ID	**Amendment**	**Treatment**	**Micro nutrient%**	**Component**	**Yearly rates Kg/acre/yr**	**Purpose**
F2	H-85 Potassium	soil			2.26	
F5	Rootex	soil		P2O5 2%; K2O 3%	2.26	plant nutrient
F1	K2CO3	soil			6.8	
F3	UREA	soil		~41.7kg N/acre/yr	90.7	
F4	Triplex micro	foliar	B 2%;Cu 2%;F 6%;Mn 6%,;Mo 0.001%; Zn 6%			
F7	Triplex Zn	soil	ZnSO4 ±25%			
	Sulfur/gypsum/humic acid	soil	N 0.45%;PO4 0.4%;K 0.91%;S 6%;T S 63%;HumicA 9.47%;FulvicA 7.57%;CaSO4*2H2O 28%; TC 6.07%; TOM 10.44%; Mg 0.26%; Comb Micro<3.40%	Comb Micro: Fe;B; Zn;Cu;Se and REE	226.76	soil acidification by soil bacteria; water penetration; increase nutrient availability, tilth, root and shoot growth; OrgA microbial growth
F6	Redox Supreme	foliar				
F8	DiKap	foliar				

Table 2: Soil Amendments: Aqueous

Aqueous Solutions								
Amendment	**Brand**	**Treatment**	**N-P-K**	**Micro nutrient%**	**Ca2+ mg/kg**	**Component**	**Yearly rates L/acre/yr**	**Purpose**
Calcine:Water Treatment	Calcine	soil					1.8	
3-way mix:	Medina	soil						
Soil Activator				Mg 0.5%;Fe 0.1%;Zn 0.1%;pH=2.5		MgSO4;FesO4;ZnSO4	1.89 soil activator	soil microbe food source
Molases							0.94 molases	
Humate						Ligno Proteins 12%	0.94 humate	Increase root growth; fruit, branching, compactness plant growth, respiration; prevent leaching; buffer plants against fertilizers
Calcium Silicate	Mainstay	soil/foliar		Ca 10%;SiO2 22%			0.94-18.9 soil	increase N and O retention and decrease leaching; water retention; improves soil biologics and plant biomass; chelator prevents carbonate and bicarbonate; removes salts and replaces with Ca; improves permeability
							0.49-4.73 foliar	
MicroAlgae	Phyco Terra	soil		P2O5 3%		chemotrophic algae	3.78	decrease soil salinity

Table 3: Texture and chemistry of natural and agricultural soils

Depth	Sand	Silt	Clay	Texture	pH	EC	Be	B	Al	P	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Ba	Ti	Pb	U	Be	B	Al	P	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Ti	Pb	U
cm	%	%	%		Water soluble fraction (mg/kg soils for elemental concentrations, mS/cm for EC)																							Acetic acid soluble faction (mg/kg soils for elemental concentrations)																			
Natural Site: Fabens																																															
0-20	95	3	2	Fine Sand	6.6	0.08	0.00	0.05	0.08	0.59	0.03	0.00	0.00	0.11	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.2	0.00	0.03	0.00	0.02	0.00	0.05	0.00	108	51.8	0.01	0.07	33	3	0.12	0.23	0.02	1.9	0.13	0.07	0.05	11	0.04	0.00	0.70	0.02
20-40	80	13	7	Loamy Fine Sand	8.3	0.76	0.00	1.14	1.44	1.16	2.11	0.00	0.01	0.70	0.00	0.01	0.04	0.12	0.14	0.00	0.00	0.0	0.00	0.00	0.00	0.01	0.01	0.04	0.00	88	33.6	0.05	0.11	34	3	0.12	0.47	0.27	4.1	1.11	0.23	0.07	113	0.07	0.00	1.23	0.15
40-60	57	38	5	Sandy Loam	7.9	5.09	0.00	5.46	0.00	0.00	1.50	0.00	0.00	0.03	0.00	0.00	0.01	0.18	0.19	0.01	0.01	6.0	0.00	0.04	0.00	0.01	0.04	0.08	7.87	85	16.9	0.12	0.13	98	2	0.22	0.63	0.13	6.2	2.09	0.42	0.10	116	0.10	0.00	1.03	0.74
60-71	51	42	7	Loam	7.5	5.61	0.00	6.46	0.00	0.00	1.28	0.00	0.00	0.05	0.00	0.00	0.01	0.23	0.18	0.01	0.01	8.0	0.00	0.02	0.00	0.01	0.04	0.08	8.18	67	41.5	0.08	0.13	119	2	0.26	0.54	0.10	0.0	1.84	0.50	0.10	68	0.12	0.00	0.60	1.24
71-81	49	43	8	Loam	7.4	6.13	0.00	4.84	0.00	0.00	0.86	0.00	0.00	0.04	0.00	0.00	0.00	0.09	0.14	0.01	0.01	7.6	0.00	0.02	0.00	0.01	0.06	0.09	7.13	53	43.1	0.06	0.14	117	2	0.25	0.45	0.08	0.0	1.65	0.47	0.10	53	0.12	0.00	0.58	1.54
81-90	43	51	6	Silt Loam	7.6	6.00	0.00	4.49	0.00	0.00	0.67	0.00	0.00	0.04	0.00	0.00	0.00	0.13	0.12	0.01	0.01	7.6	0.00	0.01	0.00	0.00	0.08	0.06	8.56	56	59.9	0.04	0.14	119	2	0.28	0.51	0.06	0.0	1.63	0.57	0.11	47	0.13	0.00	0.53	1.82
90-99	42	53	6	Silt Loam	7.5	6.23	0.00	4.32	0.00	0.00	0.50	0.00	0.00	0.04	0.00	0.00	0.00	0.07	0.09	0.01	0.01	7.5	0.00	0.04	0.00	0.00	0.07	0.07	6.39	63	70.3	0.03	0.14	100	2	0.25	0.53	0.05	0.0	1.36	0.54	0.12	51	0.11	0.00	0.52	1.74
99-109	40	58	3	Silt Loam	7.1	6.01	0.00	3.73	0.00	0.00	0.41	0.00	0.00	0.03	0.00	0.00	0.00	0.12	0.08	0.00	0.01	6.4	0.00	0.01	0.00	0.00	0.07	0.06	9.02	51	34.4	0.03	0.13	128	2	0.26	0.48	0.03	3.1	1.22	0.62	0.14	83	0.14	0.00	0.85	2.00
Pecan Fine soil profile																																															
0-10	37	50	13	silt loam	7.3	1.80	0.00	0.54	0.00	1.47	0.02	0.00	0.00	0.05	0.00	0.01	0.03	0.18	0.02	0.00	0.02	14.2	0.00	0.23	0.00	0.00	0.00	0.17	4.25	75	70.3	2.36	0.43	453	217	1.74	2.24	1.24	20.7	0.75	0.27	0.26	104	0.22	0.00	1.55	0.30
10-20	36	49	15	loam	7.4	2.85	0.00	0.48	0.00	0.98	0.02	0.00	0.10	0.04	0.00	0.01	0.02	0.17	0.02	0.00	0.02	12.3	0.00	0.16	0.00	0.00	0.00	0.16	3.19	73	66.9	0.16	0.37	501	102	1.37	2.91	0.68	12.3	0.93	0.38	0.20	128	0.22	0.00	1.84	0.29
20-30	32	63	6	silt loam	7.5	2.25	0.00	0.54	0.00	0.81	0.01	0.00	0.02	0.03	0.00	0.00	0.03	0.12	0.02	0.00	0.02	11.9	0.00	0.09	0.00	0.00	0.00	0.17	3.22	77	82.0	0.05	0.25	280	8	0.22	4.86	1.04	10.1	1.10	0.56	0.20	142	0.21	0.00	1.65	0.29
30-40	35	57	8	silt loam	7.6	2.30	0.00	0.54	0.00	0.24	0.01	0.00	0.02	0.01	0.00	0.01	0.02	0.15	0.01	0.00	0.02	7.2	0.00	0.05	0.00	0.02	0.00	0.17	2.94	84	89.3	0.04	0.27	284	8	0.28	3.20	0.54	10.6	1.14	0.51	0.23	139	0.22	0.00	1.76	0.31
40-50	32	55	14	silt loam	7.6	2.76	0.00	0.63	0.00	0.39	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.38	0.01	0.00	0.02	10.9	0.00	0.06	0.00	0.00	0.01	0.17	3.28	102	51.8	0.04	0.30	283	10	0.28	2.13	0.40	10.4	0.98	0.63	0.23	145	0.21	0.00	1.68	0.36
50-60	52	40	8	loam	7.7	1.24	0.00	0.52	0.00	0.39	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.07	0.01	0.00	0.01	6.1	0.00	0.05	0.00	0.00	0.00	0.17	1.93	108	43.7	0.05	0.30	294	21	0.32	2.10	0.45	10.2	0.78	0.64	0.19	116	0.16	0.00	1.63	0.32
60-70	30	46	25	loam	7.8	2.29	0.00	0.69	0.00	0.49	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.17	0.02	0.00	0.01	4.2	0.00	0.05	0.00	0.00	0.01	0.15	4.26	97	64.1	0.04	0.26	248	7	0.24	2.04	0.32	11.1	1.28	0.55	0.25	142	0.21	0.00	1.67	0.34
70-84	24	51	26	silt loam	7.6	3.68	0.00	0.80	0.00	0.25	0.01	0.00	0.00	0.02	0.00	0.01	0.00	0.12	0.01	0.01	0.02	12.5	0.00	0.06	0.00	0.02	0.01	0.20	4.89	105	54.4	0.04	0.30	272	8	0.23	1.59	0.33	12.2	0.99	0.65	0.28	165	0.23	0.00	1.66	0.44
84-90	6	52	43	Silty Clay	7.5	3.33	0.00	0.87	0.00	0.47	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.08	0.01	0.01	0.01	7.2	0.00	0.03	0.00	0.00	0.01	0.24	4.94	135	27.6	0.04	0.33	223	17	0.25	2.18	0.38	11.9	0.62	0.74	0.28	154	0.23	0.00	1.56	0.41
90-100	1	50	49	Silty Clay	7.8	2.78	0.00	0.80	0.00	0.63	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.09	0.01	0.01	0.01	3.2	0.00	0.01	0.00	0.00	0.01	0.19	4.88	91	22.6	0.03	0.26	228	9	0.12	1.68	0.33	11.5	0.63	0.76	0.31	183	0.22	0.00	1.19	0.39
100-110	1	24	75	Clay	7.6	3.00	0.00	0.78	0.00	0.77	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	3.0	0.00	0.02	0.00	0.00	0.01	0.18	3.95	86	24.5	0.04	0.26	266	8	0.20	1.47	0.32	11.7	0.61	0.71	0.30	170	0.19	0.00	1.35	0.36
110-120	1	39	61	Clay	7.7	3.28	0.00	0.79	0.00	0.52	0.02	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.02	0.02	0.01	4.0	0.00	0.01	0.00	0.00	0.01	0.17	4.08	81	25.6	0.04	0.24	284	6	0.16	1.50	0.32	10.8	0.65	0.72	0.30	174	0.17	0.00	1.14	0.35
120-130	1	48	51	Silty Clay	7.7	3.63	0.00	0.76	0.00	0.79	0.02	0.00	0.02	0.00	0.00	0.01	0.01	0.24	0.02	0.02	0.01	4.1	0.00	0.03	0.00	0.00	0.01	0.29	3.87	101	36.7	0.05	0.28	294	9	0.11	1.75	0.43	9.7	0.80	0.77	0.29	163	0.18	0.00	1.17	0.39
130-140	1	68	31	Silty Clay Loam	7.8	3.45	0.00	0.74	0.00	0.66	0.03	0.00	0.01	0.00	0.00	0.01	0.01	0.19	0.03	0.02	0.01	4.0	0.00	0.03	0.00	0.02	0.01	0.16	3.49	64	21.9	0.08	0.32	472	8	0.28	2.02	0.64	12.8	1.09	1.10	0.32	246	0.23	0.00	1.90	0.61
140-150	31	61	8	Silt Loam	7.7	1.74	0.00	0.60	0.00	0.38	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.14	0.03	0.01	0.02	5.3	0.00	0.09	0.00	0.00	0.01	0.19	0.00	75	20.4	0.13	0.33	536	26	0.32	1.51	0.76	9.0	0.87	0.79	0.21	277	0.19	0.00	1.89	0.91
150-160	66	29	5	Sandy Loam	7.8	1.62	0.00	0.53	0.00	0.34	0.03	0.00	0.01	0.00	0.00	0.00	0.02	0.08	0.02	0.01	0.01	2.7	0.00	0.05	0.00	0.01	0.00	0.14	0.00	82	36.5	0.09	0.24	343	37	0.59	1.21	0.45	7.1	0.65	0.49	0.12	127	0.12	0.00	1.41	0.42
160-170	49	39	12	Loam	7.6	1.85	0.00	0.55	0.00	0.40	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.21	0.03	0.01	0.01	1.6	0.00	0.03	0.00	0.00	0.00	0.15	0.00	75	26.4	0.13	0.31	396	57	0.98	1.76	0.81	8.2	0.75	0.59	0.14	147	0.15	0.00	1.68	0.43
170-180	49	48	4	Sandy Loam	7.4	1.88	0.00	0.51	0.00	0.38	0.04	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.03	0.01	0.01	1.6	0.00	0.05	0.00	0.00	0.00	0.12	1.62	63	20.5	0.10	0.22	293	45	0.55	1.39	0.57	7.2	0.61	0.44	0.12	106	0.12	0.00	1.36	0.32
180-190	74	24	1	Loamy Fine Sand	7.5	1.70	0.00	0.62	0.00	0.34	0.03	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.03	0.01	0.01	2.2	0.00	0.03	0.00	0.01	0.00	0.14	1.80	65	30.2	0.12	0.23	249	65	0.87	1.32	0.51	6.8	0.66	0.42	0.12	75	0.10	0.00	1.31	0.28
190-200	78	13	9	Sandy Loam	7.4	1.45	0.00	0.45	0.00	0.71	0.05	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.03	0.01	0.01	0.7	0.00	0.04	0.00	0.02	0.00	0.15	1.41	64	33.7	0.17	0.19	207	62	0.76	1.25	0.40	6.5	0.58	0.42	0.11	59	0.08	0.00	1.30	0.21
200-210	80	14	6	Loamy Fine Sand	7.3	1.28	0.00	0.46	0.00	0.68	0.06	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.03	0.01	0.01	0.9	0.00	0.03	0.00	0.01	0.00	0.16	1.76	72	39.3	0.17	0.21	206	42	0.76	1.24	0.41	6.7	0.56	0.42	0.12	62	0.09	0.00	1.35	0.25
210-220	78	19	3	Loamy Fine Sand	7.3	1.38	0.00	0.48	0.00	0.51	0.10	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.01	1.1	0.00	0.00	0.00	0.00	0.00	0.14	1.61	68	38.3	1.10	0.23	203	28	0.92	1.55	0.53	6.7	0.55	0.38	0.11	57	0.10	0.00	1.50	0.31
220-230	76	22	2	Loamy Fine Sand	7.3	1.51	0.00	0.65	0.00	0.43	0.08	0.00	0.02	0.00	0.00	0.01	0.02	0.13	0.02	0.10	0.01	1.8	0.00	0.02	0.00	0.02	0.01	0.17	2.09	73	35.2	1.92	0.27	191	48	1.38	1.87	0.64	7.2	0.60	0.37	0.12	53	0.09	0.00	1.68	1.19
230-240	78	18	4	Loamy Fine Sand	7.5	2.09	0.00	0.57	0.00	0.35	0.06	0.00	0.01	0.00	0.00	0.00	0.02	0.19	0.03	0.02	0.01	1.4	0.00	0.01	0.00	0.00	0.00	0.18	1.64	74	33.8	2.02	0.23	179	88	1.24	1.59	0.64	7.4	0.59	0.38	0.11	42	0.09	0.00	1.67	1.33
240-250	84	15	1	Loamy Fine Sand	7.2	1.19	0.00	0.49	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.02	0.01	1.9	0.00	0.04	0.00	0.00	0.01	0.15	1.57	77	33.0	2.03	0.25	167	122	1.17	1.42	0.60	7.1	0.57	0.35	0.11	36	0.08	0.00	1.57	1.02
250-260	84	10	5	Loamy Fine Sand	7.3	1.15	0.00	0.39	0.00	0.32	0.03	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	1.9	0.00	0.07	0.00	0.01	0.00	0.14	1.22	76	38.6	1.36	0.22	147	119	0.79	1.10	0.48	6.5	0.44	0.36	0.11	29	0.06	0.00	1.34	0.41
260-270	86	13	2	Loamy Fine Sand	7.4	1.33	0.00	0.33	0.00	0.41	0.02	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	2.5	0.00	0.09	0.00	0.00	0.00	0.10	1.30	69	86.5	0.33	0.16	149	59	0.63	0.83	0.36	5.9	0.41	0.24	0.10	29	0.06	0.00	1.04	0.22
270-280	92	7	1	Fine Sand	7.5	1.02	0.00	0.28	0.00	0.36	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	1.4	0.00	0.09	0.00	0.01	0.00	0.11	0.00	66	43.5	0.82	0.16	122	136	0.68	0.73	0.36	4.9	0.35	0.29	0.09	23	0.04	0.00	0.99	0.16
280-290	94	6	0	Fine Sand	7.2	0.96	0.00	0.25	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	1.3	0.00	0.07	0.00	0.01	0.00	0.11	0.00	57	40.5	0.75	0.14	107	123	0.57	0.55	0.29	4.5	0.32	0.28	0.08	17	0.03	0.00	0.84	0.11
Pecan Coarse soil profile																																															
0-10	44	45	11	Loam	7.2	0.49	0.00	1.24	0.00	3.32	0.04	0.00	2.30	0.02	0.01	0.02	0.00	0.00	0.03	0.00	0.01	2.5	0.00	0.13	0.00	0.02	0.00	0.11	6.96	51	396.1	1.14	0.13	332	2279	1.48	2.15	0.00	28.0	1.43	0.10	0.24	73	0.07	0.00	0.98	0.08
10-20	53	40	7	Sandy Loam	7.2	0.41	0.00	0.63	0.00	2.02	0.05	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.05	0.00	0.01	1.1	0.00	0.07	0.00	0.00	0.00	0.13	5.50	80	158.2	0.06	0.27	279	21	0.24	1.11	0.33	14.0	1.30	0.27	0.25	107	0.18	0.00	1.27	0.20
20-30	53	41	6	Sandy Loam	7.4	0.45	0.00	0.45	0.00	2.76	0.05	0.00	0.01	0.01	0.00	0.02	0.02	0.00	0.06	0.00	0.01	0.7	0.00	0.03	0.00	0.00	0.00	0.15	3.77	103	149.6	0.03	0.22	231	7	0.22	1.23	0.19	10.7	1.14	0.37	0.21	89	0.15	0.00	1.25	0.21
30-40	50	39	11	Loam	7.3	0.60	0.00	0.38	0.00	1.25	0.04	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.07	0.00	0.01	0.9	0.00	0.02	0.00	0.00	0.00	0.16	3.62	112	133.7	0.04	0.22	208	6	0.21	1.32	0.23	10.7	1.59	0.42	0.20	91	0.17	0.00	1.20	0.20
40-50	70	19	11	Sandy Loam	7.3	0.47	0.00	0.24	0.00	1.10	0.06	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	0.7	0.00	0.03	0.00	0.01	0.00	0.15	2.53	123	117.8	0.03	0.19	140	8	0.17	0.93	0.18	7.9	1.23	0.31	0.14	51	0.09	0.00	0.87	0.13
50-60	71	26	3	Sandy Loam	7.4	0.82	0.00	0.24	0.00	0.63	0.04	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	1.9	0.00	0.05	0.00	0.00	0.00	0.15	2.37	118	84.3	0.04	0.19	165	10	0.21	1.04	0.21	8.2	0.94	0.34	0.13	60	0.11	0.00	0.93	0.15
60-70	76	20	3	Loamy Fine Sand	7.3	0.66	0.00	0.27	0.00	0.64	0.05	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	1.5	0.00	0.04	0.00	0.00	0.00	0.15	2.97	120	97.7	0.04	0.18	157	8	0.18	0.98	0.20	8.1	1.15	0.35	0.14	58	0.11	0.00	0.90	0.14
70-84	86	6	8	Loamy Fine Sand	7.0	0.32	0.00	0.17	0.00	0.69	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.7	0.00	0.03	0.00	0.00	0.00	0.11	1.38	94	76.6	0.04	0.14	104	14	0.29	0.68	0.14	5.6	0.66	0.24	0.08	25	0.05	0.00	0.70	0.08
84-90	87	9	4	Loamy Fine Sand	7.2	0.65	0.00	0.17	0.00	0.43	0.04	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	1.1	0.00	0.05	0.00	0.00	0.00	0.10	1.55	92	78.2	0.05	0.18	111	11	0.40	0.78	0.15	5.1	0.72	0.19	0.08	28	0.06	0.00	0.73	0.08
90-100	92	5	2	Fine Sand	6.9	0.51	0.00	0.15	0.00	0.81	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	1.3	0.00	0.05	0.00	0.00	0.00	0.08	1.09	65	55.9	0.07	0.14	89	18	0.48	0.60	0.13	4.1	0.49	0.19	0.05	19	0.03	0.00	0.64	0.07
100-110	75	24	1	Loamy Fine Sand	7.1	0.47	0.00	0.19	0.00	0.54	0.02	0.01	0.35	0.03	0.00	0.01	0.01	0.00	0.04	0.00	0.01	1.8	0.00	0.06	0.00	0.00	0.00	0.07	1.10	69	65.8	0.11	0.15	102	10	0.56	0.69	0.13	5.5	0.53	0.17	0.07	24	0.04	0.00	0.70	0.07
110-120	64	9	28	Sandy Clay Loam	7.3	1.13	0.00	0.50	0.78	0.43	0.04	0.02	0.22	0.22	0.00	0.01	0.00	0.13	0.05	0.00	0.01	4.1	0.00	0.19	0.00	0.00	0.00	0.11	2.28	86	107.0	0.04	0.19	152	6	0.28	0.90	0.18	7.5	1.35	0.26	0.12	58	0.10	0.00	0.90	0.13
120-130	67	10	23	Sandy Clay Loam	7.6	2.78	0.00	0.50	0.00	0.31	0.04	0.00	0.53	0.00	0.00	0.01	0.00	0.00	0.06	0.00	0.01	4.1	0.00	0.07	0.00	0.00	0.00	0.14	2.50	86	105.5	0.05	0.21	153	7	0.26	0.75	0.21	7.7	1.46	0.27	0.12	66	0.10	0.00	0.98	0.16
130-140	84	14	2	Loamy Fine Sand	7.6	0.97	0.00	0.48	0.00	0.38	0.04	0.00	0.26	0.02	0.00	0.01	0.01	0.00	0.05	0.00	0.01	4.2	0.00	0.09	0.00	0.00	0.00	0.08	2.32	77	129.8	0.07	0.14	139	7	0.33	0.72	0.20	7.1	1.22	0.24	0.10	56	0.08	0.00	0.75	0.12
140-150	87	11	2	Fine Sand	7.3	0.85	0.00	0.25	0.00	0.31	0.04	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.01	2.5	0.00	0.04	0.00	0.00	0.00	0.07	1.27	54	62.3	0.14	0.11	75	8	0.51	0.34	0.15	4.4	0.52	0.15	0.05	20	0.03	0.00	0.55	0.07
150-160	95	3	2	Fine Sand	7.4	0.49	0.00	0.21	0.11	0.70	0.06	0.02	0.00	0.11	0.00	0.01	0.02	0.00	0.04	0.00	0.01	1.1	0.00	0.06	0.00	0.00	0.00	0.05	0.93	58	71.6	0.13	0.09	53	9	0.36	0.33	0.13	4.2	0.44	0.11	0.05	12	0.02	0.00	0.47	0.04
160-170	97	3	0	Fine Sand	7.1	0.34	0.00	0.14	0.00	0.46	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.7	0.00	0.02	0.00	0.00	0.00	0.06	0.95	63	67.9	0.30	0.13	54	15	0.43	0.38	0.13	3.5	0.42	0.14	0.04	10	0.02	0.00	0.49	0.04
170-180	97	2	1	Fine Sand	7.1	0.30	0.00	0.09	0.00	0.83	0.04	0.01	0.00	0.10	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.4	0.00	0.03	0.00	0.00	0.00	0.08	0.00	54	68.5	0.58	0.10	37	30	0.37	0.25	0.11	3.5	0.34	0.16	0.04	7	0.01	0.00	0.41	0.03
180-190	97	1	1	Fine Sand	7.0	0.36	0.00	0.12	0.00	0.70	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.8	0.00	0.03	0.00	0.00	0.00	0.09	0.00	54	63.8	0.62	0.11	37	29	0.39	0.28	0.15	2.9	0.33	0.14	0.04	7	0.01	0.00	0.40	0.03
190-200	97	2	1	Fine Sand	7.0	0.33	0.00	0.25	0.00	1.55	0.16	0.01	0.00	0.05	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.4	0.00	0.04	0.00	0.00	0.00	0.07	0.90	57	78.8	1.33	0.12	49	17	0.62	0.42	0.22	4.1	0.32	0.15	0.05	9	0.02	0.00	0.49	0.04
200-210	97	1	2	Fine Sand	7.3	0.37	0.00	0.25	0.23	1.24	0.11	0.02	0.00	0.13	0.00	0.01	0.02	0.00	0.05	0.00	0.01	0.4	0.00	0.06	0.00	0.00	0.00	0.07	0.00	53	77.1	0.87	0.11	43	21	0.35	0.29	0.11	3.8	0.30	0.19	0.04	9	0.02	0.00	0.35	0.04
210-220	97	1	2	Fine Sand	7.2	0.53	0.00	0.32	0.00	1.45	0.05	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.6	0.00	0.04	0.00	0.00	0.00	0.06	0.96	49	64.4	0.59	0.10	49	15	0.37	0.29	0.13	4.1	0.29	0.14	0.04	12	0.02	0.00	0.41	0.05
220-230	91	7	2	Fine Sand	7.1	0.63	0.00	0.39	0.00	1.37	0.04	0.02	0.00	0.09	0.00	0.01	0.01	0.00	0.04	0.00	0.01	1.0	0.00	0.07	0.00	0.00	0.00	0.06	1.17	52	75.4	0.51	0.08	57	15	0.46	0.31	0.15	4.6	0.32	0.17	0.05	10	0.02	0.00	0.44	0.04
230-240	92	1	7	Fine Sand	7.0	0.65	0.00	0.36	0.00	0.78	0.04	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.03	0.00	0.01	1.4	0.00	0.05	0.00	0.00	0.00	0.08	0.99	62	77.3	0.67	0.16	67	20	0.62	0.39	0.13	3.7	0.33	0.20	0.05	10	0.02	0.00	0.51	0.05
240-250	96	0	4	Fine Sand	7.0	0.53	0.00	0.31	0.00	1.20	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.9	0.00	0.04	0.00	0.00	0.00	0.08	0.94	60	68.4	0.48	0.15	72	25	0.67	0.51	0.26	5.4	0.36	0.20	0.13	11	0.03	0.00	0.52	0.05
250-260	97	2	1	Fine Sand	7.0	0.66	0.00	0.23	0.00	1.24	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.6	0.00	0.06	0.00	0.00	0.00	0.08	0.00	54	63.0	0.56	0.13	63	27	0.55	0.37	0.11	4.1	0.32	0.21	0.06	9	0.02	0.00	0.44	0.04

Table 4: Elemental chemistry of water samples collected from the pecan orchard

Water Type	Sample Date	pH	EC mS/cm	NO3 ppm	PO4 ppm	Cl ppm	SO4 ppm	Ca ppm	K ppm	Mg ppm	Na ppm	P ppm	Si ppm	Sr ppm	Be ppb	B ppb	Al ppb	P ppb	V ppb	Cr ppb	Mn ppb	Fe ppb	Co ppb	Ni ppb	Cu ppb	Zn ppb	As ppb	Se ppb	Rb ppb	Sr ppb	Cd ppb	Ba ppb	Pb ppb	U ppb
Irrigation: River Water		8.5	1043	11.3	2.3	116.4	174.7	72.8	10.6	9.7	131.6	0.6	7.5	0.8	0.02	235	2.5	890	8.5	0.1	0.8	6.3	0.7	2.2	2.7	18.6	4.8	0.5	9.4	820	0.2	88.2	0.2	2.5
		8.4	861	4.8	1.1	81.6	150.1	67.2	8.5	7.8	101.6	0.3	8.7	0.7	0	192	7.4	574	9.8	0.1	0.5	6.4	0.6	1.9	1.8	6.6	4.8	0.3	7.5	762	0.1	84.6	0.4	2.8
		8.6	1106	8.4	1.7	119.9	185.8	77.2	9.1	10.2	135.4	0.5	10.0	0.9	0	227	1.8	842	7.6	0.1	2.4	5.9	0.4	1.9	2.1	7.0	5.4	0.4	8.1	929	0.1	86.9	0.2	2.6
		8.5	842	4.9	0.9	79.2	137.9	63.4	7.9	7.1	96.1	0.3	8.7	0.7	0.03	177	3.5	497	8.3	0.1	0.2	5.2	0.5	1.7	1.7	0	4.8	0.2	7.5	763	0.1	82.1	0.1	2.6
		8.55	1110	7.1	0.8	120.0	191.9	79.0	8.7	10.7	136.1	0.3	9.4	0.9	0	232	3.6	646	9.4	0.1	0.1	6.1	0.6	2.0	1.7	11.1	5.8	0.4	8.3	936	0.1	104.0	0.3	2.7
		8.4	988	6.5	0.9	105.3	166.7	68.5	8.7	9.3	121.6	0.2	9.4	0.8	0	208	6.2	575	10.1	0.1	0.5	6.3	0.6	2.7	1.9	11.2	5.8	0.3	7.4	837	0.2	90.0	0.7	2.9
		9	1184	6.5	1.0	143.8	195.0	74.2	9.5	11.1	154.0	0.4	9.1	1.0	0	261	3.7	716	11.1	0.1	0.7	5.4	0.9	2.3	1.6	0	6.5	0.4	8.3	976	0.1	104.0	0.2	2.7
		8.64	2070	38.3	4.5	354.0	348.2	88.8	16.5	17.0	340.1	1.7	11.7	1.4	0	476	3.8	2646	13.6	0.1	11.4	11.4	1.9	3.9	1.6	12.5	7.9	1.6	14.4	1323	0.1	139.0	0.3	1.7
Irrigation: Ground Water															0	509	0	134	0.2	0.1	1183	14.3	0.1	1.4	0.0	0	3.6	0	5.0	3092	0.1	58.7	6.6	1.8
		7.34	3010												0.04	498	0	119	1.0	0.1	1192	15.0	0.2	1.5	0.0	0	3.4	0	5.2	3237	0.1	54.2	8.1	1.9
Soil Water (15 cm)		8.1	1439	9.2	5.2	139.3	282.1	147.9	24.4	12.4	153.5	1.5	17.0	1.5	0	1283	11.1	1052	28.4	0.3	1.4	59.8	1.0	16.1	7.5	80.9	49.9	0.7	17.2	12696	0.7	147.8	4.6	38.4
		8.7	1690	68.6	4.5	198.8	282.7	171.2	28.5	18.5	192.3	1.4	15.2	1.8	0	1265	7.1	656	34.1	0.3	1.4	71.6	0.9	17.8	8.5	42.7	48.7	0.8	17.3	13362	0.1	115.1	0.2	36.6
				101.2	1.2	728.2	1310.8	561.2	43.6	90.9	611.8	0.4	22.9	6.2	0.03	1125	3.0	744	29.0	0.5	2.0	59.1	0.8	13.5	7.0	201.1	47.9	0.8	14.5	11891	0.1	90.0	0	26.9
															0.03	841	0	1828	2.2	0.2	547.7	142.7	1.5	4.7	2.5	0.0	7.7	0.1	9.6	3977	0.0	277.8	0	4.4
Soil Water (30 cm)		7.9	2910	212.7	11.4	311.9	695.5	356.4	44.3	39.4	317.7	3.9	21.6	4.1	0	443	8.3	2435	15.4	0.6	2.2	13.9	0.4	5.2	9.3	43.4	15.8	0.3	5.5	1473	0.2	110.3	1.2	1.5
		7.9	2600	114.7	6.6	305.5	548.9	286.4	38.1	32.7	308.5	2.5	19.6	3.3	0	401	4.9	2188	10.0	0.2	2.8	14.6	0.4	3.5	8.5	61.7	16.0	0.3	7.3	1709	0.2	121.5	0.8	2.8
Soil Water (60 cm)				259.0	3.6	742.5	1399	524.1	54.8	94.0	629.6	1.6	30.2	6.0	0	861	4.1	2295	19.9	0.2	57.3	33.5	1.8	10.7	7.2	44.3	15.9	1.2	14.3	5799	0.2	151.5	0.3	12.0
				548.2	0.4	824.5	1534	609.1	49.9	102.6	686.9	0.4	28.8	6.9	0.03	899	35.3	697	19.3	0.2	20.2	35.8	1.1	9.8	6.1	41.1	7.1	1.2	11.9	6602	0.2	161.2	0.4	6.3
		7.92	4820	268.4	4.3	422.5	575.6								0	742	2.3	858	21.5	0.3	3.7	33.4	0.9	8.7	6.3	43.0	14.0	1.0	9.1	5901	0.1	102.1	0	22.0
															0	708	0	847	21.7	0.2	7.9	28.1	0.6	5.8	4.6	0.0	15.6	0.9	9.1	4950	0.04	104.0	0	17.5
Soil Water (120 cm)		8.1	4630	191.9	1.6	1952	3103	1007	89.4	238.9	1568.0	0.8	25.4	13.1	0	743	11.9	5536	5.8	0.4	9.6	37.5	0.9	15.2	30.4	240.0	25.5	0.5	8.7	3858	0.2	186.0	1.0	4.4
		7.8	4310	254.7	0.4	2080	3286	1067	90.9	248.4	1648.5	0.6	25.6	13.9	0.1	675	9.1	3509	10.1	0.2	2.5	41.6	0.5	16.1	13.7	54.4	19.7	0.4	7.8	3179	0.1	144.2	0.4	5.7
		7.67	4350	492.4	0.8	1804	2796								0.02	463	1.7	2329	10.6	0.2	0.7	22.2	0.5	4.5	6.0	16.1	14.4	0.3	6.5	3928	0.1	150.7	0	10.6
Water Well 1		7.8	2770	0.7	0.2	376.7	577.4	193.3	20.8	24.2	404.4		18.1	2.1	0.03	714	1.8	0	4.2	0.1	763	14.7	6.2	9.2	1.2	66968	14.6	0.1	3.3	2059	0.1	85.9	0.8	1.4
		8	3100	20.6	0.3	360.3	591.7	264.4	27.6	36.4	417.5		20.4	3.1	0.1	775	3.0	200	14.9	0.1	192	17.5	4.7	9.9	3.0	6317	20.9	0.4	5.6	2897	0.03	120.6	0.8	4.8
		7.9	1356	0.5	0.2	172.0	231.1	82.0	13.6	4.9	186.3		15.1	0.9	0	302	2.1	108	4.4	0.1	147	6.1	5.0	5.4	1.1	19704	18.8	0.2	2.5	849	0.2	55.8	6.2	0.7
		7.52	1506	n.a.	0.8	195.3	264.0	76.8	11.2	2.8	192.3		15.4	0.7	0	340	0	70	1.6	0.03	205	5.3	6.0	5.7	1.2	104919	12.3	0.1	2.3	729	0.3	54.3	4.5	0.6
															0	675	0	0	2.2	0	327	26.7	9.0	10.1	1.8	27196	1.3	0.2	4.1	2344	0.1	100.3	0	5.0
		6.68													0.03	486	0	54	0.1	0.02	226	4299.0	5.6	5.7	0.0	7127	3.0	0.1	3.5	2077	0.04	81.4	0	1.5
Water Well 2		8	2260	0.3	0.2	166.1	229.5	79.6	14.0	5.1	195.0	0.1	15.5	0.9	0.1	360	2.2	168	8.5	0.05	107	6.1	5.1	6.5	2.0	6575.1	19.9	0.2	2.6	844	0.3	55.4	3.1	0.7
		7.95	2600	1.1	0.5	325.4	511.3	210.8	23.0	37.9	345.5	0.0	16.8	2.7	0	561	5.0	378	6.0	0.05	444	13.8	2.0	7.0	3.5	6.0	31.3	0.4	4.1	2544	0.1	81.3	0.5	3.4
															0	378	0	344	6.2	0	892	10.4	2.6	5.6	2.3	0	37.7	0.1	2.9	1766	0.1	63.3	0	2.0
		6.73	3280												0	418	0	321	3.7	0.1	1508	47.9	3.0	7.3	0	0	31.0	0.0	4.2	3699	0.1	109.4	0	4.9
Water Well 3		7.6	2900	1.4	0.3	370.3	551.7	190.8	32.0	56.3	339.6	0.0	18.4	3.0	0	488	0	197	10.2	0.1	103	11.4	5.0	8.5	2.7	0	26.1	0.3	6.5	2780	0.0	71.8	0	2.6
		7.49	3130	0.5	0.8	381.4	612.1	297.6	30.8	58.8	368.9	0.0	18.0	3.7	0.04	550	5.8	434	5.8	0.1	573	27.5	5.7	9.5	2.6	0	23.3	0.2	6.0	3609	0.1	130.6	0.3	2.8
															0	738	0	256	11.4	0.1	400	25.9	3.8	9.8	7.5	12.2	19.0	0.2	5.5	4546	0.1	153.5	0	4.2

Table 5: Trace metal loading rates via soil amendments

Fertilizer Loading Rates						
B	P	V	Fe	Zn	As	Pb
µg/m^2/yr	µg/m^2/yr	µg/m^2/yr	µg/m^2/yr	µg/m^2/yr	µg/m^2/yr	µg/m^2/yr
0.8	131.0	0.08	1.8	2.5	0.01	1.3

Table 6: Mass balance: Trace metals

Trace Metal	Irrigation Input (90 years)	Soil Amendment Input (90 years)	Water Leachable	Acid Leachable	Mobile in Groundwater (90 years)
	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
As	0.6	0.001	0.18	2.9	1.0
Pb	0.2	0.01	0.004	2.7	0.05
P	87.0	11.8	4.0	389	10.3
V	0.9	0.007	0.2	1.3	0.3
Zn	0.8	0.2	0.02	26.8	520.9
B	34.5	0.07	1.3	7.2	23.1
Fe	0.9	0.07	0.1	396.5	13.7

Table 7: Trace metal concentrations: Soil amendments

Soil Amendment	**B**	**P**	**V**	**Fe**	**Zn**	**As**	**Pb**
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
F1	0.0	667.7	2.9	13.7	67.6	0.0	50.4
F2	211.5	968.3	4.0	2087.4	184.3	0.7	53.0
F3	26.8	614.8	3.1	16.1	102.9	0.1	51.4
F4	23508.5	664.7	3.2	46884.1	74819.2	0.1	54.2
F5	145.2	206890.3	3.5	405.1	0.0	17.9	61.1
F6	11648.4	71504.2	4.6	18614.6	35128.2	4.5	64.4
F7	0.0	691.9	1.2	41.5	267281.6	0.0	63.3
F8	0.0	140404.6	62.7	751.4	118.5	8.7	46.5

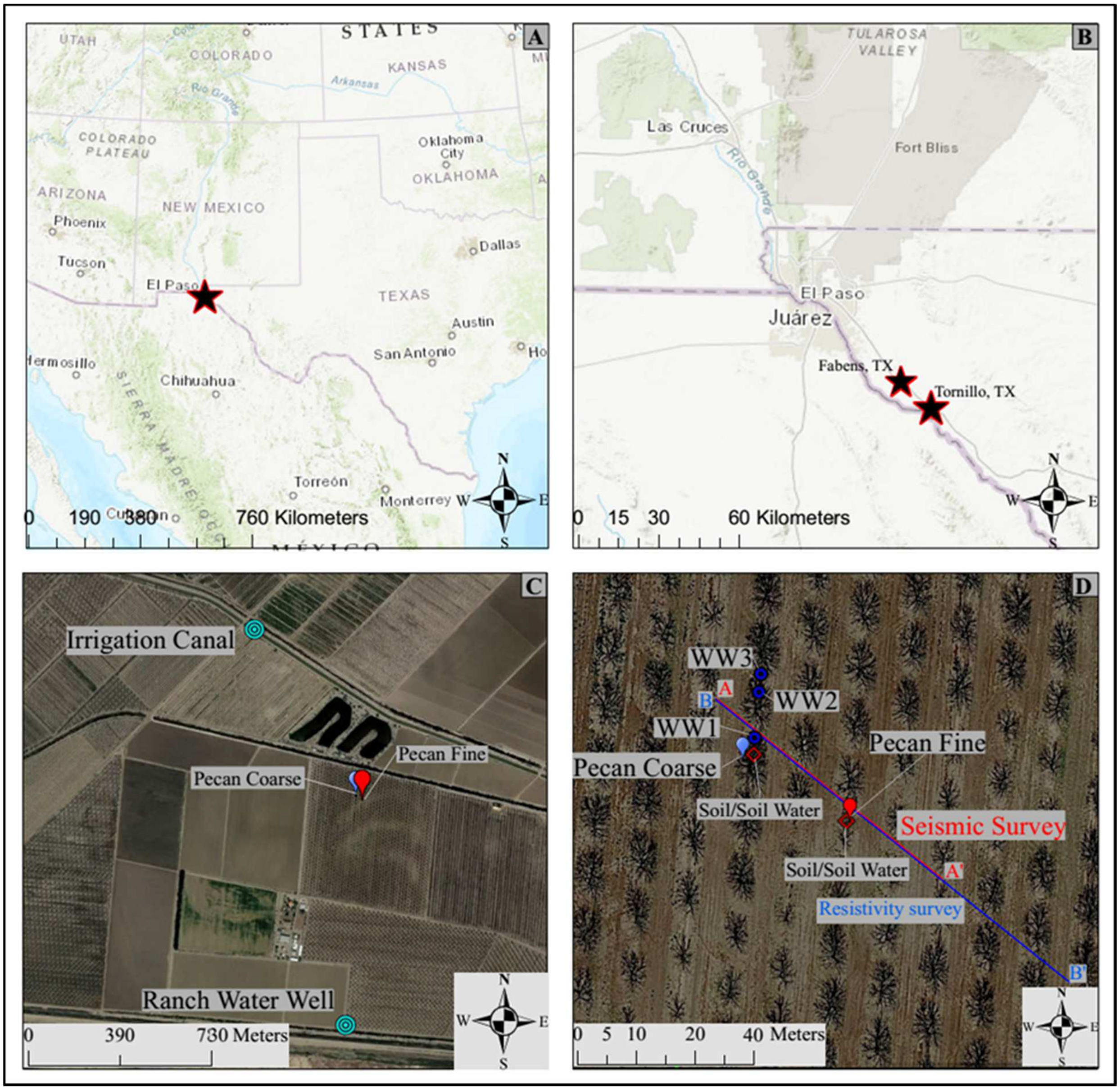


Figure 1: Location (A, B) and terrain (C) maps of the pecan orchard in Tornillo, Texas along the Rio Grande valley. Within the pecan orchard, two sites were chosen (Pecan Coarse and Pecan Fine) where soils and soil water samples were collected (C, D). In addition, irrigation water was sampled from irrigation canal and a ranch water well (blue circles in C), and groundwater was collected from three wells (WW1, WW2 and WW3; dark blue circles in D). Seismic survey and resistivity survey were carried out along A-A' and B-B'.

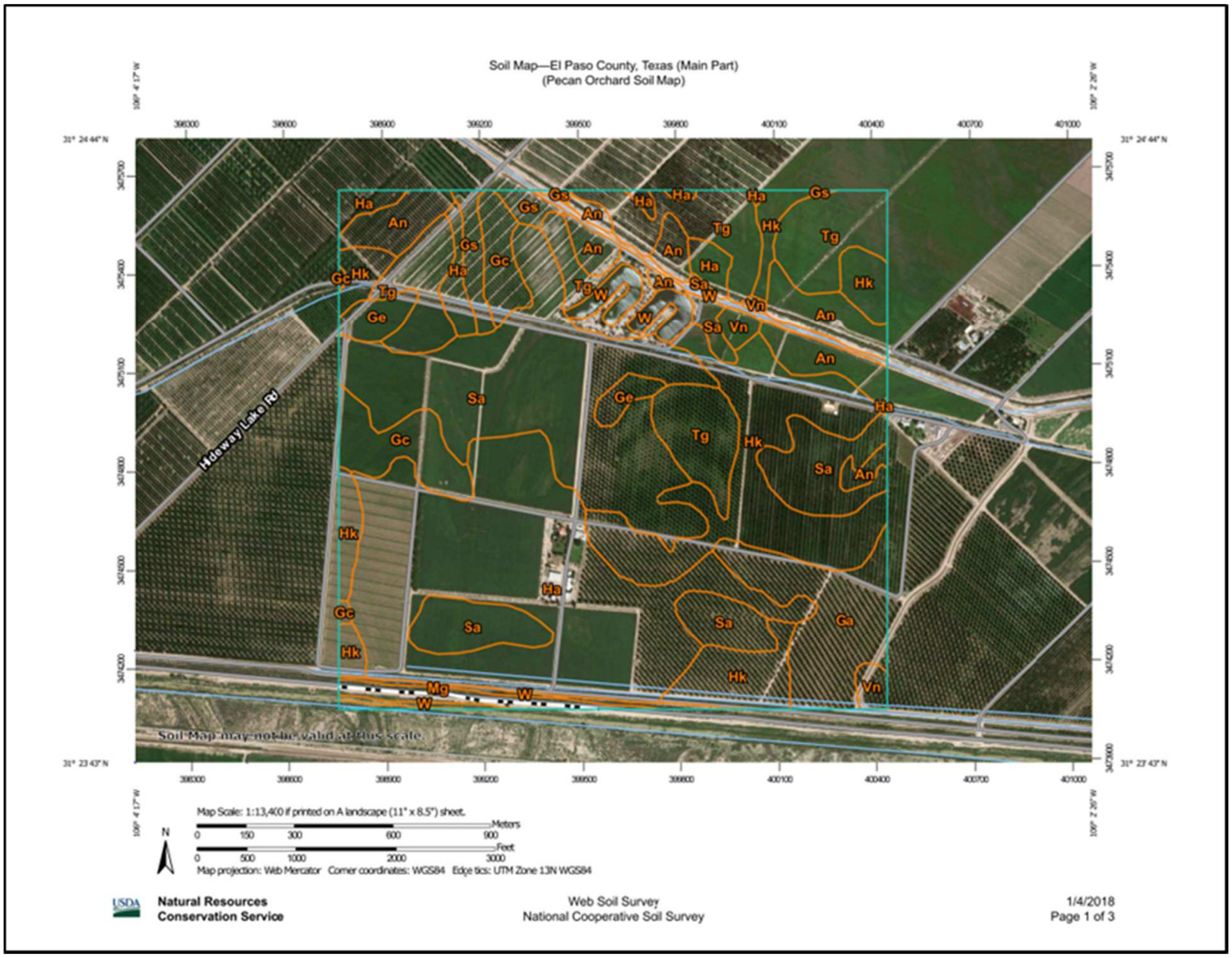


Figure 2: A USDA soil series map shows that soils in the study area belong to Ge, Tg, and Sa.

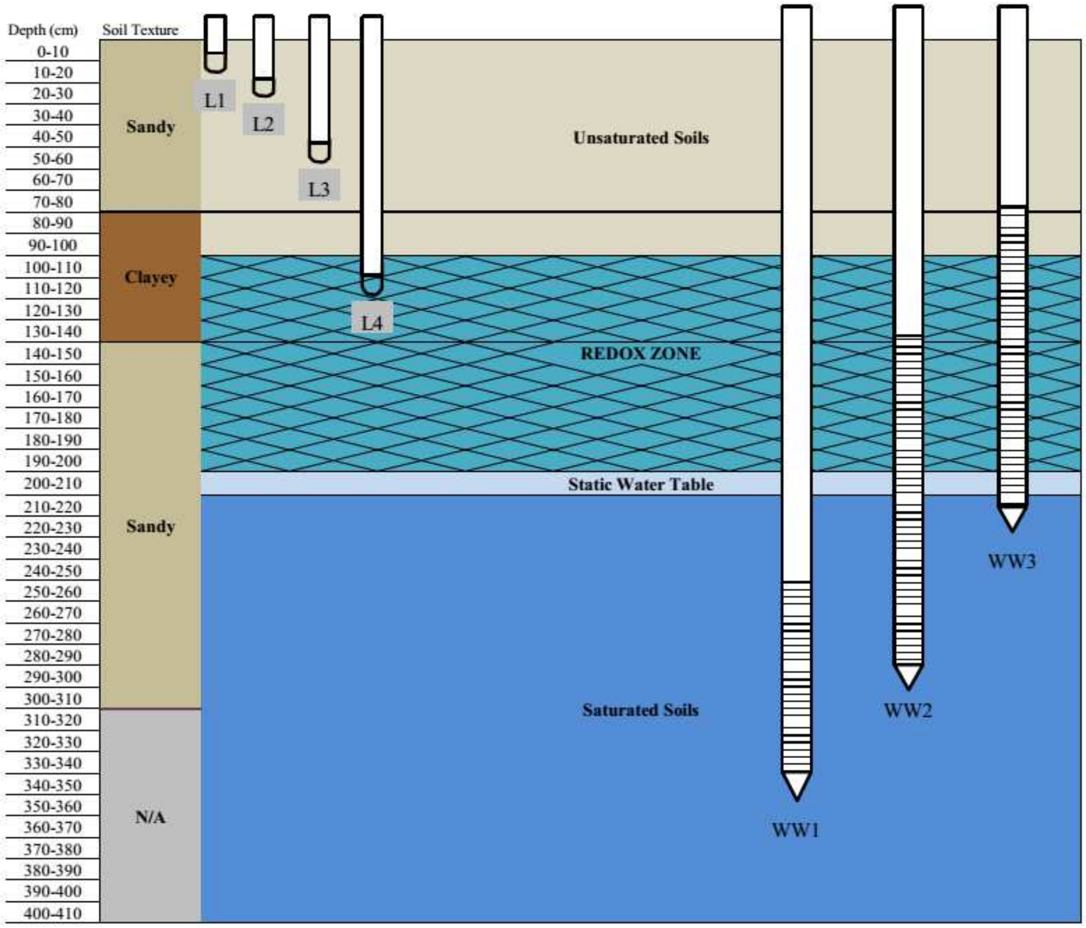


Figure 3: The depths of soil water lysimeters and groundwater wells with references to layers of different soil texture.

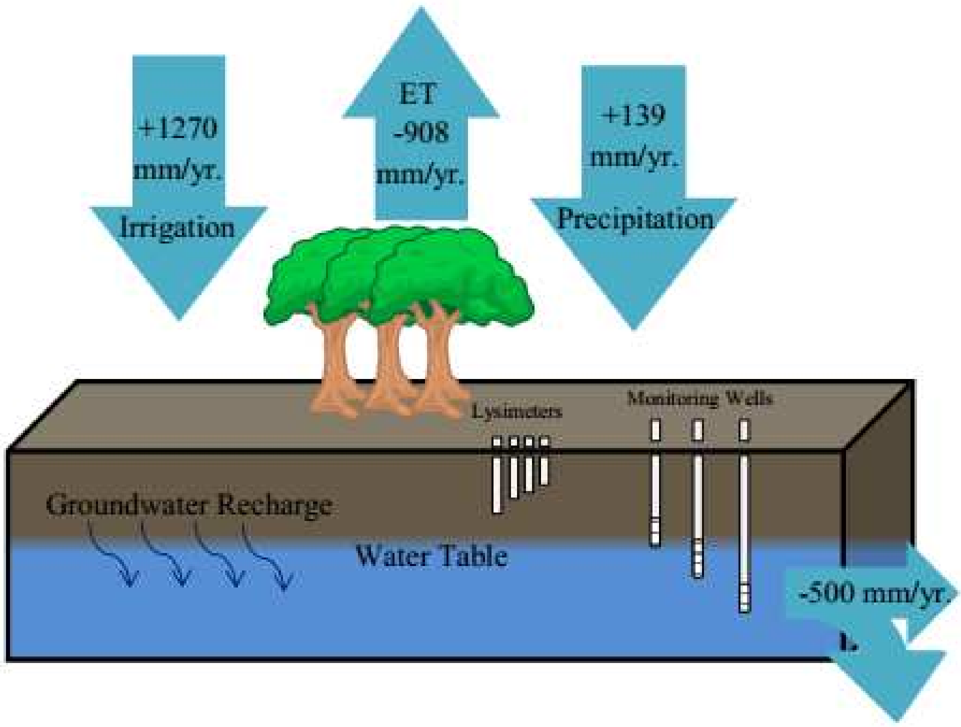


Figure 4: Water mass balance at the pecan orchard, with annual rates of precipitation (+), irrigation (+), evapotranspiration (-), and groundwater recharge/lateral flow (-).

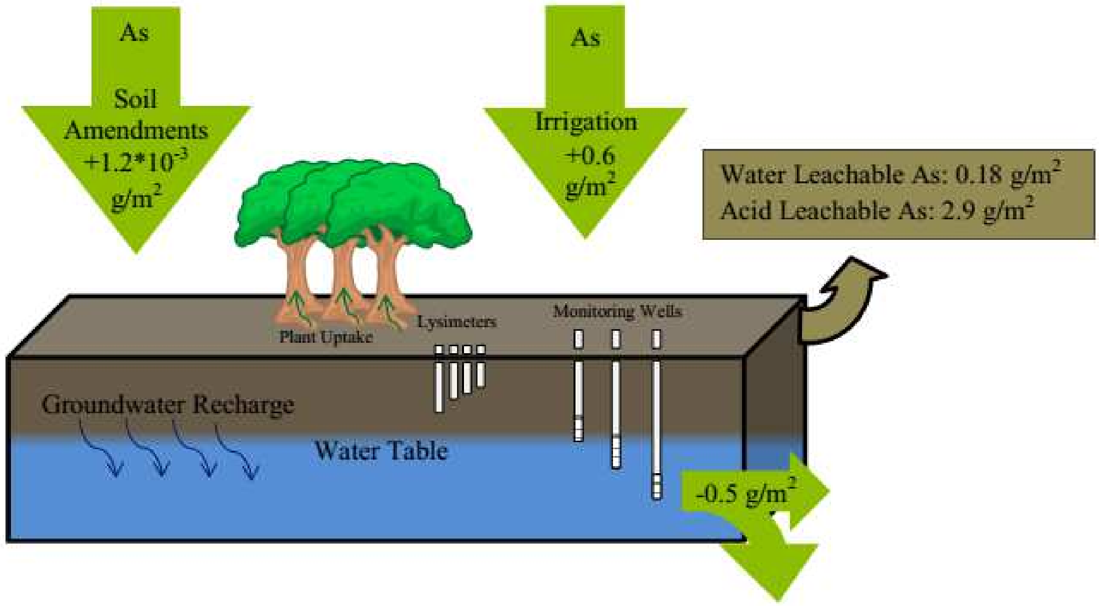


Figure 5: Arsenic (As) mass balance at the pecan orchard. Loading rates were estimated for the past 90 years, where soils were cultivated for cotton (60 years) and pecan (30 years).

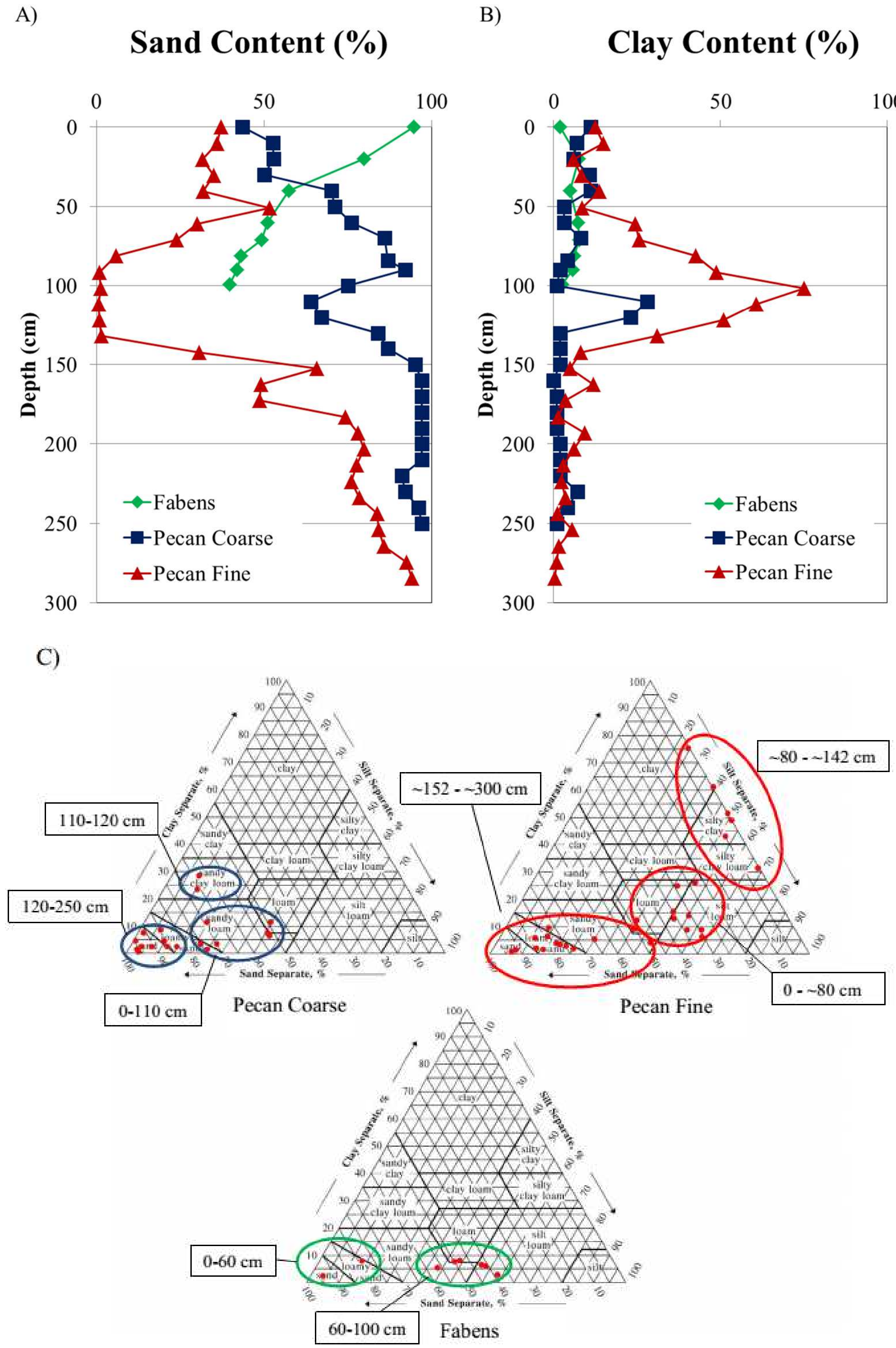
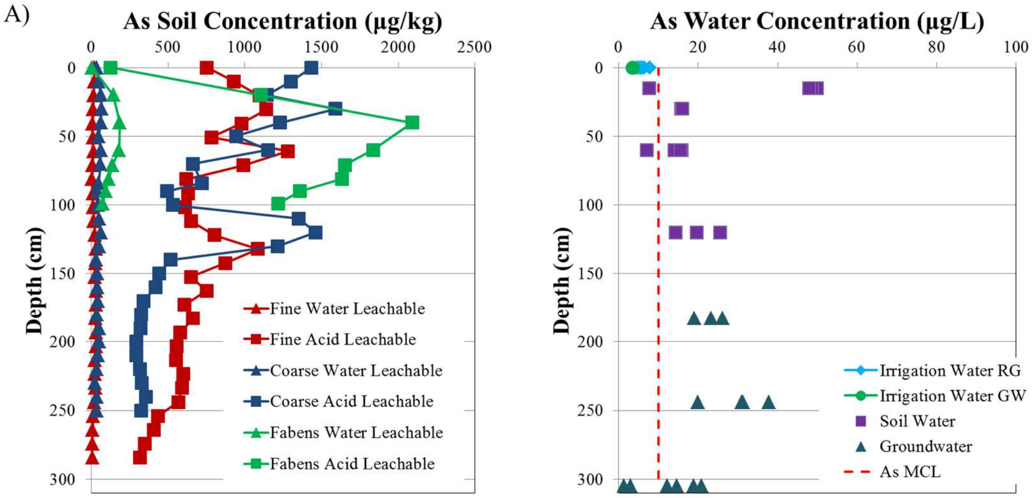
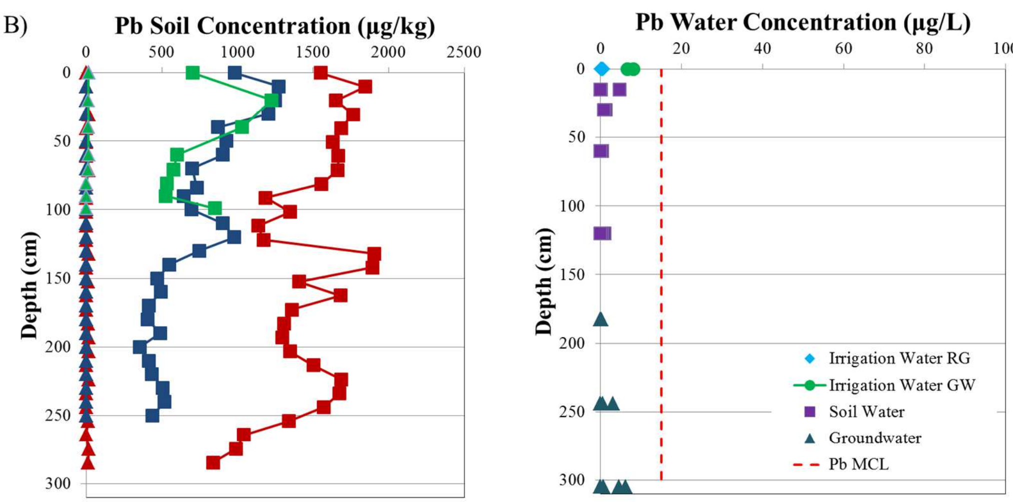


Figure 6: Sand (A) and clay (B) percentages as a function of depth as well as soil texture (C) at the Pecan Coarse, Pecan Fine, and the Fabens sites. Samples from the Fabens location only reached a depth of approximately 1m.

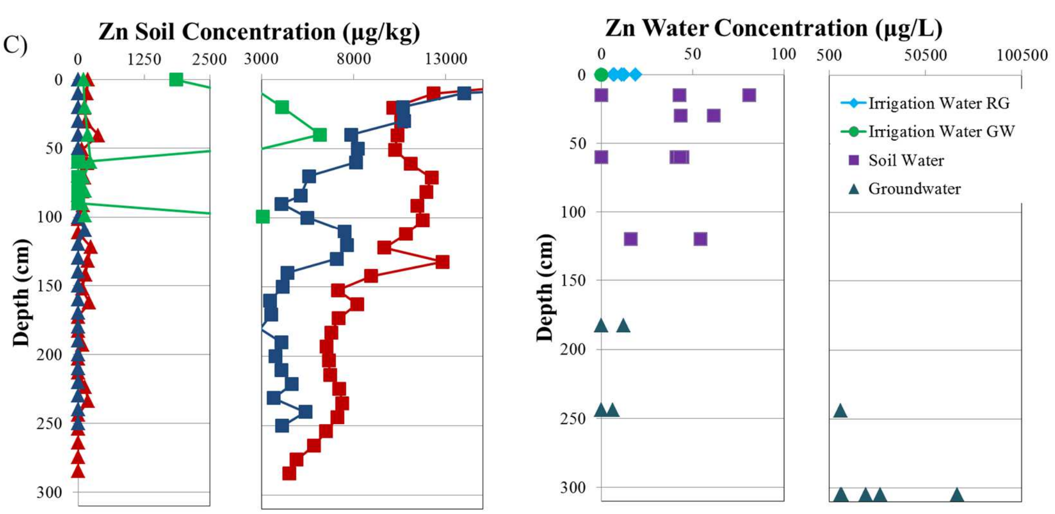
A)


As Soil Concentration (µg/kg)
As Water Concentration (µg/L)
Depth (cm)
Fine Water Leachable
Fine Acid Leachable
Coarse Water Leachable
Coarse Acid Leachable
Fabens Water Leachable
Fabens Acid Leachable
Irrigation Water RG
Irrigation Water GW
Soil Water
Groundwater
As MCL

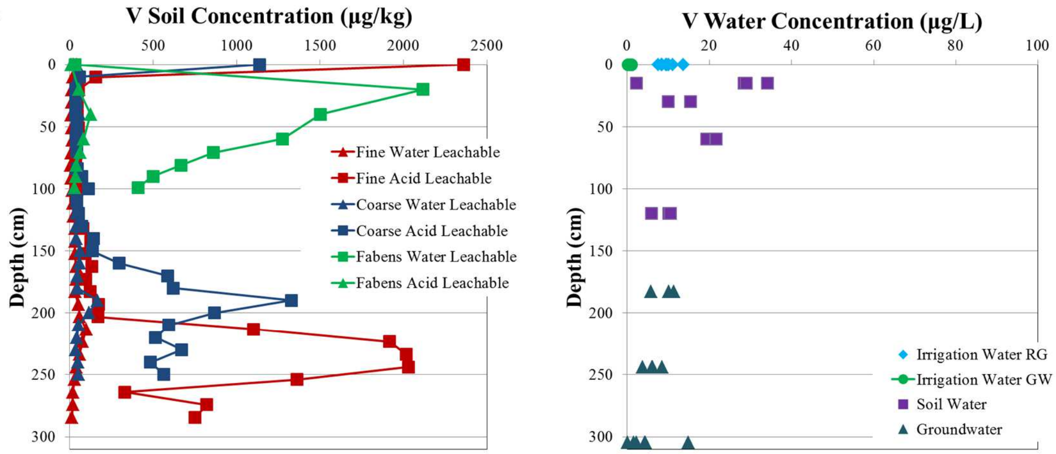
B)


Pb Soil Concentration (µg/kg)
Pb Water Concentration (µg/L)
Depth (cm)
Irrigation Water RG
Irrigation Water GW
Soil Water
Groundwater
Pb MCL

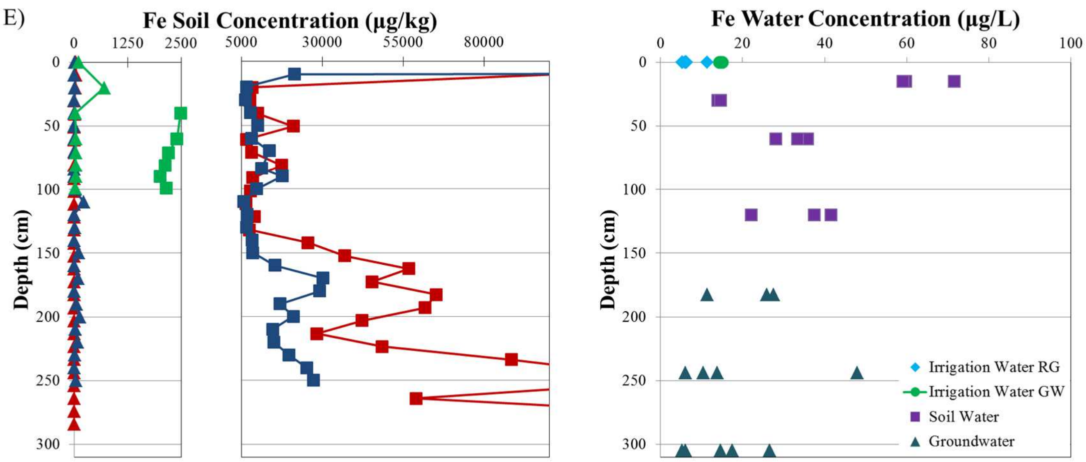
C)


Zn Soil Concentration (µg/kg)
Zn Water Concentration (µg/L)
Depth (cm)
Irrigation Water RG
Irrigation Water GW
Soil Water
Groundwater

D)


V Soil Concentration (µg/kg)
0
500
1000
1500
2000
2500
Depth (cm)
0
50
100
150
200
250
300
Fine Water Leachable
Fine Acid Leachable
Coarse Water Leachable
Coarse Acid Leachable
Fabens Water Leachable
Fabens Acid Leachable
V Water Concentration (µg/L)
0
20
40
60
80
100
Irrigation Water RG
Irrigation Water GW
Soil Water
Groundwater

E)


Fe Soil Concentration (µg/kg)
0
1250
2500
5000
30000
55000
80000
Depth (cm)
0
50
100
150
200
250
300
Fe Water Concentration (µg/L)
0
20
40
60
80
100
Irrigation Water RG
Irrigation Water GW
Soil Water
Groundwater

F)

G)

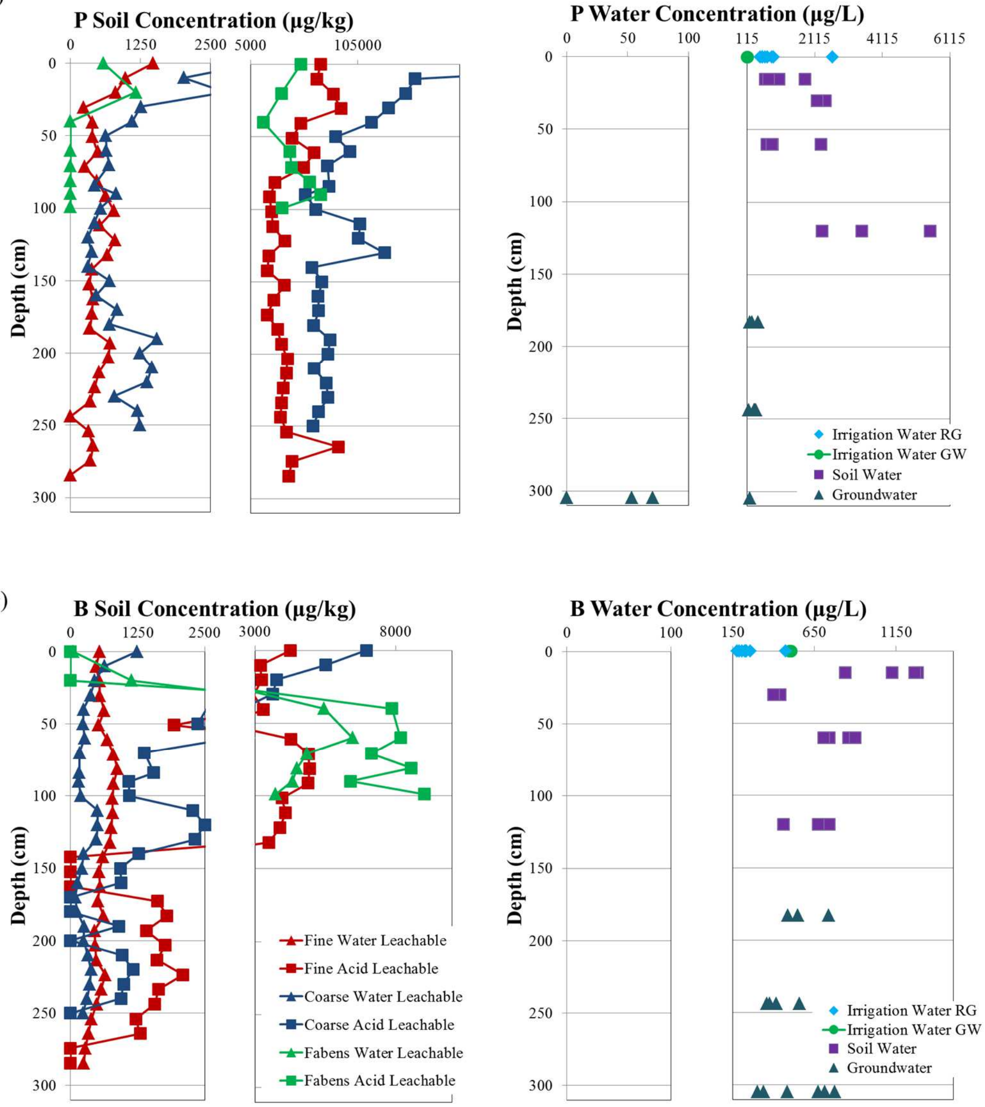
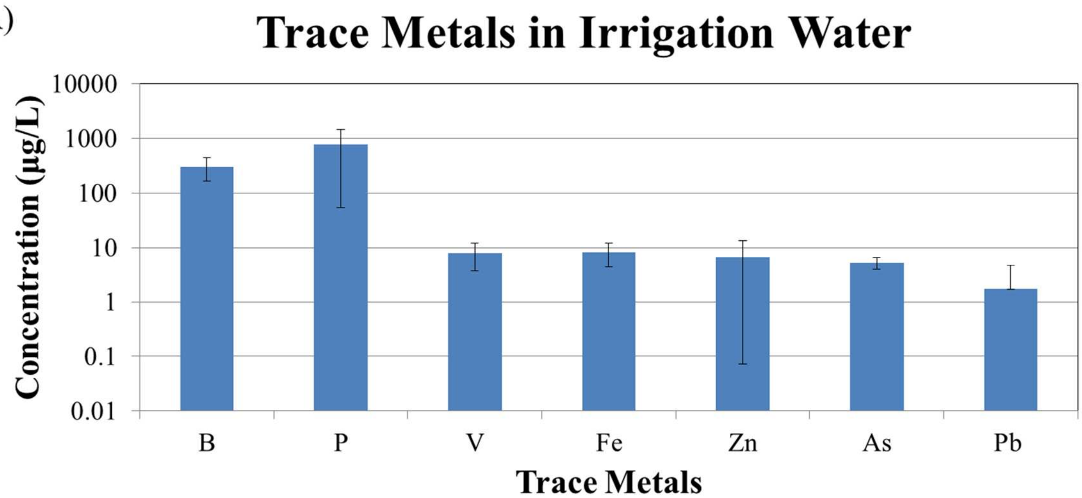
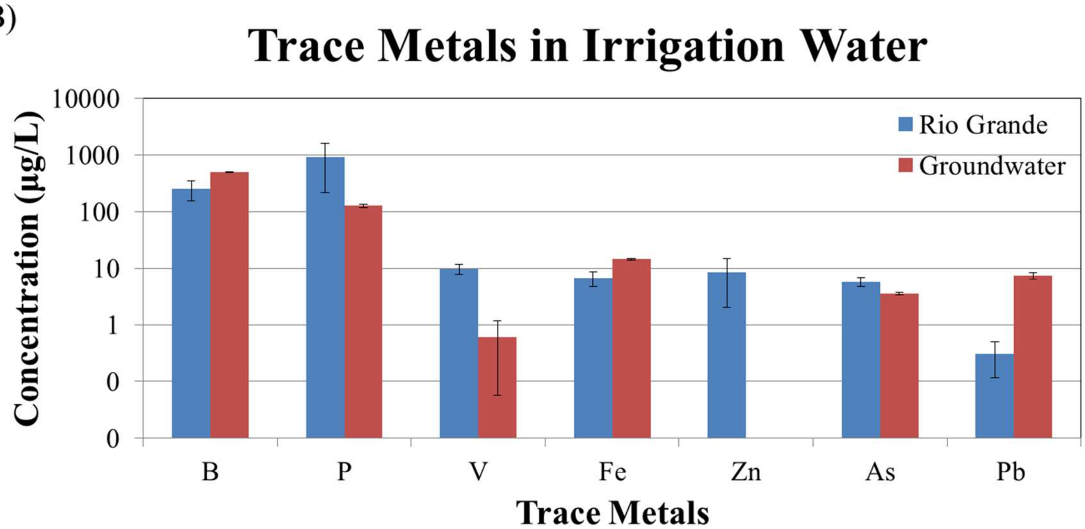


Figure 7: Trace metal concentrations of water leachable and acid leachable fractions in soils and in water samples (0 for irrigation water, 15 cm, 30 cm, 60 cm and 120 cm for soil waters and 200 cm (WW3), 250 cm (WW2), and 300 cm (WW1), depths for groundwaters). Soil concentrations values are reported in µg/kg while water concentrations values are reported in µg/L.

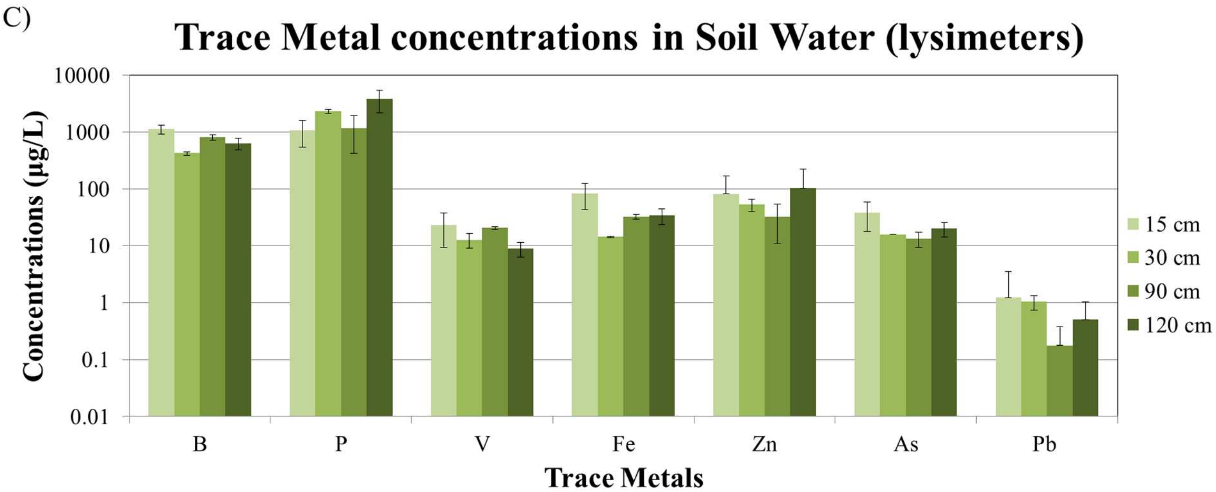
A)


Trace Metals in Irrigation Water
Concentration (µg/L)
10000
1000
100
10
1
0.1
0.01
B
P
V
Fe
Zn
As
Pb
Trace Metals

B)


Trace Metals in Irrigation Water
Concentration (µg/L)
10000
1000
100
10
1
0
0
Rio Grande
Groundwater
B
P
V
Fe
Zn
As
Pb
Trace Metals

C)


Trace Metal concentrations in Soil Water (lysimeters)
Concentrations (µg/L)
10000
1000
100
10
1
0.1
0.01
15 cm
30 cm
90 cm
120 cm
B
P
V
Fe
Zn
As
Pb
Trace Metals

D)

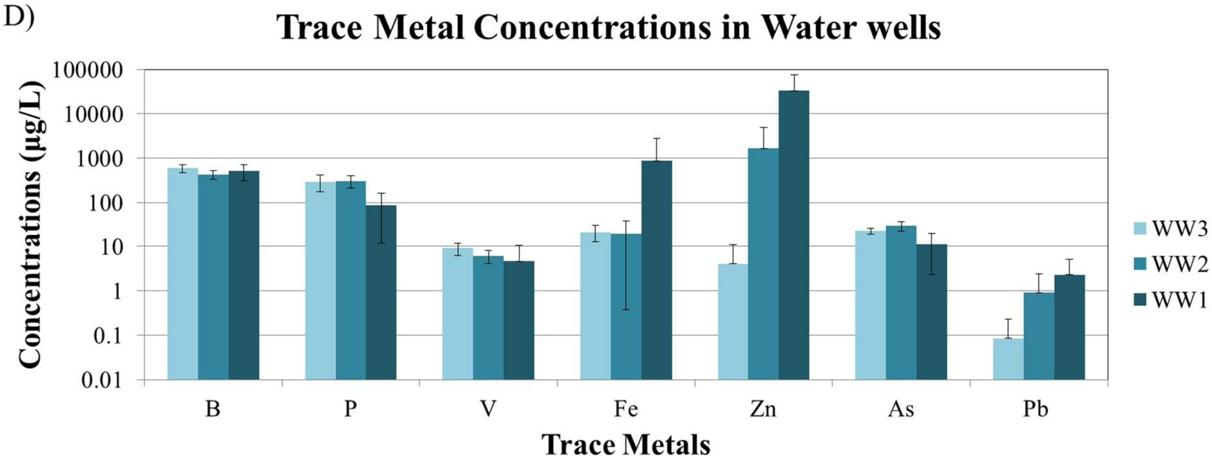


Figure 8: Average trace metal concentrations in irrigation water (A), Rio Grande vs local groundwater (B), soil water (C) and ground water (D) samples with standard deviations.

A)

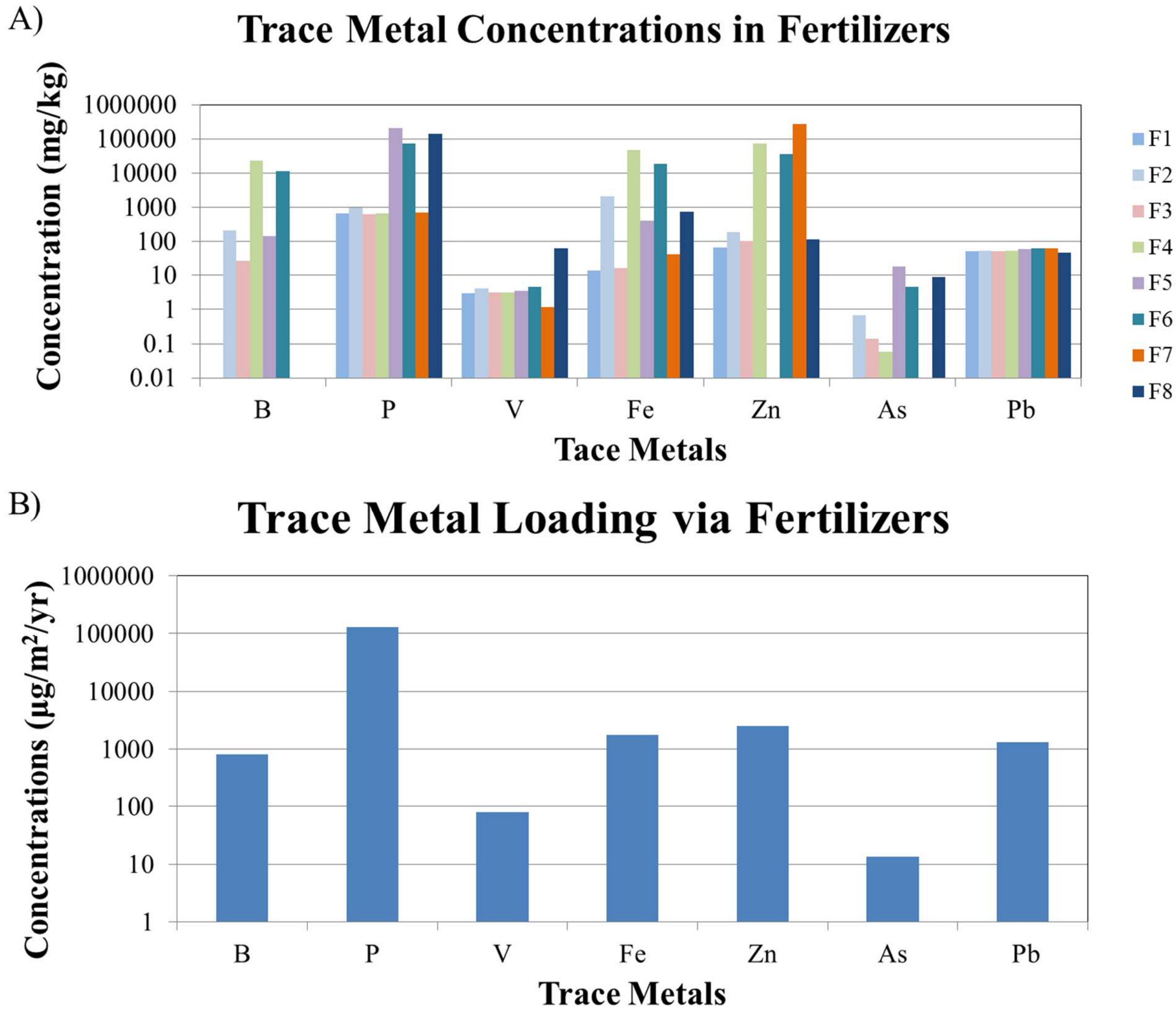
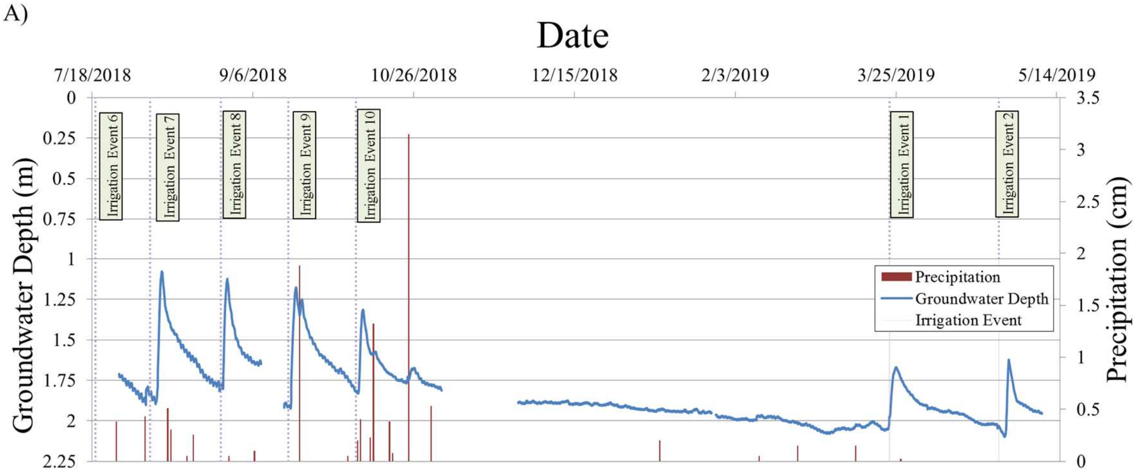
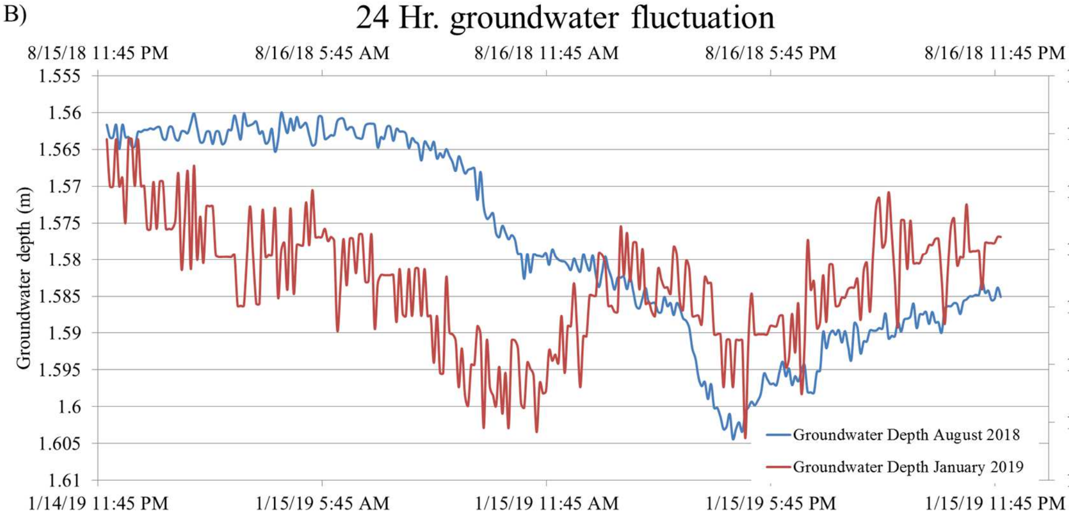


Figure 9: Concentrations (A) and loading (B) of different fertilizers in their water soluble fractions.

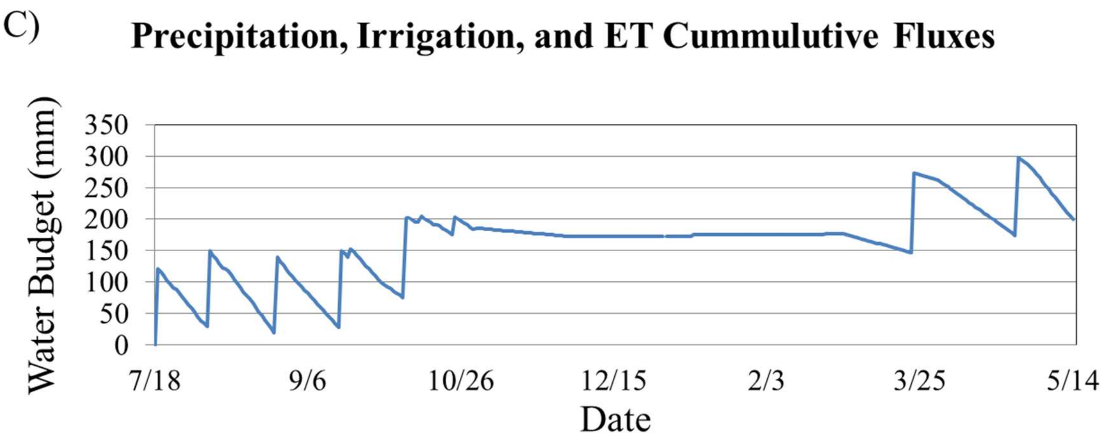
A)


Date
7/18/2018
9/6/2018
10/26/2018
12/15/2018
2/3/2019
3/25/2019
5/14/2019
Groundwater Depth (m)
Precipitation (cm)
Irrigation Event 6
Irrigation Event 7
Irrigation Event 8
Irrigation Event 9
Irrigation Event 10
Irrigation Event 1
Irrigation Event 2
Precipitation
Groundwater Depth
Irrigation Event

B)


24 Hr. groundwater fluctuation
8/15/18 11:45 PM
8/16/18 5:45 AM
8/16/18 11:45 AM
8/16/18 5:45 PM
8/16/18 11:45 PM
Groundwater depth (m)
Groundwater Depth August 2018
Groundwater Depth January 2019
1/14/19 11:45 PM
1/15/19 5:45 AM
1/15/19 11:45 AM
1/15/19 5:45 PM
1/15/19 11:45 PM

C)


Precipitation, Irrigation, and ET Cummulutive Fluxes
Water Budget (mm)
7/18
9/6
10/26
12/15
2/3
3/25
5/14
Date

D)

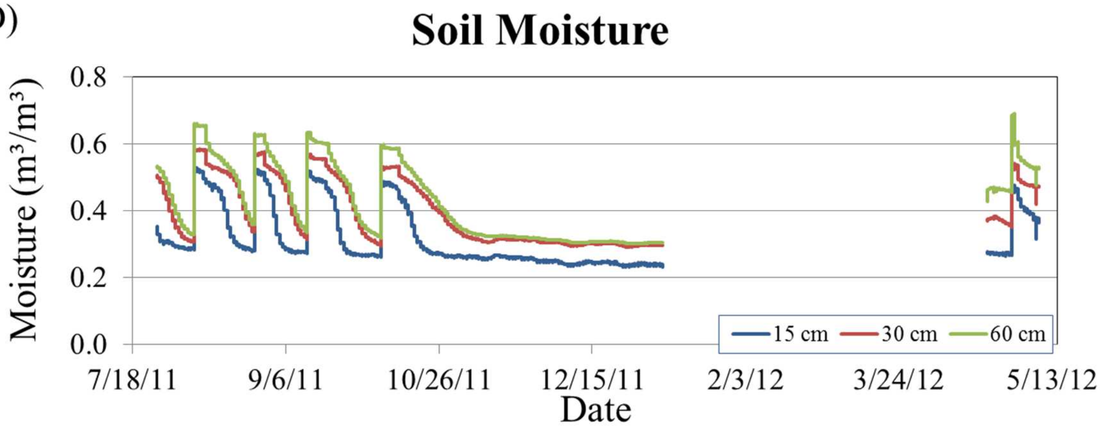


Figure 10: Groundwater level fluctuations are shown to change after irrigation events and days of precipitation (A). Diurnal fluctuations were observed in measurements taken from data loggers. A date during growing season and a date during winter were plotted to show details into changes of groundwater levels throughout a 24 hr. period (B). Precipitation, irrigation, and ET fluxes are combined to observe fluxes of the water budget (C). Soil moisture data was collected at 15 cm, 30 cm, and 60 cm bgs during growing season at Pecan fine (Cox et al., 2018) and plotted in the same date range (D).

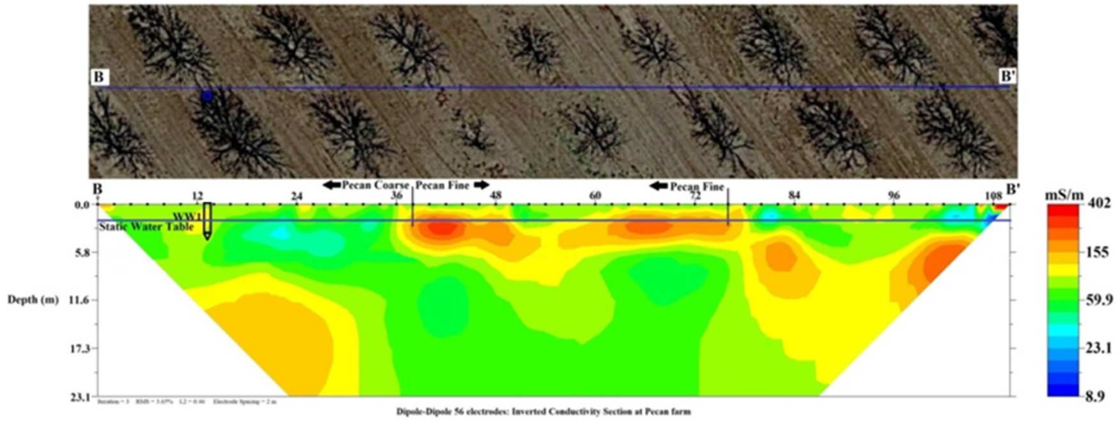


Figure 11: Inverted conductivity model aligned with the 69m transect at B – B' from Figure 1D.

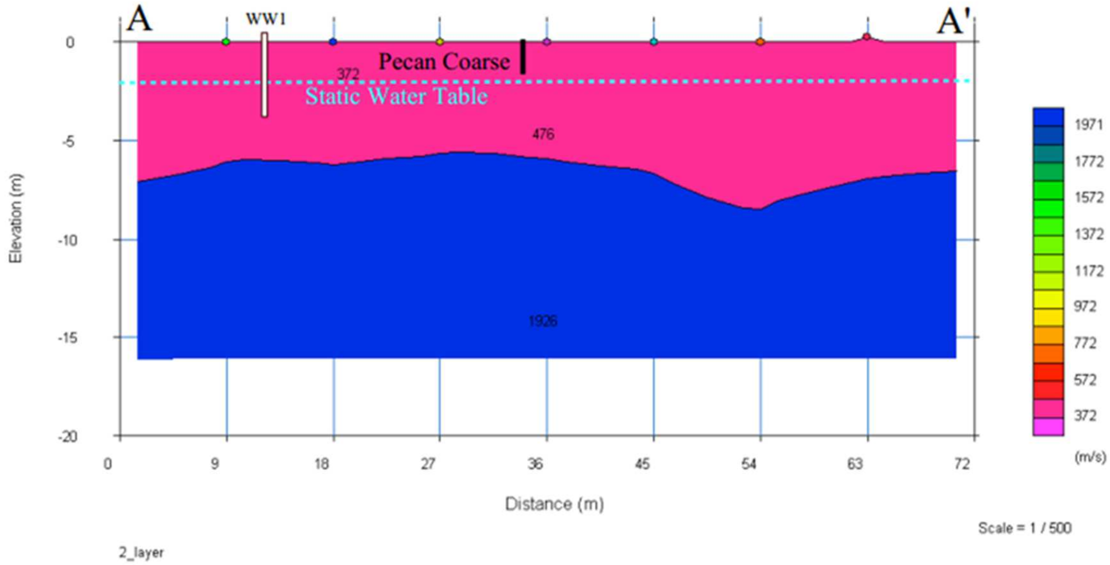


Figure 12: Seismic survey 2D model showing varying velocities at A – A’ from Figure 1D.

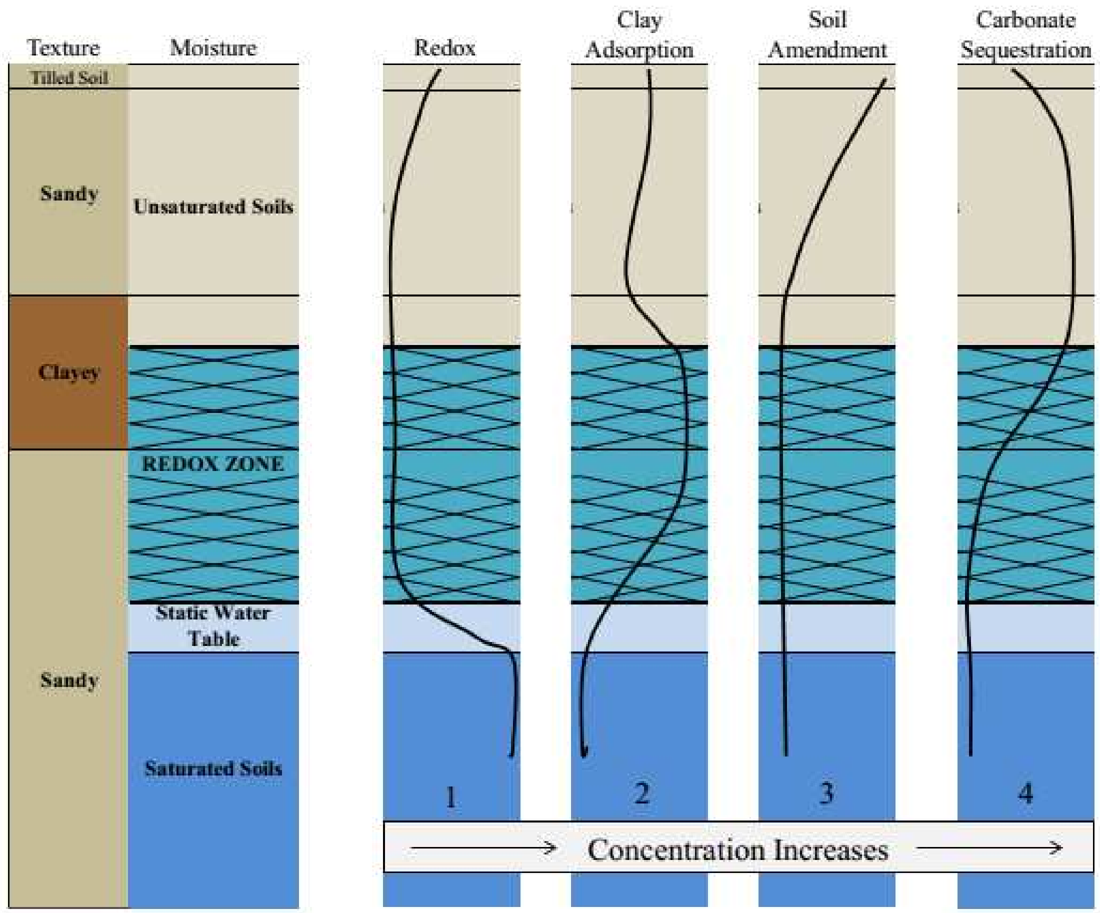


Figure 13: This conceptual model showcases a depth profile with the major soil texture characteristics, static water table, redox potential depth, and unsaturated soils. Conceptual concentration trends affected by different conditions (redox conditions, clay adsorption, input at surface (irrigation/soil amendment), and carbonate sequestration/salt buildup) are displayed.

References

Ashworth, J. B. (1990). Evaluation of Ground-Water resources in El Paso County, Texas. *Texas Water Development Board.*

Ayotte, J. D., Gronberg, J. A. M., & Apodaca, L. E. (2011). Trace elements and radon in groundwater across the United States, 1992-2003. United States Geological Survey *Scientific Investigations Report 2011-5059* 1-115 p.

Böhlke, J. K. (2002). Groundwater recharge and agricultural contamination. *Hydrogeology Journal*, *10*(1), 153–179. https://doi.org/10.1007/s10040-001-0183-3

Borrok, D. M., & Engle, M. A. (2014). The role of climate in increasing salt loads in dryland rivers. *Journal of Arid Environments*, *111*, 7–13. https://doi.org/10.1016/j.jaridenv.2014.07.001

Carter, J. D., Dent, F., & Peckham, R. C. (1963). Summary Of The Ground-Water Aquifers In The Rio Grande Basin. (63). *Texas Water Commission*

Cox, C., Jin, L., Ganjegunte, G., Borrok, D., Lougheed, V., & Ma, L. (2018). Soil quality changes due to flood irrigation in agricultural fields along the Rio Grande in western Texas. *Applied Geochemistry*, *90*(October 2017), 87–100. https://doi.org/10.1016/j.apgeochem.2017.12.019

Ganjegunte, G. K., Clark, J. A., Sallenave, R., Sevostianova, E., Serena, M., Alvarez, G., & Leinauer, B. (2017). Soil salinity of an urban park after long-term irrigation with Saline ground water. *Agronomy Journal*, *109*(6), 3011–3018. https://doi.org/10.2134/agronj2017.06.0369

Huang, K., Luo, X., & Zheng, Z. (2018). Application of a combined approach including contamination indexes, geographic information system and multivariate statistical models in levels, distribution and sources study of metals in soils in Northern China. *PLoS ONE*, *13*(2), 1–19. https://doi.org/10.1371/journal.pone.0190906

Komorowski, A., & Szulc, W. (2017). Impact of traffic routes on the content of trace elements in soils in Warsaw agglomeration. *Soil Science Annual*, *68*(2), 87–92. https://doi.org/10.1515/ssa-2017-0010

Kumar Sharma, R., Agrawal, M., & Marshall, F. (2007). Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotoxicology and Environmental Safety*, *66*(2), 258–266. https://doi.org/10.1016/j.ecoenv.2005.11.007

Lal, N. (2016). Effects of Acid Rain on Plant Growth and Development. *E-Journal of Science & Technology*, *11*(5), 37–77.

Lambert, R. B., Kolbe, C. M., & Belzer, W. (2008). Quality of Water and Sediment in Streams Affected by Historical Mining , and Quality of Mine Tailings , in the Rio Grande / Río Bravo Basin , Big Bend Area of the United States and Mexico, *U.S. Geological Survey Scientific Investigations*.Report 2008 – 5032.

Loska, K., Wiechulła, D., & Korus, I. (2004). Metal contamination of farming soils affected by industry. *Environment International*, *30*(2), 159–165. https://doi.org/10.1016/S0160-4120(03)00157-0

Lowe, R. P., & Lowe, B. R. P. (1952). Pollution Control of the Rio Grande in New Mexico Published by : Water Environment Federation POLLUTION CONTROL OF THE RIO

GRANDE IN NEW MEXICO *. *Water Environment Federation*, *24*(8), 1021–1024. Retrieved from http://www.jstor.org/stable/25031943

Lucho-Constantino, C. A., Álvarez-Suárez, M., Beltrán-Hernández, R. I., Prieto-García, F., & Poggi-Varaldo, H. M. (2005). A multivariate analysis of the accumulation and fractionation of major and trace elements in agricultural soils in Hidalgo State, Mexico irrigated with raw wastewater. *Environment International*, *31*(3), 313–323. https://doi.org/10.1016/j.envint.2004.08.002

Nicolli, H. B., Suriano, J. M., Gomez Peral, M. A., Ferpozzi, L. H., & Baleani, O. A. (1989). Groundwater contamination with arsenic and other trace elements in an area of the pampa, province of Córdoba, Argentina. *Environmental Geology and Water Sciences*, *14*(1), 3–16. https://doi.org/10.1007/BF01740581

Olajire, A. A., Oluyemi, E. A., Ayodele, E. T., & Fawole, O. O. (2005). Characterization of trace metal leachability from highway construction solid waste using the toxicity characteristic leaching procedure. *International Journal of Environmental Health Research*, *15*(2), 151–158. https://doi.org/10.1080/09603120500061997

Puls, R. W., & Barcelona, M. J. (1996). Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures. In *EPA Ground Water Issue*. https://doi.org/10.1056/NEJMoa030660

Reddy, S. K., Venkata, G., & Reddy, S. (2017). The Mobility of Trace Metals from Soil to Plant in Irrigation Fields around Tummalapalle Uranium Mine in Kadapa District, Andhra Pradesh. *Madras Agriculture Journal*, *104*(3), 32–36.

Rios-arana, J. V, Walsh, E. J., & Gardea-torresdey, J. L. (2003). Assessment of arsenic and heavy metal concentrations in water and sediments of the Rio Grande at El Paso – Juarez metroplex region. *El Sevier*, *29*, 957–971. https://doi.org/10.1016/S0160-4120(03)00080-1

Satterthwaite, D. (2009). The implications of population growth and urbanization for climate change. *Environment and Urbanization*, *21*(2), 545–567. https://doi.org/10.1177/0956247809344361

Scanlon, B., Keese, K., Bonal, N., Deeds, N., Kelly, V., & Litvak, M. (2005). Evapotranspiration Estimates with Emphasis on Groundwater Evapotranspiration in Texas. *University of Texas at Austin.*

Sheng, Z., & Liu, Y. (2015). Evapotranspiration of flood-irrigated pecans under drought conditions in El Paso , TX. In *In Emerging Technologies for Sustainable Irrigation, ASABE/IA Irrigation Symp. St. Joseph, Mich.:ASABE* (Vol. 7004).

Szynkiewicz, A., Witcher, J. C., Modelska, M., Borrok, D. M., & Pratt, L. M. (2011). Anthropogenic sulfate loads in the Rio Grande, New Mexico (USA). *Chemical Geology*, *283*(3–4), 194–209. https://doi.org/10.1016/j.chemgeo.2011.01.017

Tay, C. K., & Hayford, E. (2016). Levels, source determination and health implications of trace metals in groundwater within the Lower Pra Basin, Ghana. *Environmental Earth Sciences*, *75*(18). https://doi.org/10.1007/s12665-016-6034-2

Texas Water Development Board. (1973). *Texas Water Development Board (TWDB) Groundwater Database (GWDB) Well Information Report for State Well Number 49-40-810*.

Wong, C. S. C., Wu, S. C., Duzgoren-aydin, N. S., Aydin, A., & Wong, M. H. (2007). Trace metal contamination of sediments in an e- waste processing village in China. *Environmental Pollution*, *145*(2), 434–442.

Zimmerman, A. J., & Weindorf, D. C. (2010). Heavy Metal and Trace Metal Analysis in Soil by Sequential Extraction: A Review of Procedures. *International Journal of Analytical Chemistry*, *2010*, 1–7. https://doi.org/10.1155/2010/387803

Vita

Emmanuel Sosa obtained his bachelors degree in geology from the University of Texas in El Paso (UTEP) in 2014. He pursued a career with an environmental and geotechnical consulting firm in El Paso, Texas. Mr. Sosa became involved with various projects associated with groundwater monitoring and soil sampling at sites with contamination from hydrocarbons, soil sampling for geotechnical evaluations, environmental assessments, and environmental oversight at demolition projects prior to returning to UTEP. Mr. Sosa returned to UTEP in 2017 to pursue a graduate degree in environmental science and completing his degree in 2019.

Contact Information: sosae915@gmail.com