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LAND APPLICATION OF INDUSTRIAL EFFLUENT ON A CHIHUAHUAN DESERT ECOSYSTEM: IMPACT ON SOIL PHYSICAL AND HYDRAULIC PROPERTIES

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Graduate student Pradip Adhikari collects samples from catch funnels at the site and carefully measure

The catch funnels were placed at regular intervals to measure the distribution of water from the sprinkler system used at the site.

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Plant and Environmental Sciences, New Mexico State University

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ABSTRACT

Land application of treated industrial effluent could be beneficial especially in areas where water stress is a major concern primarily due to limited water resources, higher water demands, and limited economic resources. The primary objectives of this study were to: (1) determine the influence of lagoon treated wastewater on physical and chemical properties of soil in canopy and intercanopy areas, (2) compare soil physical and chemical properties in the irrigated and unirrigated plots, (3) determine the variability of soil physical and chemical properties, and (4) identify the minimum number of principal components (PCs) necessary to explain the total variability in soil physical and chemical properties. The West Mesa Industrial Park near Las Cruces, New Mexico USA has applied lagoon treated industrial effluent since 2002 to 36-ha of Chihuahuan Desert native vegetation (mesquite and creosote) by a fixed-head sprinkler irrigation system. Core and bulk soil sample were collected from under mesquite and creosote canopies and intercanopy areas from two irrigated plots and one unirrigated plot.

From 2002 to 2007, the average sodium adsorption ration (SAR) of irrigation water was 32.97, electrical conductivity (EC) 3.90 dS m^{-1}, and pH 9.7. The sprinkler uniformity coefficient for both irrigated plots was low and soil EC measured at the end of the irrigation uniformity tests showed some correlation with the treated wastewater distribution. More water was collected under the canopies (116.62 ± 5.18 cm^3) than the intercanopy areas (82.55 ± 5.87 cm^3). In general, soil physical properties, including bulk density (BD), sand, silt, and clay contents did not show any significant effect of treated wastewater application. The saturated hydraulic conductivity (K_s) and drainable porosity (θd) were lower and the available water content (AWC) was higher at 0-20 cm depth of the irrigated plots than unirrigated plot. Higher values of chloride (Cl^-) under creosote canopies at 100-150 cm depth than mesquite canopies and intercanopy areas of the irrigated plots were due to higher canopy interception of sprinkler sprays and deeper leaching of the solute and could be a source of groundwater pollution.

In irrigated plots at 0-20 cm depth, pH (>9) and Na^+ (>693 mg kg^{-1}) were higher in the intercanopy areas than under the vegetation canopies. Variability in soil properties identified by coefficient of variation (CV) ranked NO_3^- (CV=0.65), Cl^- (0.65); SAR (0.47), K_s (0.41), Na^+ (0.38), ESP (0.38) and EC (0.37) as most variable; silt (0.32), AWC (0.20), field capacity (FC; 0.16) and organic matter (OM; 0.17) as moderately variable; and sand (0.01), clay (0.08), BD (0.03) and pH (0.03) as least variable. The PCA grouped soil properties into five distinct PCs: soil salinity, soil sodicity, water transmission, soil texture, and water storage based on the attributes present in each one of them. Overall, compared to the unirrigated area, the salinity and sodicity in the irrigated areas had increased more than one order of magnitude at 0-20 cm depth. The PCs composed of the variables associated with soil salinity and sodicity explained a large variability of the measured attributes. Since these indicators are directly associated with the chemical properties of treated wastewater, there is a need to initiate efforts to reduce the chloride and sodium concentrations of the applied treated wastewater. Deep rooted mesquite and creosote bushes are the primary vegetation in the study area. The majority of the mesquite roots are usually distributed within top 100 cm depth and creosote within the top 25 cm. Average SAR for 100 cm depth under canopies was 18.46 ± 2.56 and could threaten the survival of woody and especially the perennial herbaceous plant species growing in the study area.

Keywords: wastewater, sodicity, salinity, hydraulic conductivity, available water content, uniformity coefficient

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INTRODUCTION

Southern New Mexico is located in the Mexican Highland section characterized by broad desert basins and discontinuous ranges (Gile et al., 1981). Prominent mountains in the East and Northwest part, intermontane basins, and the Rio Grande Valley are the major physiographic features of the regions (Gile et al., 1981). Upper La Mesa, Lower La Mesa, valley border, structural benches, valley rim, inner valley scarp and flood plain are some of the landforms of the West Mesa site (Figure 1). The West Mesa is the relict basin floor that contains the remnants of middle Pleistocene age, indicating the surface is old and soil development process is stable (Gile et al., 1981). The soils themselves commonly show only minor evidence of erosion and sedimentation. The A horizons are thin and in some places absent. Presence of dunes indicates that there has been considerable shifting of material on the surface by wind. However, strong soil development beneath this surficial zone of movement suggests that the West Mesa has been nearly stable for a long period of time. The West Mesa is divided into two levels, Upper La Mesa and Lower La Mesa. The elevation of Lower La Mesa is about 1273 m and Upper La Mesa is 1333 m to 1364 m. These two levels formed due to the tectonic activities that occur episodically during late Tertiary to late Quaternary period by the Robledo Fault zone. The surficial sediments have different ages, which indicate that the tectonic activities have occurred before the surficial sediments were deposited in the Lower La Mesa.

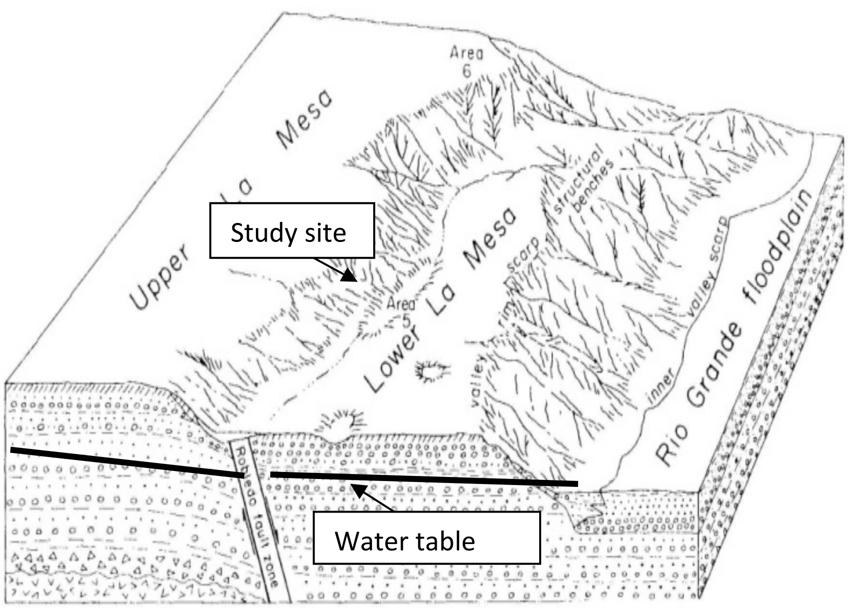


Figure 1: Block diagram showing the landforms of West Mesa (adopted from Gile et al., 1981)

Young coppice dunes occur in most of the West Mesa usually under mesquite (*Prosopis glandulosa* Torr. *var glandulosa*) canopy and occasionally under four-wing saltbush (*Atriplex canescens* (Prush) Nutt.). The dunes in these areas were formed when drastic changes in vegetation occurred during 1885-1920 (Gile et al., 1981). Many areas between the dunes are barren and few consist of annual and perennial grass and forbs. These coppice dunes are the result of wind erosion, presence of loose sand in the surface layer, disappearance of grass cover, and the characteristic of desert shrubs. Coppice dunes are formed when the desert shrub-like mesquite intercepts the sand particles carried by the winds and trap them under its canopy. Mesquite bush grows vigorously on loose sand and is not readily killed by slow sand burial. If the process continues, a mound of sand eventually is built and held together by the coppice. Mesquite shrubs in Southern New Mexico are the dominant nitrogen fixing woody plants, also known as 'fertility islands' (Reyes-Reyes et al., 2003).

Southern New Mexico is characterized as semi-arid, where wastewater reclamation and reuse for irrigation has become an important issue in water resources planning. This has occurred as a result of increasing fresh water scarcity, high-nutrients in wastewater, and the high cost of advanced treatment required for other applications. The United Nations Millennium Development Goal also targets the use of wastewater for irrigation to reduce the water deficit (cited in Hamilton et al., 2007). The Hyderabad Declaration on Wastewater Use in Agriculture Part –I also focuses on wastewater use as a resource of increasing global importance in urban and peri-urban agriculture for sustaining livelihoods, food security, and the quality of the environment (cited in Hamilton et al., 2007). Parameters evaluated in this study were electrical conductivity (EC), total dissolved solids (TDS), sodium absorption ratio (SAR), suspended heavy metals, and organic matter (OM).

Treatment of urban and industrial wastewater is complex, expensive, and requires energy and technology. The safe disposal of the wastewater is also a challenge because the effect of wastewater to the soil and plant environment is complex and depends upon the amount of harmful elements present in the wastewater. Reuse of treated industrial effluent could be beneficial especially in areas where water stress is a major concern primarily due to limited water resources, higher water demands, and limited economic resources. Wastewater can add nutrients to the soil, which can stimulate plant growth, plant NO_3^- uptake, turnover of soil NO_3^-, and denitrification. Wastewater can also affect soil physical properties, like bulk density (BD), drainable porosity (θd), soil moisture retention and saturated hydraulic conductivity (K_s). A major objective of land application systems is to allow the physical, chemical, and biological properties of the soil-plant environment to assimilate wastewater constituents without adversely affecting beneficial soil properties that control the transformation, transport, storage, and release of nutrients and contaminants into the wider environment (Magesan, 2001). However, when wastewater is applied beyond the assimilation capacity of the soil-plant system, it provides a source of readily leachable nutrients or contaminants (Magesan and Wang, 2003).

The levels of dissolved OM and suspended solids in effluents depend on the quality of the raw sewage water and the degree of treatment (Mamedov et al., 2000). Addition of OM in wastewater increased the moisture retention capacity by reducing the soil BD and increasing soil θd (Tarenitzky et al., 1999). Suspended solids present in effluents also accumulate in soil voids and physically block water-conducting pores leading to a sharp decline in soil hydraulic properties (Mamedov et al., 2000). Suspended materials in the wastewater reduced the K_s in silt loam soils more than in sand and sandy loam (Vinten et al., 1983). The reduction in K_s could be due to the retention of OM during infiltration and the change of pore size distribution as a result of expansion or dispersion of soil particles. On the other hand, high exchangeable sodium percentage (ESP) due to the wastewater application did not affect K_s in coarse texture soil (Juwarkar and Subrehmanyam, 1987; Abedi-Koupi et al., 2006).

Changes due to irrigation vary greatly and are largely dependent on the quality of the irrigation water (Babcock et al., 2009). However, little work has been conducted on native vegetation located in the Chihuahuan desert ecosystem. Irrigation led to a significant increase in OM content on some sandy, semiarid soils in Texas (Bordovsky et al., 1999). In contrasts, no differences in pH, carbon and nitrogen content of soil and significant differences for salt and phosphorus accumulation were reported in irrigated than unirrigated soils of Zimbabwe (Hussein et al., 1992; Presley et al., 2004).

In the arid West Mesa study site, the water table was deep (~100 m from soil surface; Gile et al., 1981) and the probabilities of leached nutrients or toxic elements reaching groundwater were low. Arid land soils are generally calcareous throughout and have a high pH in the upper soil horizons favoring the precipitation of most heavy metals and reduce the risk of groundwater pollution. The goal of land application of wastewater is to maximize vegetative cover to increase the capacity of the site to serve as a sink for wastewater contaminants, minimize salt accumulation in the root zone, and avoid NO_3^- leaching into the groundwater (Ruiz et al., 2006). In this context, application of treated biological wastewater on arid and semiarid shrubs could be economical and environmentally beneficial.

Soil is a dynamic, living, natural body that forms and continually changes at different rates and along different pathways. In dry conditions, soil variability plays a significant role in crop performance where spatial variability of soil texture can show the moisture shortage effect on plant stand variability across the field (Al-Kaisi, 2006). Soil quality is defined as the ability of soil to function (Doran and Parking, 1994), varies in time and space, and influences soil functions such as water and nutrient movement and their redistribution and supply to plants (Shukla et al., 2004b). Knowledge of the variability of soil physical and chemical properties is essential to selecting as well as effectively applying management decisions for the proper application of treated effluent. The variability in soil properties is associated with spatial, temporal or management related factors that can impact groundwater pollution, grain yield, or biomass production. Variability can be accessed from two perspectives: (i) the relative magnitude of these sources of variability on a soil property, and (ii) the combined effect of variability of some of these properties (van Es et al., 1999).

In a review of several published data sets, Jury (1989) reported that BD is the least variable (<0.10), followed by drainable porosity (θd) (> 0.10), water content at 1.5 MPa suction (0.15 to 0.50) as moderate to most, and K_s (> 1.00) as the most variable. Agbu and Olsen (1990) investigated the variability of some soils in east-central Illinois and reported moderate variability for silt and clay contents (CV = 0.23 to 0.24) and soil organic carbon (SOC) concentration (0.15), and high variability for sand content (0.74). Webb and others (2000) observed that CV increased in the order: total porosity = field water capacity < wilting point < total available water = clay content < macroporosity < sand content < K_s, with K_s exhibiting high variability within horizons, between profiles, and within soil series.

Several researchers have attempted to understand soil variability in different situations. While many have discussed the importance of variability of soil properties on crop production, little has been found on variability of soil properties due to wastewater application. Using soil texture, pH and other topographic variables, Kravchenko and Bullock (2000) observed that 5-71% of the variability in corn yield was attributed to these properties. Pierce and others (1995) studied the variability in soil chemical properties with corn grain yield for three Michigan soils. They reported CV was least for pH, and moderate to most (CV of 0.34 to 0.39) for potassium and phosphorous concentration.

Principal Component Analysis (PCA) is widely used in all forms of data analysis from neuroscience to computer graphics (Shlens, 2005) and is useful to reduce the higher dimension of data to lower dimension without significant loss of information (Kambhatla and Leen, 1997). Using PCA, a large number of correlated variables can be reduced into groups that are linear functions of the original variables (Johnson and Wichern, 1992; Brejda et al., 2000a; b). Each variable in the group is responsible for the correlation among the group of soil attributes that comprise it. With the minimal additional effort, PCA provides a roadmap for how to reduce a complex data set to a lower dimension in a simplified structure (Shlens, 2005). Eleven soil attributes such as mineral soil carbon concentration, mineral soil nitrogen concentration, extractable soil ammonium nitrate, carbon nitrogen ratio, particulate organic matter concentration, mineral-associated organic matter concentration, and silt and clay content were grouped into three PCs, namely, soil carbon factor, soil nitrogen factor, and soil texture factor (Garten et al., 2007). In another study, principal component analysis used 20 soil attributes such as biomass, K_s, pH, EC, infiltration rate, BD, sand, silt, and clay and grouped them into five PCs: water transmission, soil aeration, soil pore connection, soil texture, and moisture statues (Shukla et al., 2006). Similarly, Bachmann and Kinzel (1992); Wander and Bollero, (1999); Shukla et al., (2004a) used PCA and reduced the complex data set into lower dimensions. Most of these efforts were made to group the soil physical and chemical properties into fewer factors using PCA for the agricultural soils. However, very few accounts are available on use of PCA for arid soils irrigated with treated wastewater.

The main objective of this research was to study the effect of treated effluent application on soil physical and chemical properties of Chihuahuan Desert soil after six years of application. The specific objectives were to: (1) determine the influence of lagoon treated wastewater interception by shrub canopies on physical and chemical properties of soil, (2) compare soil physical and chemical properties in the irrigated and unirrigated plots, (3) determine the variability of soil physical and chemical properties, and (4) identify the minimum number of PCs necessary to explain the total variability in soil physical and chemical properties. The hypotheses for this research were that (1) the application of treated effluent will change the soil physical and chemical properties, and (2) the interception by the tree canopies will increase the amount of wastewater received under the canopies, consequently creating greater differences in chemical and physical properties of soil between the canopy and intercanopy areas in the irrigated sites.

MATERIALS AND METHODS

Experimental site

The West Mesa industrial and municipal wastewater land application facility (West Mesa) is located near Las Cruces, NM approximately 23 km from New Mexico State University (longitude W 106° 54.408’ latitude N 32° 15.99’, altitude 1298 m; Fig. 2). Industrial and municipal treated wastewater is applied on the surface through sprinkler irrigation. Research at West Mesa land application site was started in 2002.The West Mesa industrial and municipal land application facility was established in 2002 by the City of Las Cruces at the West Mesa

Industrial Park. This area houses a wastewater treatment plant and a land application system. The untreated industrial and municipal wastewater generated from dairy processing and metal wire fabrication industries is treated with 1,500 m^3 d^{-1} capacity treatment plant, which can discharge 200 m^3 d^{-1} treated wastewater to the 36-ha study site. The effluent first enters the synthetically lined complete mix cell (4,500 m^3 capacity), where aerators aid in microbial decomposition of wastewater contaminants. The wastewater is then transferred to synthetically lined, partial mix cells (9,000-m^3 capacity), where it is further aerated, followed by a non-mixing cell that allows the settling of solids. The wastewater is then finally transferred to a 4,600-m^3 synthetically lined holding pond before being land applied. Aerated lagoon effluent, or secondary treated effluent application on this site began in February 5, 2002 to the Chihuahuan Desert upland adjacent to the wastewater treatment plant by 1,243 fixed-head sprinklers operated by automated pump. The treated plots received various amount of treated effluent due to temporal fluctuations in tenant-generated wastewater and the high evaporation losses from the wastewater lagoons through the peak summer months. During the late summer, the application onto the treated site increases usually due to the decrease in evapotranspiration and increase in tenant's wastewater discharge.

The area is dominated by woody perennials such as creosote (*Larrea tridentata,* (DC) Cov.*)* and honey mesquite *(Prosopis glandulosa* Torr. *var glandulosa)* whose percent groundcover in 2002 were approximately 8.7 and 14.4%, respectively (Babcock et al., 2009). The visual observation during the spring and early summer months of 2008 revealed that approximately 80% of the irrigated area was covered with perennial vegetation including, desert daisy (*Bebbia juncea* Benth.), snakeweed (*Gutierreiza* Lag.), pigweed (*Amaranthus* L.), spiderling (*Boerhavia* L.), sagebrush (*Artemisia* L.) and chinchweed (*Pectis* L.). Gibbens and others (2005) reported that grass cover has decreased drastically with the increase in shrubs during 1885-1998 at Jornada Experimental Range located 37.5 km north of Las Cruces. One reason for decreasing grass cover is that chemicals are produced by creosote bushes, which cause allelopathic effects and suppress the growth of grasses near its periphery (Woodell et al., 1969).

Soils of experimental site

Soil texture of the dune materials in the West Mesa site ranges from sand to light sandy loam with little or no gravel. Dunes on the east of the Rio Grande Valley near Jornada Road are on typic torripsamments and are classified into two types according to their color (Gile et al., 1981). One of them is 5YR hue and other is 10YR hue. A horizons distinction of 5YR type dune is C1/C2/ C3/Ab/B1tb/B21cab/B22tcab/K1b and 10YR dune is C1/C2/B2b/B3cab/C1 cab/C2cab/C3b (Gile et al., 1981).

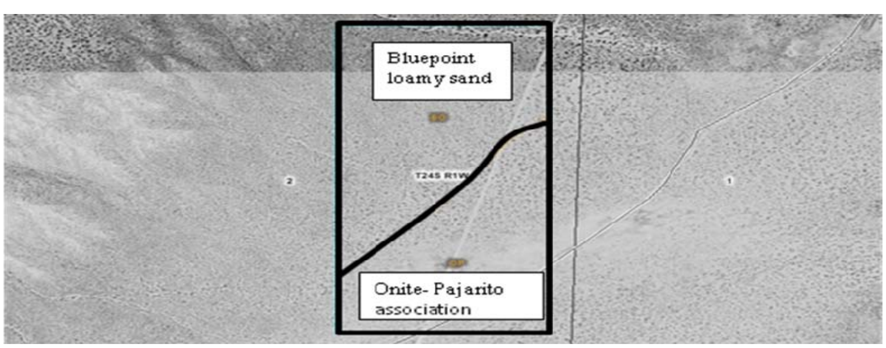


Figure 2: Soil map of study site (http://websoilsurvey.nrcs.usda.gov/app)

Soil series identified in and around the West Mesa site are Onite (coarse-loamy, mixed, superactive, thermic Typic Calciargids), Pintura (mixed, thermic Typic Torripsamments), Bucklebar (Typic Haplargid) (Gile et al., 1981), Pajarito (coarse-loamy, mixed, superactive, thermic Typic Haplocambids), and Bluepoint (mixed, thermic Typic Torripsamments) (USDA-NRCS, Web soil survey; www.ortho.ftw.nrcs.usda.gov; Fig. 2). Soils of the Onite series are well drained with medium runoff and moderate to rapid permeability and are formed in old alluvium derived mainly from acid igneous rocks. Onite soils are on piedmont slopes and valley fills and have slopes of 1 to 8 percent. Soils of the Pajarito series are also well drained, generate slow runoff, moderate to rapid permeable, and are formed in a sandy to moderately sandy mixed sediments from mixed sources. These soils are typically on plains, bajadas, and alluvial fans and can have slopes of 0 to 15 percent (dominantly 1 to 3 percent). The average annual precipitation is 13 cm and average annual air temperature is about 17^{o}C. The Bluepoint soil series is somewhat excessively drained with very low or low runoff; rapid permeability and are formed in eolian materials from mixed rock sources. Bluepoint soils are on dunes and sand sheets and slopes range from 0 to 50 percent.

Soil sampling and analysis

Three plots were identified for soil sampling and analysis: (i) unirrigated (ii) irrigated-I and (iii) irrigated-II (Fig. 3; Adhikari, 2008). Three mesquite and three creosote shrubs were selected randomly in each plot. Shrubs within the irrigated plot-I and irrigated plot-II were located on the periphery of a sprinkler uniformity test site. Four sampling points were selected under each canopy (four cardinal directions within the canopy) and three on the intercanopy area. Intact soil cores were taken by core sampler (19 cm length and 5.5 cm diameter) from the sampling point at 0-20 cm and 20-40 cm depth. Similarly bulk soil samples were taken by metal auger (3 cm diameter) from each sampling point at 0-20, 20-40, 40-60, 60-80, 80-100 and 100-150 cm depths. A total of 186 core samples and 486 bulk soil samples were collected. Visual observations were made to detect the signs of stress and leaf burn likely due to the treated wastewater application.

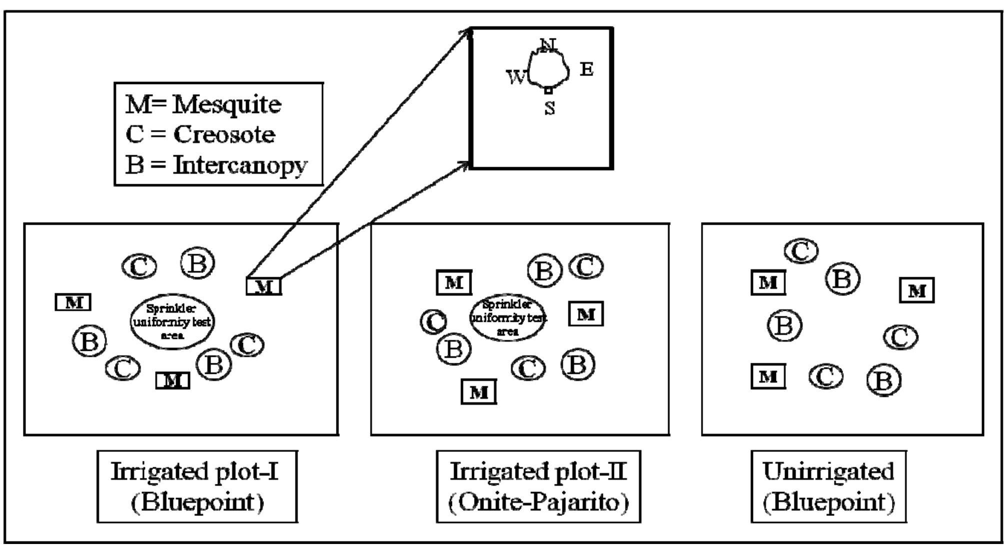


Figure 3: Soil sampling design in the experimental area (not drawn to the scale)

Standard methods were used to determine the soil chemical and physical properties in the lab. Soil cores were trimmed and the BD was determined by the method of Blake and Hartge (1986). All cores were saturated with tap water immediately after trimming by slowly raising the water level in the trough. The K_s was determined by the constant head method (Klute and Dirksen, 1986). Volumetric moisture content (θ) of each core was determined at 0, 0.003, 0.006 Megapascal (MPa) using a tension table; and 0.03, 0.1, 0.3, 1, 1.5 MPa using a pressure plate apparatus. The van Genuchten (1980) model was fitted to the measured soil moisture retention [$h(\theta)$] curves to obtain the air entry value ($1/\alpha$), the pore size distribution parameter (λ), and empirical parameters (n and m) by the retention curve (RETC) program of van Genuchten and others (1991).

$$\begin{aligned} S_e &= \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + (\alpha h)^n\right]^{-m} \ldots. h < 0 \\ &= \theta_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots h \geq 0 \end{aligned} \tag{1}$$

where S_e is the degree of saturation $0 \leq S_e \leq 1$, θ_s and θ_r are saturated and residual water contents. The RETC uses a non-linear least-squares optimization approach to estimate the unknown model parameters and empirical constants affecting the shape of the retention curve.

Particle size analysis was performed by hydrometer method (Gee and Bauder, 1986). Chemical properties, like EC and pH were determined on 1:2 ratio of soil:water. For NO_3^- calculation, a 2.5 gram of sieved soil sample was mixed with 25 ml of 2N Potassium chloride (KCl) solution in a 125 ml Erlenmeyer flask and was shaken for one hour using a mechanical shaker. The solution was filtered through 2V Whatman filter paper before analysis. The extract was used to analyze the amount of nitrate-nitrogen (NO_3^--N) through the technicon autoanalyzer. The amount of NO_3^- was calculated from NO_3^--N. For Cl^- analysis, about 5 g of soil and 25 ml of DI water were mixed in a centrifuge tube, shaken for an hour in a mechanical shaker, and centrifuged for15 minutes at 2000 rpm speed. A mixture consisting of 5 ml of final soil solution, 35 ml of DI water, and 2 ml of nitric acid was titrated with the 0.1N silver nitrate by 798 MPT Titrino. Only one sample was analyzed for OM, SAR, and Na^+ from unirrigated control because no treated wastewater was applied to this plot and an earlier study (Babcock, 2006; Babcock et al., 2006) showed no significant differences in soil chemical properties between 2002 and 2006. In addition, 126 composite soil samples were sent to Harris Lab, Columbus, Nebraska for analysis of various chemical properties like pH, EC, Cl^-, NO_3^-, OM, cation exchange capacity (CEC) and SAR. The ESP was calculated using following relationship (Richards et al., 1954):

$$ESP = \frac{100(-.0126 + .01475\, SAR)}{1 + (-.0126 + .01475\, SAR)} \tag{2}$$

During August 2007, treated wastewater samples were collected directly from the sprinklers and analyzed for EC, SAR, Cl^-, Na^+, and NO_3^- at the Soil Water and Agricultural Testing Lab at NMSU (Tables 1). Other chemical properties including the heavy metal concentrations of wastewater influent and treated effluent from 2002-2007 were provided by the City of Las Cruces, Water Quality Lab (Appendix 1).

Sprinkler uniformity test

Sprinkler uniformity tests were conducted to determine the effectiveness of sprinklers to discharge the water uniformly. Sprinklers (Senninger #3012 1-3/4) were placed on a 12.2 x 12.2 m square grid, or 4-point spacing. The average height of the sprinkler head was about 0.61m from the ground. The sprinkler heads have a design operating pressure of 0.3 MPa and flow rate of 0.0003 $m^3 s^{-1}$. At designed pressure and flow, the precipitation rate of each individual sprinkler is 0.74 cm h^{-1}. A total of 72 sprinkler lines, each with 18 sprinklers, were installed on the application site, and the heads were spaced 12 m down each line and 12 m between each sprinkler line. A sprinkler distribution uniformity assessment was done by using the widely accepted guideline of American Society of Agricultural Engineers standard #3301 (ASAE Standards, 1993). Uniformity of application was calculated by Christiansen's coefficient (Cu) equation (Christiansen, 1942). A coefficient below 60% indicates that the application rates are not uniform, while a coefficient >80% indicates that application rates over the area are similar and the water is distributed evenly (Dorota and Yeager, 2005).

$$Cu = 100\left(1.00 - \sum |dv| / nX\right) \quad (3)$$

where *Cu* = Christiansen's coefficient; *Dv* = deviations of volume of water collected in the catch funnel from the mean catch volume; *n* = number of catch funnels; *X* = mean volume collected in catch funnel.

When performing the sprinkler uniformity test, uncontrollable variables like wind speed and direction must be taken into account because these variables significantly affect the sprinkler irrigation uniformity (Solomon, 1990). The 4-point sprinkler spacing was chosen where creosote or mesquite shrubs were located only on the periphery. Catch funnels of 18.6 cm diameter were placed within the 4-point spacing on a square grid at 1.6 m interval. Two sprinkler uniformity trials were performed in each irrigated plot. At the end of the sprinkler uniformity test, soil sample were collected close to each catch funnel from a depth of 0-20 cm. These samples were analyzed for soil moisture content (θ), EC, and pH. Contour maps were drawn using Surfer® 8 (Golden Software, Inc. 1993-2002) and the variations of sprinkler water distribution were compared with those for EC and pH with the uniformity test area.

Irrigation scheduling

Irrigation scheduling to the West Mesa study site was performed using a web-based model (Ruiz et al., 2006). Weather data recorded at the NMSU Fabian Garcia Experimental Station in Las Cruces by the New Mexico Climate Center were used for calculating the reference evapotranspiration (ET_0). The ET_0 for the previous week was multiplied by crop coefficients for creosote and mesquite to estimate plant water demand in the following week. The average of creosote and mesquite ET on a volumetric basis was applied to the irrigated plot. Irrigation scheduling of treated industrial effluent in the Chihuahuan desert was estimated from crop coefficient (K_c), reference evapotranspiration (ET_o), and growing degree days (GDDs) of the native vegetation (Ruiz et al., 2006).

$$K_c = \frac{ET_c}{ET_0 \; or \; ET_r} \tag{4}$$

$$GDD = \frac{T_{\max} + T_{\min}}{2} - T_{base} \tag{5}$$

where T_{max} and T_{min} are daily maximum and minimum temperatures (^{o}C) and T_{base} is crop specific base temperature (^{o}C).

Statistical analysis

Statistical analysis was carried out for three plots – two irrigated plots that received treated effluent and one unirrigated (control) plot that received no irrigation. To assess differences in soil chemical and physical properties among plots, one-way analysis of variance (ANOVA) with contrasts was performed. Similarly, ANOVA was also performed to assess differences in soil chemical and physical properties between the canopies within the plots. Levene's test was used to test homogeneity of variances. After detecting significant differences, Tukey's HSD was performed to assess where differences existed between groups. Tukey's HSD was used for multiple comparison tests to minimize the experiment-wise Type I error. Shapiro-Wilks test was used to test for normality of the data. All statistical analysis was performed using SAS® software version 9.1.3 (SAS Institute Inc., 2002-2003).

Two data sets were prepared to remove the stochastic effects of wastewater application, one by combining the data of the two irrigated plots and the other by combining all data from three plots (two irrigated and one unirrigated). The mean and median were used as primary estimates of central tendency, and standard deviation, standard errors, CV, kurtosis, skewness, and minimum and maximum were used to describe the degree of variability in soil physical and chemical properties (SAS Institute Inc., 2002-2003). Skewness measures the deviations of the distribution from symmetry. When the skewness is positive, median values are either equal to or smaller than the mean and most of the values locate to the right of mean. In negative skewness, median values were greater than the mean and most of the values locate on the left of the mean. When the data are normally distributed or perfectly symmetrical, skewness will be zero. Similarly, kurtosis is the measure of peakedness or flatness of the probability distribution. Positive kurtosis indicates a more acute peak around the mean with fat tails, while negative kurtosis indicates a smaller peak around the mean with thin tails (SAS® software version 9.1.3; SAS Institute Inc., 2002-2003). In standard normal distribution, the kurtosis value is three. For each dataset, Pearson correlations among soil physical and chemical properties were obtained using Microsoft Office Excel (Microsoft Corporation, 2007).

The PCA was performed on all the measured soil attributes including sand, silt, clay, K_s, BD, AWC, FC, θd, OM, NO_3^-, pH, EC, Na^+, Cl^-, SAR, and ESP, using correlation matrix (SAS Institute Inc., 2002-2003). The correlation matrix was used because measured soil attributes had different dimensions. It uses the standardized data with zero mean and unit variance. PCs with eigenvalues > 1 were retained, and those with eigenvalues < 1 were not considered further as they could explain less variance than that for a measured attribute. Eigenvalues are the amount of variance explained by each factor (Sharma, 1996). The eigenvalue < 1 indicated that the PC could express less variance than an individual attribute, and, therefore, it was rejected (Sharma, 1996; Shukla et al., 2004a). The retained PCs were subjected to varimax rotation to maximize the correlations between PCs and the measured attributes by distributing the variance of each factor (SAS Institute Inc., 2002-2003). A measured soil attribute was assigned to a PC for which it had the highest value of communality estimate.

RESULTS

Treated wastewater quality and application

Influent and treated effluent analysis showed high amounts of TDS, Cl^-, Na^+, NO_3^-, and SAR (Table 1). Most of the treated effluent chemical values were higher than influent chemical values except for NO_3^- in some years. Chemical composition of treated wastewater was also dependent on the water sampling season. The wastewater chloride content was 706.00 ± 0.00 mg L^{-1} during the summer of 2006 and 439.00 ± 249.00 mg L^{-1} during the winter (Appendix 1).

Table 1: Influent and treated effluent chemical values means and standard errors from 2002-2007

	----------TDS (mg L^{-1})-----------		---------Chloride (mg L^{-1})---------	
Year	Influent	Effluent	Influent	Treated Effluent
2002	1063.91 ± 125.91	2758.91 ± 199.76	283.58 ± 43.58	1133.08 ± 105.46
2003	1358.00 ± 172.40	2080.00 ± 171.90	176.60 ± 14.33	327.60 ± 17.19
2004	1432.00 ± 153.89	1838.00 ± 111.10	177.00 ± 13.34	244.60 ± 19.68
2005	1782.50 ± 457.29	2557.50 ± 333.17	240.00 ± 28.33	329.00 ± 47.27
2006	1866.66 ± 450.41	3160.00 ± 900.68	320.66 ± 43.07	528.00 ± 169.00
2007	760.00 ± 0.00[a]	3150.00 ± 0.00[a]	190.00 ± 0.00 [a]	785.15 ± 118.85[b]
Average	1377.17 ± 226.65	2590.73 ± 286.10	231.20 ± 23.77	557.905 ± 79.57
	--------------Nitrate (mg L^{-1})----------		------------Sodium (mg L^{-1})---------	
2002	1.15 ± 0.97	0.75 ± 0.48	294.36 ± 56.25	697.27± 38.49
2003	38.44 ± 24.66	33.48 ± 2.83	395.80 ± 71.56	650.60 ± 61.04
2004	6.59 ± 6.2	34.72 ± 3.70	456.00 ± 54.94	600.20 ± 39.46
2005	0.31 ± 0.66	4.69 ± 1.10	502.25 ± 122.26	903.25 ± 120.69
2006	1.46 ± 0.44	13.46 ± 2.94	332.00 ± 83.57	1175.33 ± 149.69
2007	4.51± 0.00[a]	2.19 ± 1.57[b]	356.00 ± 0.00[a]	1220.26 ± 220.23[b]
Average	8.74 ± 5.48	14.88 ± 2.10	389.40± 64.76	874.49 ± 104.81
	-----------EC (dS m^{-1})---------------		-------------------SAR------------------	
2002	1.66 ± 0.19	4.310 ± 0.31	13.22 ± 4.13	14.26 ± 1.35
2003	2.12 ± 0.26	3.25 ± 0.26	10.40 ± 1.79	26.10 ± 2.37
2004	2.23 ± 0.24	2.87 ± 0.17	12.12 ± 1.17	28.10 ± 2.21
2005	2.78 ± 0.71	3.99 ± 0.52	11.25 ± 2.47	42.47 ± 6.03
2006	2.91 ± 1.21	4.93 ± 1.40	7.55 ± 1.91	41.47 ± 4.33
2007	1.18 ± 0.00[a]	4.04 ± 0.06[b]	8.59 ± 0.00[a]	45.44 ± 2.83[b]
Average	2.14 ± 0.43	3.90 ± 0.45	10.52 ± 1.91	32.97 ± 3.18

Source-City of Las Cruces, Water Quality Lab

[a] only from January

[b] treated wastewater sampled during uniformity test and analyzed in SWAT lab

Treated effluent was analyzed for various heavy metals like copper (Cu), molybednm (Mo), calcium (Ca), mercury (Hg), aluminum (Al), lead (Pb), nickel (Ni), selenium (Se), and silver (Ag). During 2004 only, Cu (0.01 mg L^{-1}) and Mo (0.16 ± 0.01 mg L^{-1}) were detected in the treated effluent. Heavy metals like Cu (0.05± 0.03 mg L^{-1}), Mo (0.16 ± 0.02 mg L^{-1}), Al (0.08 ± 0.04 mg L^{-1}) and Zn (0.02 ± 0.00 mg L^{-1}) were detected during 2005 and did not exceed the United States Environmental Protection Agency (USEPA) drinking water standards (USEPA drinking water standards Cu <1.3 mg L^{-}, Mo <10 mg L^{-}, Al 0.05-2 mg, Zn <5 mg L^{-}) (USEPA, http://www.epa.gov/safewater/contaminants/index.html).

From 2002 to 2007, the entire 36-ha received a total of 330.47 cm of water, during this period a total of 197.37 cm came from the treated effluent application and remaining 133.10 cm came from precipitation. During the same period, the total ET was 878.91 cm, which was the average nonstressed ET for mesquite and creosote shrubs (Table 2). Thus, nonstressed ET far exceeded the water inputs and the ratio of total water applied to ET was about 0.38.± 0.04. Overall, vegetation in the entire experimental site was water stressed. Little or no treated wastewater was applied during the summer months when ET demands were high primarily due to unavailability of wastewater (Fig. 4). Nonstressed ET calculated for creosote was higher than that for the mesquite each year.

Table 2: Amounts of treated wastewater, precipitation, and evapotranspiration (ET) during 2002-2007

Year	Waste water	Precipitation	Total applied	Creosote ET	Mesquite ET	Average crop ET	Deficit
	------------	------------	------------	cm	------------	------------	------------
2002	32.50	16.85	49.35	135.64	129.29	132.47	79.94
2003	20.46	12.44	32.90	145.02	140.58	142.80	107.65
2004	56.28	25.53	81.81	147.02	146.48	146.77	64.96
2005	33.73	23.77	57.54	129.12	117.09	123.16	65.54
2006	17.62	33.93	51.55	170.30	179.83	175.18	128.83
2007	36.79	20.45	57.24	177.66	143.63	158.53	101.29
Ave.	32.90	22.16	55.07	150.79	142.82	146.49	91.36

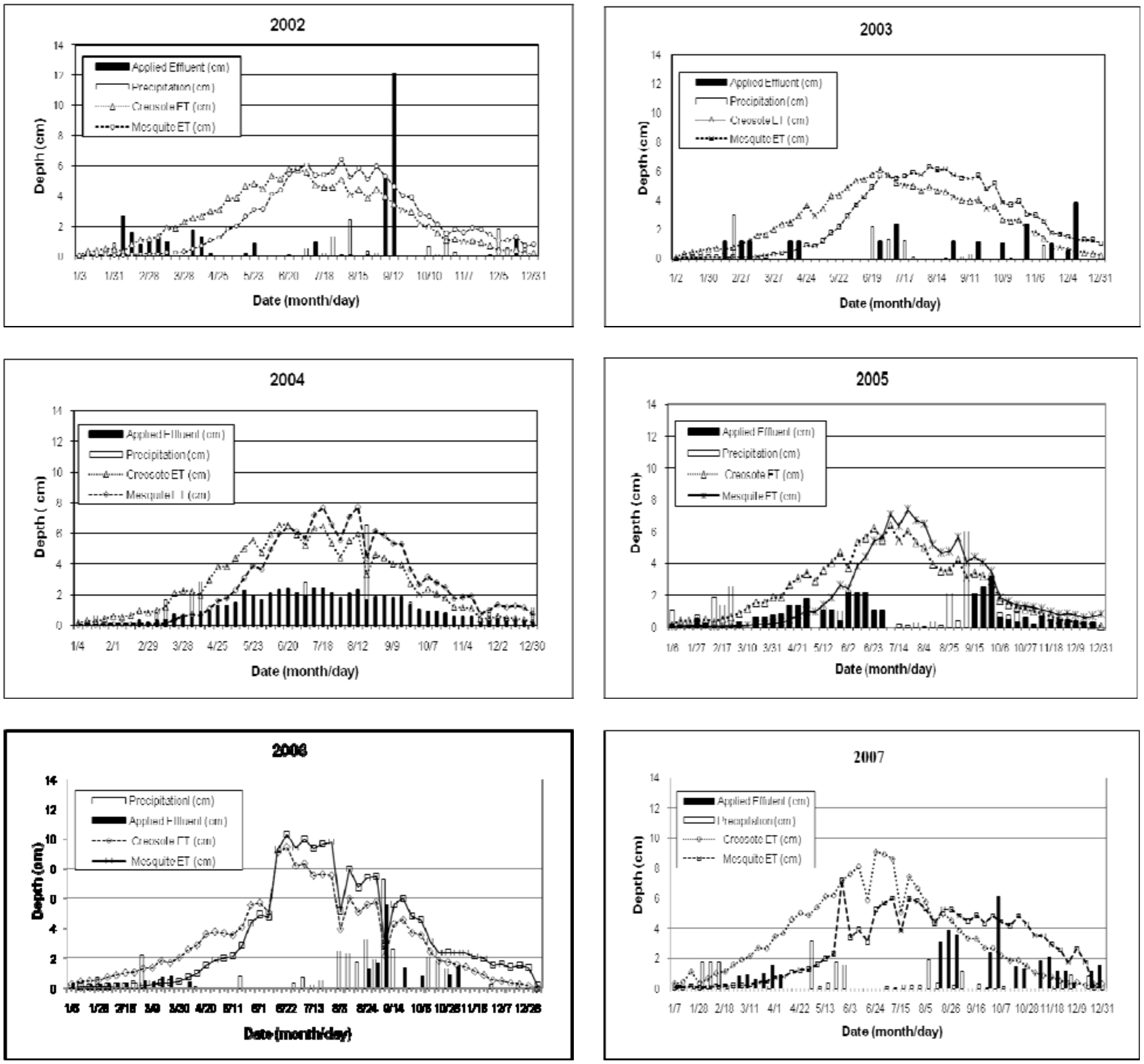


Figure 4: Evapotranspiration, precipitation, and applied treated effluent during 2002-2007

Sprinkler distribution uniformity

The CU values (Eq. 3) were fairly low, 49.34 ± 2.23% for irrigated-I and 61.57 ± 2.11% for irrigated plot-II (Table 3). The sprinklers in irrigated plot-I were installed on a trapezoidal rather than on a square grid. The spacing of sprinklers was 11 m by 12.70 m and 11.48 m by 14.18 m in irritated plot-I and 11.89 m by 12.59 m and 12.01 m by 11.42 m in irrigated plot-II (Fig. 5). Average volume collected was higher under canopies (116.62 ± 5.18 cm^3) than in intercanopy area (82.55 ± 5.87 cm^3), and volume collected under creosote canopies was higher (124.83 ± 3.96 cm^3) than under mesquite canopies (98.87 ± 8.27 cm^3) (Adhikari, 2008).

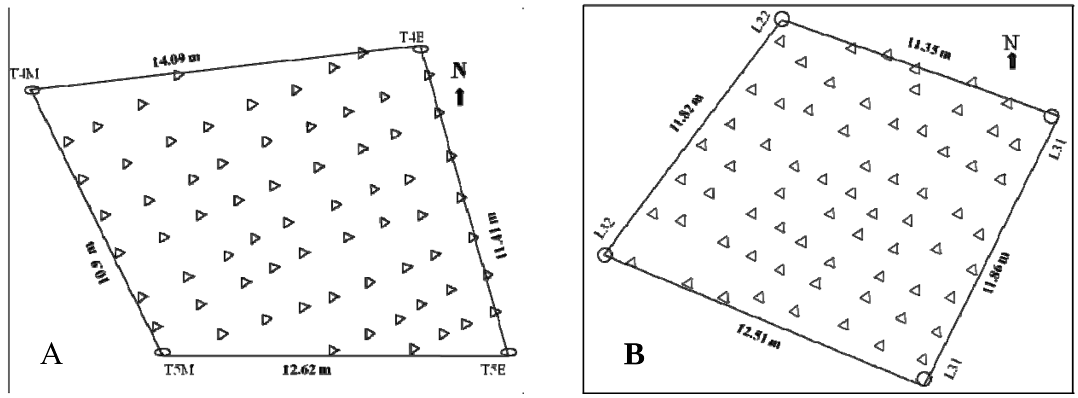


Figure 5: Location of catch funnel and 4-point sprinkler in the uniformity test area in (A) irrigated plot-I and (B) irrigated plot-II.

Table 3: Christiansen's uniformity coefficient, wind speed, and wind direction during the time of sprinkler uniformity test

Irrigated-I	Total time (min)	Wind speed at	Wind speed* (km h^{-1})	Wind* direction	Christiansen's coefficient
Trial -1	40	1.32 PM	32.50	ESE	
		1.54 PM	31.50	SE	51.57
Trial -2	38	2.35 PM	31.50	ESE	
		2.53 PM	29.00	SE	47.11
Mean---			**31.56 ± 0.72**	**SE**	**49.34 ± 2.23**
Irrigated-II					
Trial-1	42	9.33 AM	5.60	E	
		9.56 AM	5.60	E	59.46
Trial-2	41	10.53 AM	1.60	E	
		11.13 AM	1.60	E	
		10.33 AM	5.60	NE	63.68
Mean---			**4.00 ± 0.97**	**E**	**61.57 ± 2.11**

*Las Cruces Airport (http://www.wunderground.com/us/NM/Las%20Cruces.html)

The contour map of sprinkler distribution uniformity in irrigated plot-I showed more patches of dark and white colors than the contour map of irrigated plot-II (Fig. 6). This indicated that sprinkler distribution in the irrigated plot-II was more uniform than in the irrigated plot-I. The EC contour maps correlated with sprinkler distribution contour maps in some locations. For example, in irrigated plot-I near the coordinates (2.5 m, 2.5 m) measured precipitation was 160 cm^3 (or high) and within the same area EC was 0.95dS m^{-1} (or high) (Fig. 7). Similarly, in irrigated plot-II near the coordinates (1.5 m, 2.9 m) measured precipitation was 250 cm^3 and measured EC was 0.90 dS m^{-1} (Fig. 7). In some other places, lower values of EC were observed where less water was collected in the catch funnel. However, no correlations were observed between pH and sprinkler distribution uniformity in both irrigated plots (Fig. 8).

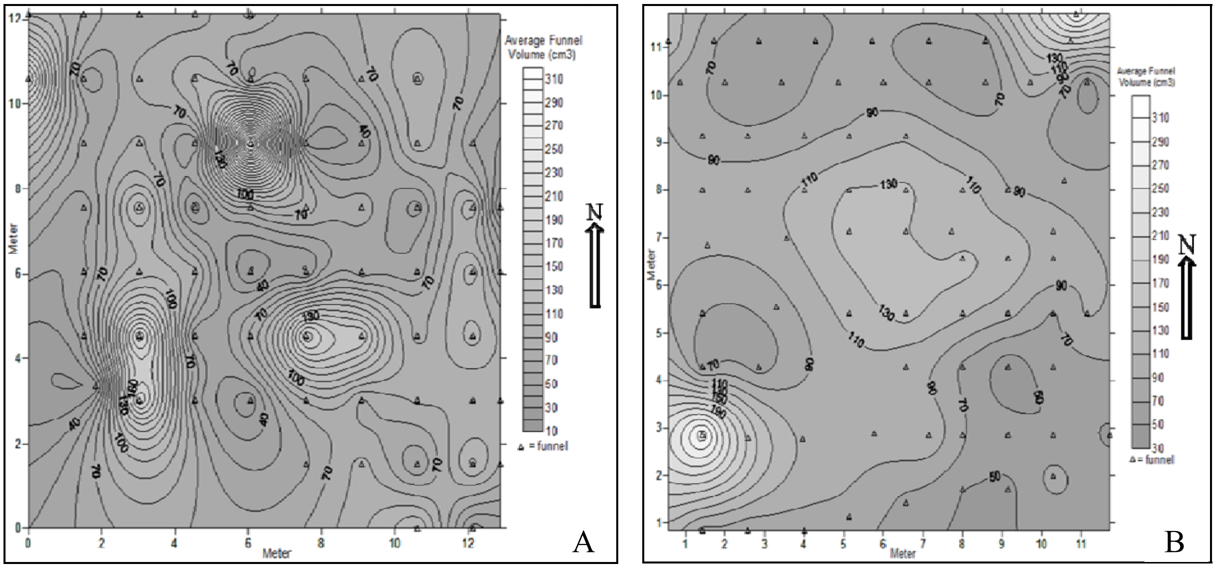


Figure 6: Sprinkler distribution uniformity contour map of 4-point spacing in (A) irrigated plot-I and (B) irrigated plot-II

Note-Color scale to the right of the contour map, precipitation is reported as average catch funnel volume during one hour in cm^3. Lighter colored areas represent higher volumes of water received by catch funnels than darker areas. Contours for volume 40 cm^3, 70 cm^3, 100 cm^3, 130 cm^3 and 160 cm^3 are labeled.

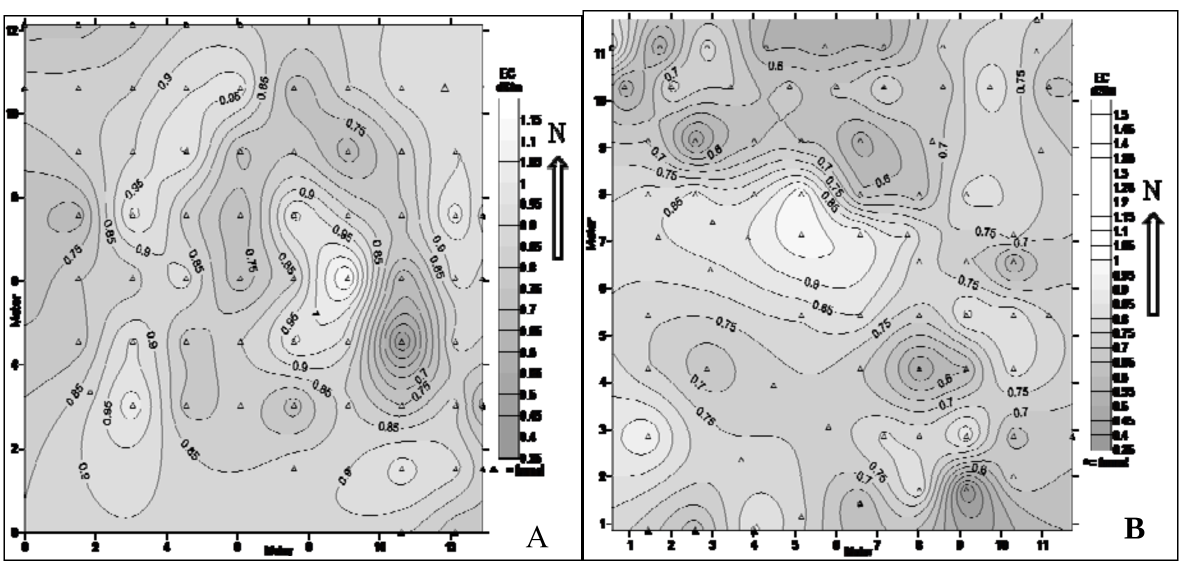


Figure 7: EC contour map of 4-point sprinkler uniformity test area in (A) irrigated plot-I and (B) irrigated plot-II

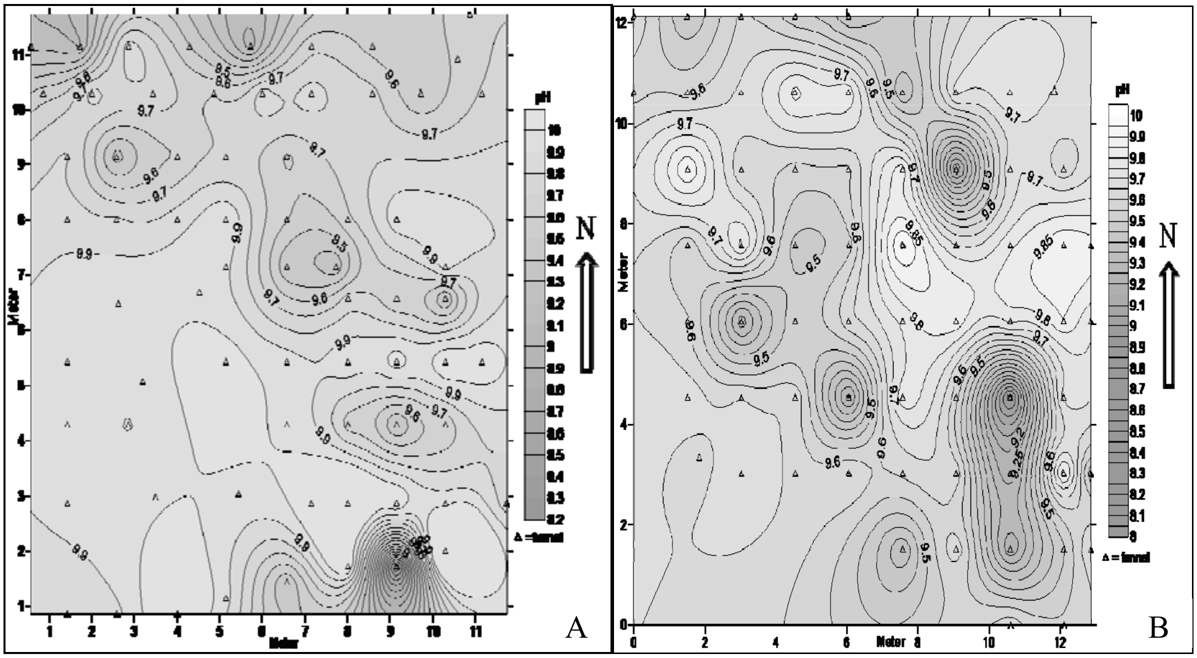


Figure 8: pH contour map in 4-point sprinkler uniformity test area in (A) irrigated plot-I and (B) irrigated plot-II

Soil physical properties

In the unirrigated plot, one-way ANOVA contrasts detected significant differences between vegetation canopies and intercanopy areas for K_s ($P < 0.001$) and BD ($P < 0.004$) at 0-20 cm depth (Appendix 2). Significant differences were detected for K_s and sand content between mesquite canopies and intercanopy areas at 0-20 cm depth in irrigated plot-I (Appendix 2). Where significant differences were detected, mesquite canopies have higher K_s and sand content than intercanopy areas (Table 4).

No significant differences were detected between vegetation canopies and intercanopy areas for BD, silt, and clay contents in irrigated plot-I at 0-20 cm depth (Appendix 2). Similarly, no significant differences were detected between vegetation canopies and intercanopy areas for BD, $K_{s,}$ sand, silt, and clay content in irrigated plot-I at 20-40 cm depth (Appendix 2).

In irrigated plot-II at 0-20 cm depth, significant differences were detected for K_s under the canopies of mesquite, creosote, and intercanopy areas (Appendix 2). The K_s was higher under mesquite canopies (18.20 ± 1.29 cm h^{-1}) than creosote canopies (14.20 ± 0.78 cm h^{-1}) and intercanopy areas (4.80 ± 0.34 cm h^{-1}) (Table 4). Higher K_s under mesquite canopies than intercanopy areas and creosote canopies were due to higher sand content and more developed networks of macrospores underneath mesquite canopies. A significant difference was also detected between mesquite and creosote canopies for sand content at 20-40 cm depth in irrigated plot-II only.

Although there were some numerical differences, one-way ANOVA contrasts did not detect significant differences in BD, sand, silt, and clay contents between both irrigated plots and the unirrigated plot at 0-20 cm depth (Appendix 2). This indicated that there was no evidence of an effect of treated wastewater application on BD, particle size, or soil texture in irrigated plots although type-II errors were not determined. However, significant differences in K_s values were detected among plots and K_s were higher in the unirrigated than irrigated plot-I only. At 20-40 cm depth, significant differences were detected for K_s between irrigated and unirrigated plots and average K_s of canopies and intercanopy areas in the unirrigated plot was 11.65 ± 1.52 cm h^{-1}, irrigated plot-I was 6.11 ± 1.67 cm h^{-1} and in irrigated plot-II was 8.23 ± 2.71 cm h^{-1} (Table 5) (Adhikari et al., 2008a; b).

Table 4: Mean, standard errors, and one-way ANOVA contrasts between plots for particle size, bulk density (BD), and hydraulic conductivity (K_s) at 0-20 cm depth.

Vegetation	Sand %	Silt %	Clay %	BD Mg m^{-3}	K_s cm h^{-1}
			Irrigated-I		
Mesquite	89.19 ± 0.06	3.67 ± 0.05	7.14 ± 0.13	1.54±0.01	13.64 ± 1.58
Creosote	88.94 ± 0.16	3.41 ± 0.22	7.62 ± 0.08	1.49±0.00	11.65 ± 1.97
Intercanopy	87.96 ± 0.57	4.20 ± 0.33	7.84 ± 0.09	1.57 ± 0.01	8.20 ± 0.72
Average	88.70 ± 0.26	3.76 ± 0.20	7.53 ± 0.10	1.53 ± 0.01	11.16±1.42
			Unirrigated		
Mesquite	89.77 ± 0.31	3.61 ± 0.24	6.62 ± 0.37	1.52 ± 0.00	22.20 ± 2.82
Creosote	89.69 ± 0.41	3.83 ± 0.41	6.48 ± 0.72	1.57 ± 0.01	12.35 ± 0.30
Intercanopy	88.64 ± 1.15	4.00 ± 0.57	7.36 ± 0.57	1.59 ± 0.03	11.00 ± 1.40
Average	89.37 ± 0.62	3.81 ± 0.40	6.82 ± 0.55	1.56 ± 0.01	15.18 ±1.50
			Irrigated-II		
Mesquite	89.35 ± 0.66	3.67 ± 0.72	6.98 ± 0.21	1.51 ± 0.01	18.2 ± 1.29
Creosote	88.98 ± 0.43	3.90 ± 0.36	7.12 ± 0.16	1.50 ± 0.03	14.00 ± 0.78
Intercanopy	89.12 ± 1.33	2.83 ± 1.20	8.05 ± 0.33	1.55 ± 0.01	4.80 ± 0.34
Average	89.15 ± 0.80	3.47 ± 0.76	7.38 ± 0.23	1.52 ± 0.01	12.33 ± 0.80
ANOVA			P-value		
Irri-I vs. Uni	0.055	0.315	0.201	0.074	**<0.001**
Irri-II vs. Uni	0.093	0.106	0.319	0.285	0.496
Irri-I vs. Irri-II	0.085	0.523	0.057	0.603	0.459

P-values less than $\alpha = 0.05$ are significantly different and are bolded
Irri: Irrigated
Uni: Unirrigated

In the unirrigated plot, one-way ANOVA contrasts did not detect any significant differences between vegetation canopies and intercanopy areas for AWC, FC and θd at 0-20 cm depth. However, significant differences in AWC and FC were detected at 20-40 cm depth between mesquite and intercanopy areas of the unirrigated plot (Appendix 3). No significant differences were detected between vegetation canopies and intercanopy areas for θd at 20-40 cm depth (Appendix 3).

In both irrigated plots at 0-20 and 20-40 cm depth, one-way ANOVA contrasts did not detect any differences between vegetation canopies and intercanopy areas for AWC, FC, and θd (Appendix 3). There is no evidence of an effect of treated wastewater on AWC, FC, and θd. Similarly, one-way ANOVA contrasts did not detect significant differences for AWC between irrigated and unirrigated plots at 0-20 cm depth. Average AWC at 0-20 cm depth in irrigated plot-I was 2.39 ± 0.24 cm; irrigated plot-II was 2.17 ± 0.29 cm and the unirrigated plot was 1.71 ± 0.15 cm (Table 6). Significant differences were detected for θd and FC between irrigated plot-II and the unirrigated plot at 0-20 cm depth.

Table 5: Mean, standard errors, and one-way ANOVA contrasts between plots for particle size, bulk density (BD), and hydraulic conductivity (K_s) at 20-40 cm depth.

Vegetation	Sand %	Silt %	Clay %	BD Mg m^{-3}	K_s cm h^{-1}
			Irrigated-I		
Mesquite	89.04 ± 0.35	3.91 ± 0.07	7.05 ± 0.23	1.60 ± 0.01	7.23 ±1.35
Creosote	88.95 ± 0.16	3.33 ± 0.08	7.72 ± 0.14	1.50 ± 0.03	5.30 ± 1.33
Intercanopy	88.61 ± 0.33	3.66 ± 0.33	7.73 ± .57	1.59 ± 0.01	5.80 ± 2.33
Average	88.87 ± 0.28	3.63 ± 0.26	7.50 ± 0.31	1.56 ± 0.01	6.11 ± 1.67
			Unirrigated		
Mesquite	89.36 ± 0.27	3.52 ± 0.07	7.12 ± 0.73	1.59 ± 0.01	13.55 ± 0.90
Creosote	89.23 ± 0.62	3.30 ± 0.41	7.47 ± 0.52	1.56 ± 0.01	10.80 ± 2.12
Intercanopy	89.73 ± 0.95	3.00 ± 0.00	7.27 ± 0.49	1.56 ± 0.03	11.60 ± 1.56
Average	89.44 ± 0.61	3.27 ± 0.16	7.29 ± 0.58	1.57 ± 0.01	11.65 ± 1.52
			Irrigated-II		
Mesquite	89.02 ± 0.13	3.96 ± 0.71	7.02 ± 0.35	1.53 ± 0.04	9.70 ± 2.86
Creosote	87.98 ± 0.38	3.80 ± 0.08	8.22 ± 0.37	1.52 ± 0.00	8.00 ± 1.57
Intercanopy	88.61 ± 0.33	3.50 ± 0.15	7.89 ± 0.11	1.53 ± 0.01	7.00 ± 3.70
Average	88.53 ± 0.28	3.76 ± 0.31	7.71 ± 0.27	1.52 ± 0.01	8.23 ± 2.71
ANOVA			P-value		
Irri.-I vs. Uni.	0.128	0.654	0.052	0.427	**<0.001**
Irri-II vs. Uni	0.211	0.302	0.064	0.314	**<0.001**
Irri-I vs. Irri-II	0.744	0.558	0.813	0.181	0.217

P-value less than α = 0.05 are significantly different and are bolded
Irri: Irrigated
Uni: Unirrigated

At 20-40 cm depth, significant differences were detected for AWC between irrigated plot-II and the unirrigated plot where average AWC for irrigated plot-II was 1.74 ± 0.13 cm and for the unirrigated plot was 1.49 ± 0.16 cm (Table 6). Higher AWC in the irrigated plot might be due to slightly low BD in the irrigated plot than in the unirrigated plot. Similarly, significant differences for FC were detected between the irrigated and unirrigated plots. An average FC was 0.17 ± 0.01 cm for irrigated plot-I, 0.19±0.01 cm for irrigated plot-II and 0.12± 0.0 for the unirrigated plot (Table 6). Significant differences were also detected for θd between irrigated plot-II and unirrigated plot, and irrigated plot-I and irrigated plot-II (Table 6).

The van Genuchten (1980) model was fitted to the measured soil moisture retention [h(θ)] curves (Figs. 9, 10 and 11; Appendix 4 and 5) to obtain the bubbling pressure or air entry value and particle size distribution parameters (Table 7). The coefficient of determination (R^2) between measured and model fitted h(θ) ranged from 0.96 to 0.99. The bubbling pressure, which is the inverse of α, was higher under vegetation canopies and intercanopy areas in the unirrigated plot than in both the irrigated plots.

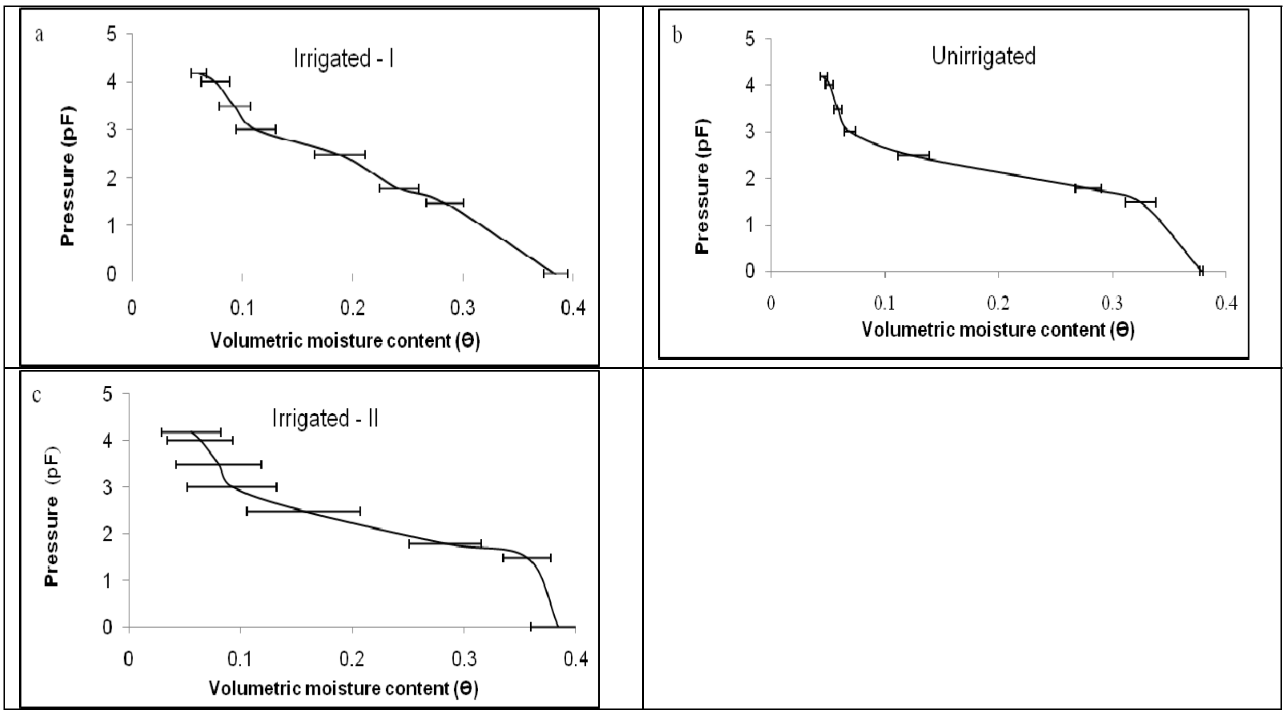


Figure 9: Soil moisture release curves of mesquite canopy at 0-20 cm depth by plot where pF is log of pressure in centimeters (a) irrigated plot-I, (b) unirrigated, and (c) irrigated –II

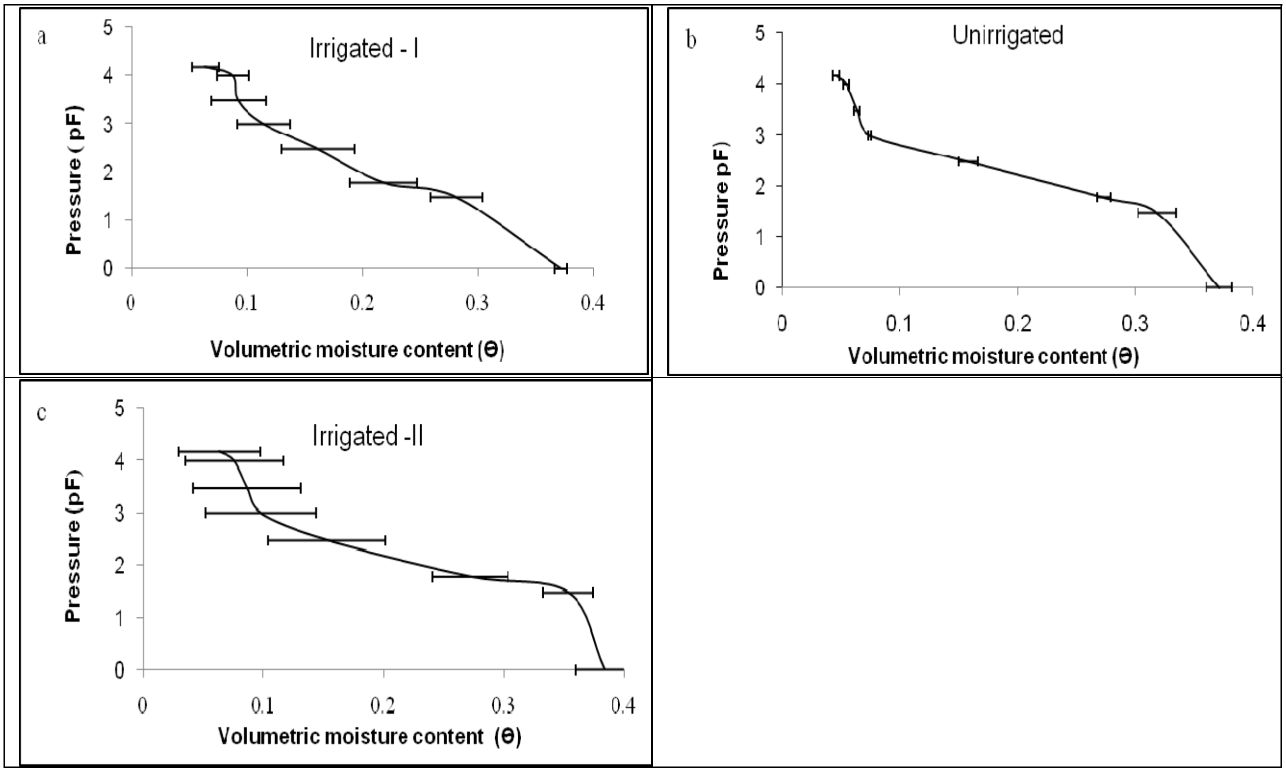


Figure 10: Soil moisture release curves of creosote canopy at 0-20 cm depth by plot where pF is log of pressure in centimeters (a) irrigated plot-I, (b) unirrigated, and (c) irrigated plot-II

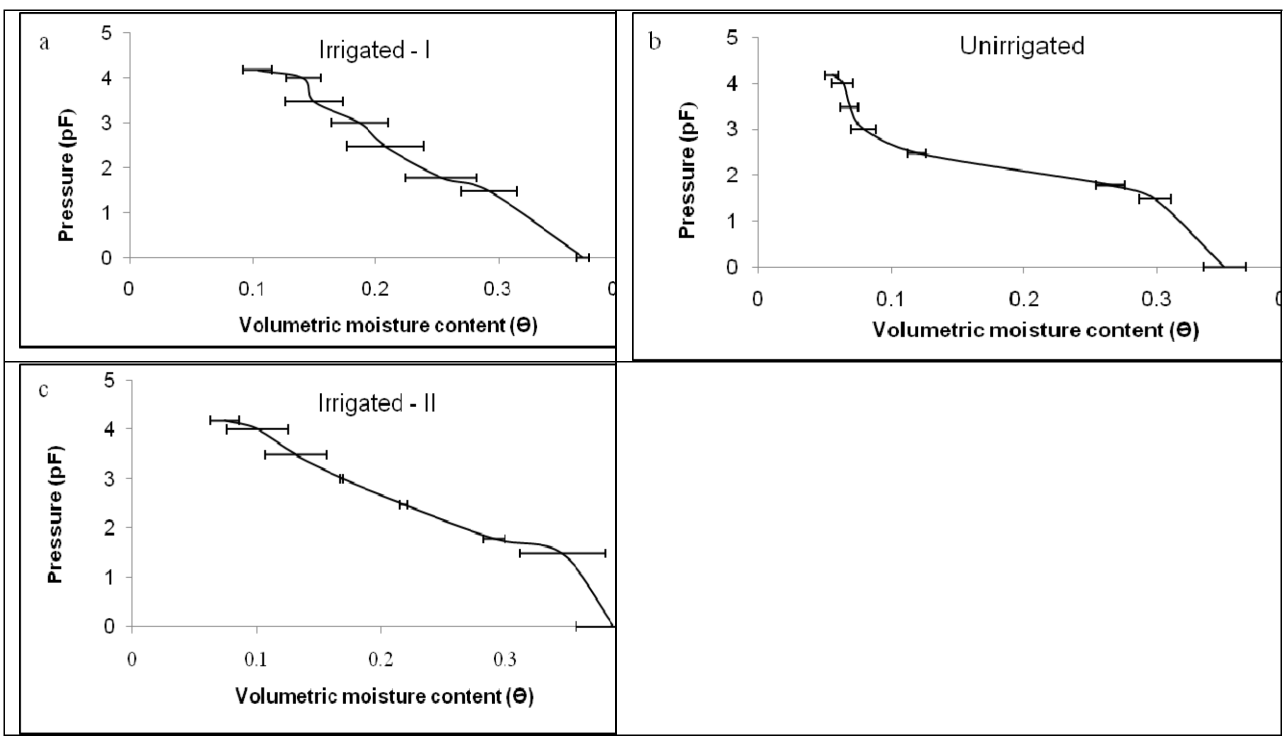


Figure 11: Soil moisture release curves of intercanopy area by plot where pF is log of pressure in centimeters at 0-20 cm (a) irrigated plot-I, (b) unirrigated, and (c) irrigated plot-II

Table 6: Mean, standard errors, and one-way ANOVA contrasts between plots for available water content (AWC), field capacity (FC), and drainable porosity (θd) at 0-20 and 20-40 cm.

Vegetation	AWC	FC	θd	AWC	FC	θd
	---cm---					
	---0-20 cm depth---			---20-40 cm depth---		
	---Irrigated-I---					
Mesquite	2.06 ± 0.25	0.16 ± 0.01	0.12 ± 0.03	1.81 ± 0.29	0.17 ± 0.01	0.15 ± 0.02
Creosote	2.90 ± 0.19	0.21 ± 0.01	0.11 ± 0.01	1.71 ± 0.22	0.18 ± 0.01	0.14 ± 0.01
Intercanopy	2.21 ± 0.29	0.17 ± 0.01	0.10 ± 0.01	1.55 ± 0.37	0.16 ± 0.01	0.16 ± 0.03
Average	2.39 ± 0.24	0.18 ± 0.01	0.11 ± 0.01	1.69 ± 0.29	0.17 ± 0.01	0.15 ± 0.06
	---Unirrigated---					
Mesquite	1.85 ± 0.13	0.11 ± 0.00	0.14 ± 0.01	1.83 ± 0.11	0.14 ± 0.01	0.10 ± 0.01
Creosote	2.02 ± 0.15	0.13 ± 0.00	0.11 ± 0.14	1.63 ± 0.22	0.13 ± 0.01	0.13 ± 0.01
Intercanopy	1.27 ± 0.19	0.11 ± 0.00	0.12 ± 0.00	1.01 ± 0.16	0.10 ± 0.00	0.17 ± 0.02
Average	1.71 ± 0.15	0.12 ±0.00	0.12 ± 0.05	1.49 ± 0.16	0.12 ± 0.01	0.13 ± 0.01
	---Irrigated-II---					
Mesquite	2.08 ± 0.21	0.17 ± 0.01	0.13 ± 0.00	1.21 ± 0.18	0.22 ± 0.01	0.11 ± 0.00
Creosote	2.37 ± 0.14	0.20 ± 0.01	0.10 ± 0.00	2.11 ± 0.10	0.20 ± 0.00	0.09 ± 0.00
Intercanopy	2.07 ± 0.53	0.16 ± 0.00	0.10 ± 0.02	1.91 ± 0.13	0.17 ± 0.00	0.13 ± 0.01
Average	2.17 ± 0.29	0.17 ± 0.01	0.11 ± 0.01	1.74 ± 0.13	0.19 ± 0.01	0.11± 0.01
ANOVA	---P-value---					
Irri-I vs. Uni	0.823	**0.047**	**0.029**	0.053	**0.048**	0.170
Irri-II vs. Uni	0.446	**0.005**	0.094	**0.030**	**0.043**	**0.010**
Irri-I vs. Irri-II	0.620	0.390	0.290	0.130	0.350	**0.010**

P-values less than α = 0.05 are significantly different and are bolded
Irri: Irrigated, Uni: Unirrigated

Table 7: Mean and standard errors for the van Genuchten (1980) parameters at 0-20 cm depth in both irrigated and unirrigated plots.

Plots	Vegetation	θr	θs	α	η	R^2	α^{-1} cm
Irrigated-I	Mesquite	0.03 ± 0.02	0.38 ± 0.00	0.65 ± 0.15	1.35 ± 0.03	0.98	1.54
	Creosote	<0.001	0.36 ± 0.01	0.94 ± 0.47	2.10 ± 0.89	0.98	1.06
	Intercanopy	<0.001	0.35 ± 0.05	0.83 ± 0.47	1.13 ± 0.00	0.99	1.22
Unirrigated	Mesquite	0.04 ± 0.00	0.37 ± 0.00	0.17± 0.05	1.93 ± 0.13	0.99	5.88
	Creosote	0.03 ± 0.01	0.36 ± 0.00	0.17 ± 0.05	1.77 ± 0.19	0.98	5.56
	Intercanopy	0.04 ± 0.00	0.36 ± 0.00	0.18 ± 0.00	1.79 ± 0.05	0.99	5.56
Irrigated-II	Mesquite	0.05 ± 0.01	0.37 ± 0.00	0.38 ± 0.04	1.35 ± 0.04	0.98	2.63
	Creosote	0.09 ± 0.02	0.39 ± 0.00	0.44 ± 0.04	1.39 ± 0.08	0.96	2.27
	Intercanopy	0.01± 0.01	0.37 ± 0.02	0.50 ± 0.04	1.21 + 0.02	0.99	2.00

Where θr is residual soil moisture, θs is saturation soil moisture, α and η are equation parameters, R^2 is coefficient of determination

Soil chemical properties

Soil chemical properties are given in Appendices 6 and 7. Chloride content was higher under creosote canopies than mesquite and intercanopy areas in irrigated plot-I at all depths (Figs. 12A-C). The Cl^- content showed an almost linear increase with depth under creosote and intercanopy areas (Figs 12A-C) and indicated Cl^- leaching under creosote canopies and intercanopy areas. High Cl^- content under creosote canopies than intercanopy areas and mesquite canopies could also be due to the higher treated wastewater interception by creosote canopies (Appendix 6). One-way ANOVA contrasts detected differences between mesquite and creosote canopies and between mesquite canopies and intercanopy areas of irrigated plots at 0-20 cm depth (Appendix 8 and 9). Similar differences were detected between mesquite canopies and creosote canopies at 0-20 cm depth of irrigated plot-II (Appendix 9). One-way ANOVA contrasts detected differences for Cl^- between irrigated plots and unirrigated plots at all depths (Appendix 11).

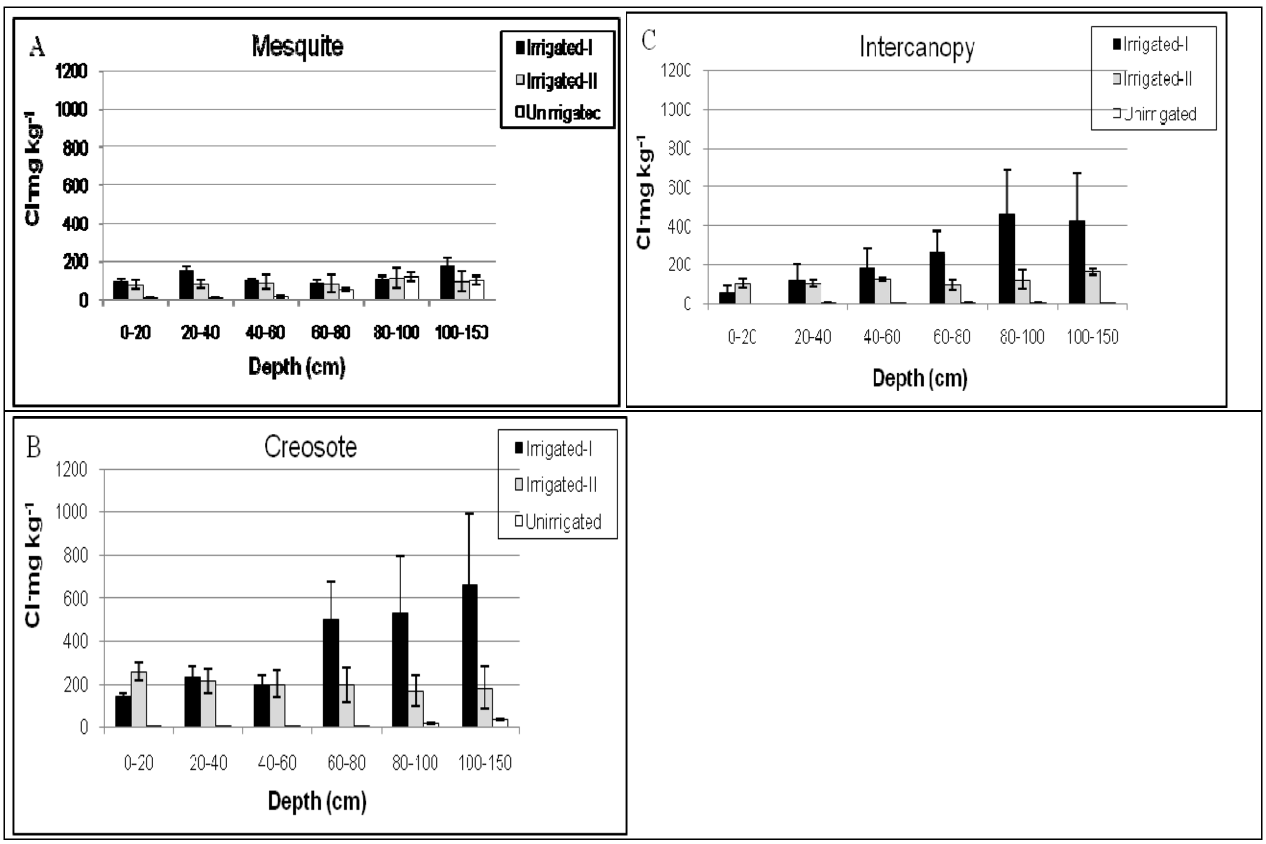


Figure 12: Chloride in three plots under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

Nitrate content was higher under mesquite canopies in both irrigated plots than under creosote canopies and intercanopy areas at 0-20 cm depth (Figs. 13A-C). Nitrogen fixation from the atmosphere by the mesquite roots and decomposition of litter are the probable reasons for higher NO_3^- under mesquite canopies at most depth. Higher NO_3^- at upper depths and lower at deeper depths indicated no leaching of NO_3^- toward groundwater level. Similarly higher NO_3^-

under creosote canopies might be due to the higher interception of wastewater by the canopies.

One-way ANOVA contrasts detected differences for NO_3^- between creosote canopies and intercanopy areas at 0-20 cm depth, between mesquite and creosote canopies at 60-80 and 100-150 cm, and between mesquite canopies and intercanopy areas at 100-150 cm depth in the irrigated plot-I (Appendix 8). Within irrigated plot-II, differences were detected between creosote canopies and intercanopy areas and between mesquite and creosote canopies at 0-20 cm and at 100-150 cm depth only (Appendix 9). One-way ANOVA contrasts for NO_3^- content detected differences between irrigated and unirrigated plots at most depths (Appendix 11).

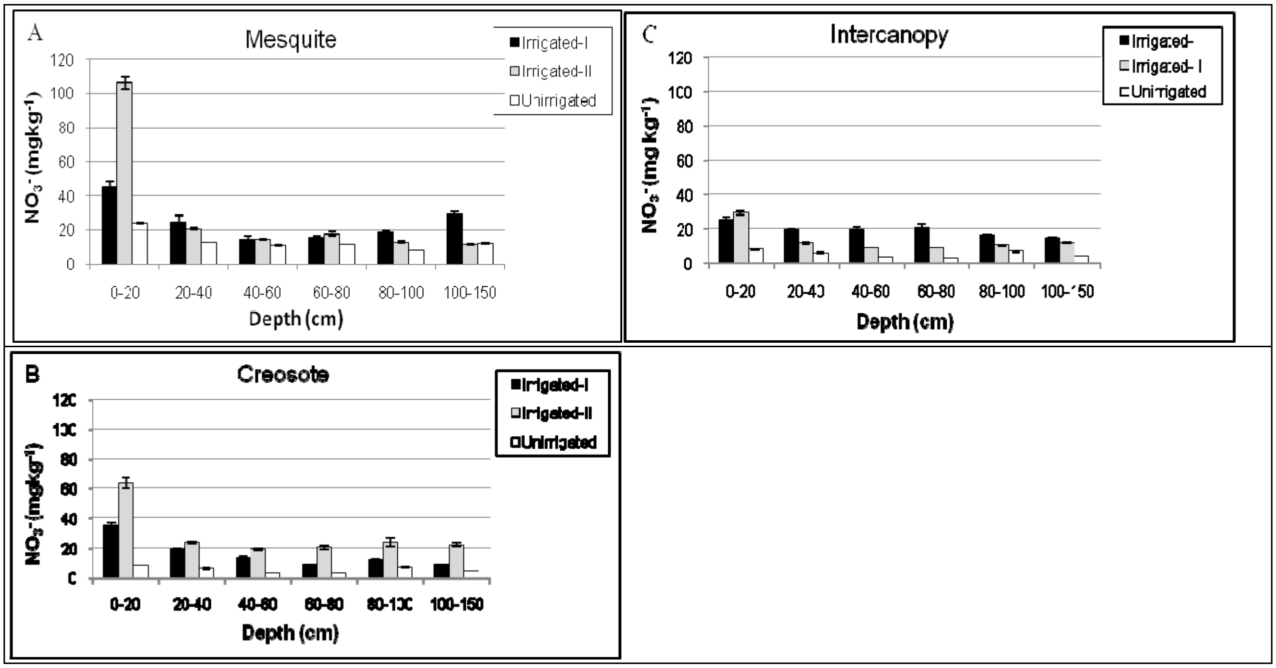


Figure 13: Nitrate (NO_3^-) in three plots under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

Soil pH was similar (9.20 ± 0.01 to 9.80 ± 0.09) under vegetation canopies and intercanopy areas in both irrigated plots until 60 cm depth. Below 60 cm depth, pH under the creosote canopies and intercanopy areas of the irrigated plot-I slightly decreased (Appendix 6). However, pH in the irrigated plot-II showed similar patterns at all measured depths under vegetation canopies and intercanopy areas (Figs. 14A-C).

One-way ANOVA contrasts did not detect differences between vegetation canopies and intercanopy areas for pH in the irrigated plots (Appendix 8 and 9). However, between irrigated and unirrigated plots, significant differences were detected at most depths for the pH (Appendix 11).

High EC values were observed under creosote canopies than mesquite canopies at 0-20 cm depth of the irrigated plot-I (Figs. 15A-C). Higher EC under creosote canopies might be the result of higher treated wastewater interception by the canopies. Similarly, high EC of 2.50 ± 0.53 dSm^{-1} was obtained under creosote canopies at 100-150 cm depth and low of 0.89 ± 0.24 dS m^{-1} at 0-20 cm depth of intercanopy areas in irrigated plots (Appendix 6). EC was similar under vegetation canopies at all measured depths of the unirrigated plot (Figs. 15A-B). EC in the irrigated-I increased by depth under both vegetation canopies and intercanopy areas (Figs. 15A-C). One-way ANOVA detected differences between mesquite and creosote canopies for EC at 0-20 cm depth of the irrigated plot-I (Appendix 8). Differences for EC were detected between irrigated plots and the unirrigated plot at most depths (Appendix 11).

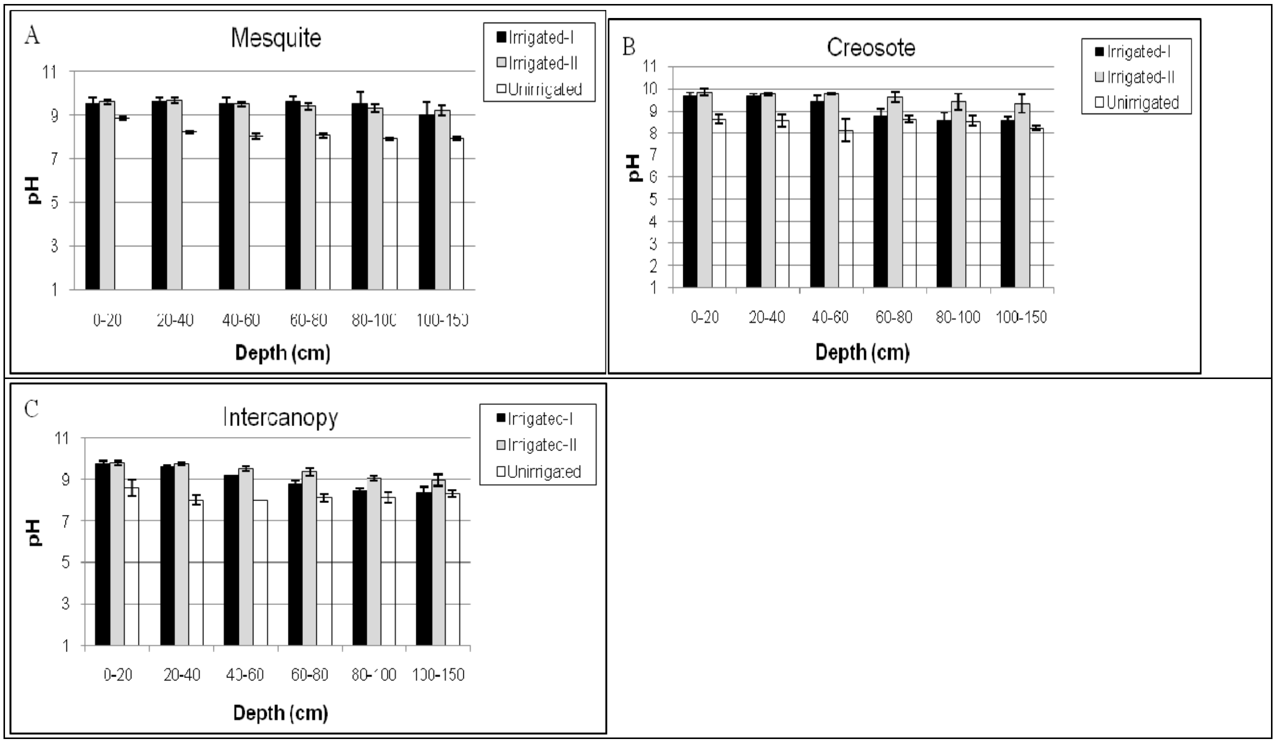


Figure 14: pH in three plots under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

The Na^+ content was higher in the intercanopy areas at 0-20 cm depth than under vegetation canopies in both irrigated plots (Figs. 16A-C). Higher Na^+ in upper depths in the intercanopy areas might be due to the lower K_s and θd at the intercanopy areas than under the vegetation canopies that accumulated Na^+ in the upper depths. Within the irrigated plot-I, one-way ANOVA contrasts detected differences for Na^+ between mesquite canopies and intercanopy areas at 0-20 cm depth only (Appendix 8). Differences were detected for Na^+ between irrigated plot-I and irrigated plot-II at 0-20 and 40-60 cm depth only (Appendix 11).

The SAR was higher under mesquite than creosote and intercanopy areas at 0-20 cm depth in both irrigated plots (Figs. 17A-C). Similarly, SAR was higher under creosote canopies than intercanopy areas at 0-20 cm depth of irrigated plot-II (Appendix 7). Higher SAR under creosote canopies than intercanopy areas may be due to the interception of treated wastewater by creosote canopy. SAR decreased by depth in intercanopy areas but mesquite and creosote canopies did not show any specific trends by depth in the irrigated plots. One way ANOVA contrasts did not detect differences for SAR between vegetation canopies and intercanopy areas in the irrigated plot-I (Appendix 8). Differences were only detected between creosote canopies and the intercanopy at 0-20 and 60-80 cm depth of irrigated plot-II (Appendix 9).

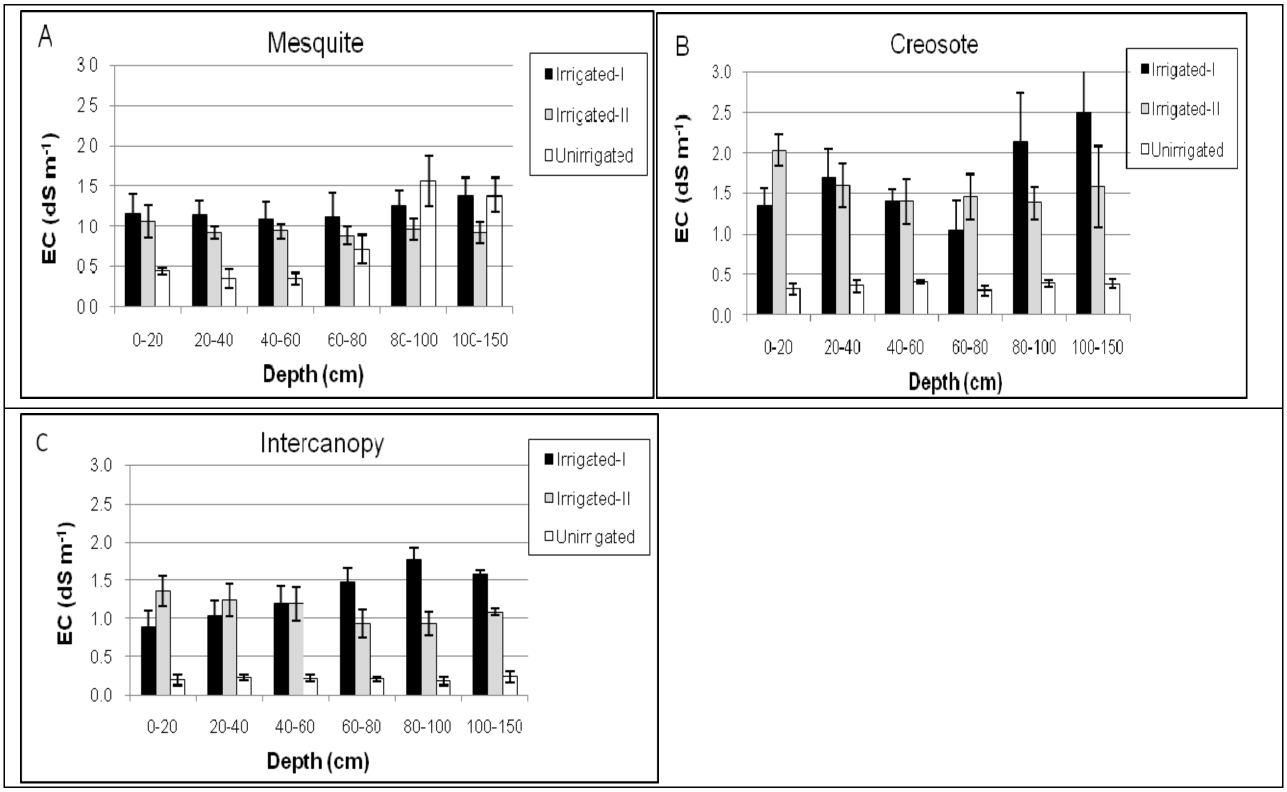


Figure 15: Electrical conductivity (EC) in three plots under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

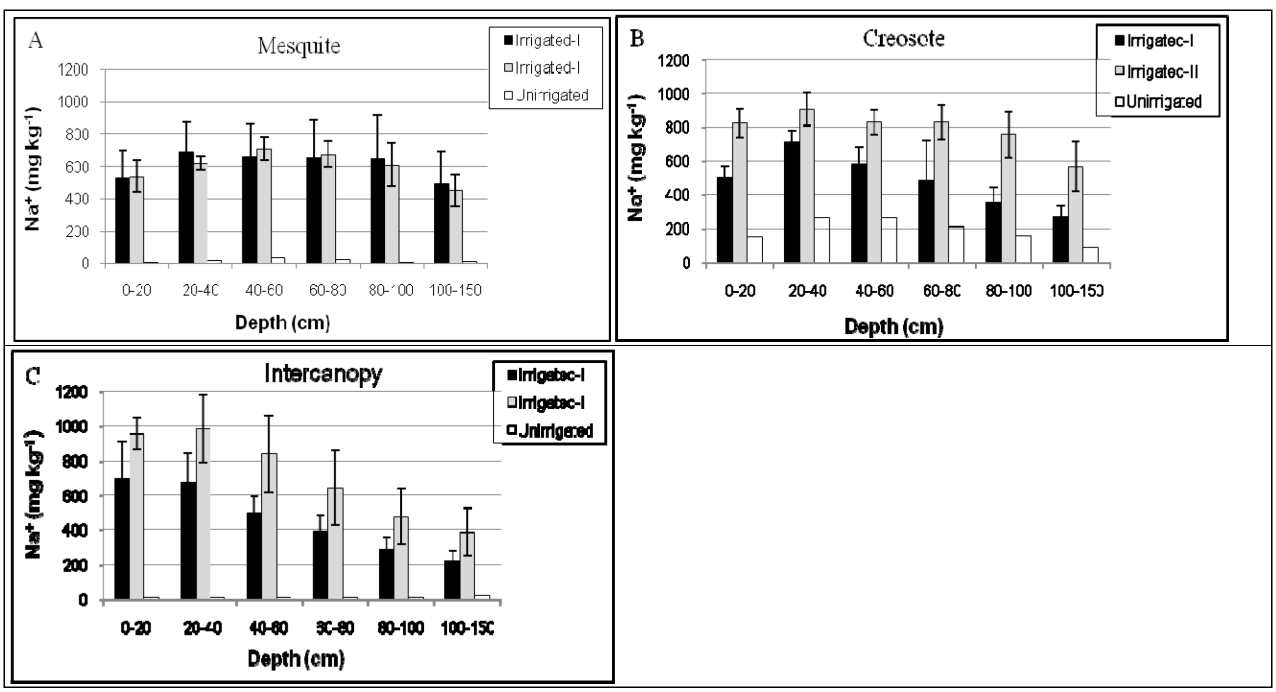


Figure 16: Sodium in three plots under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

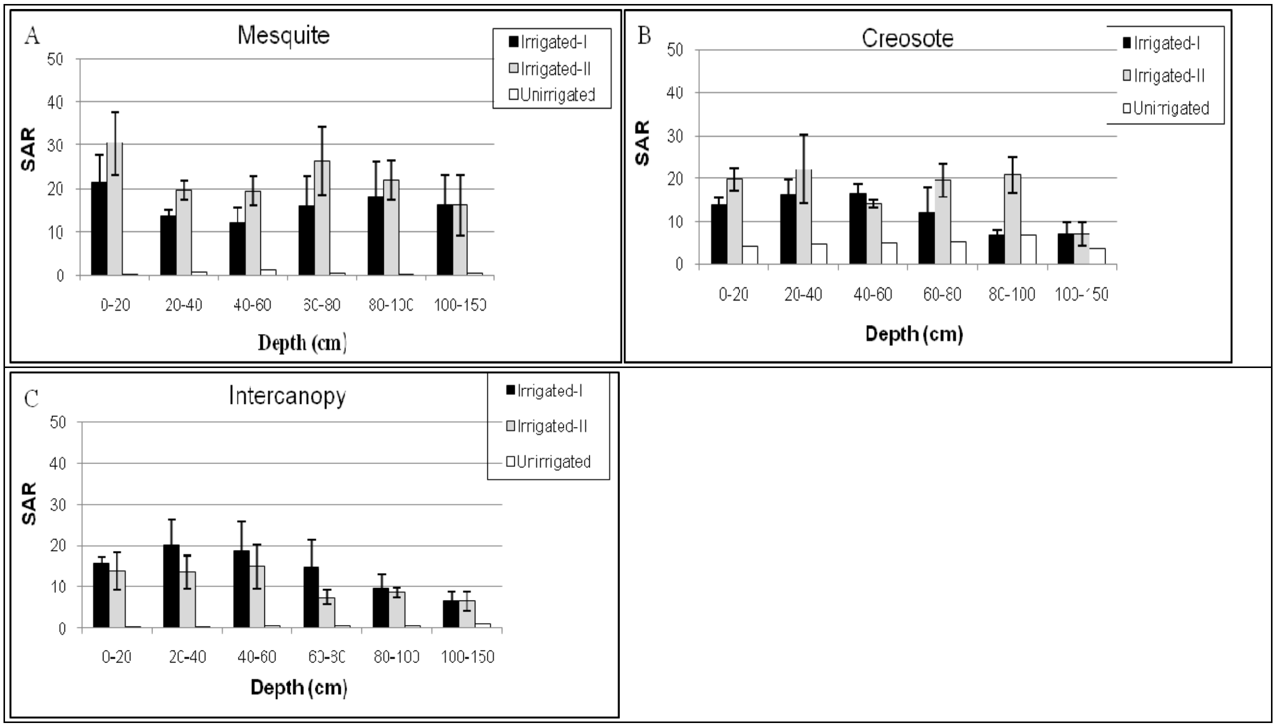
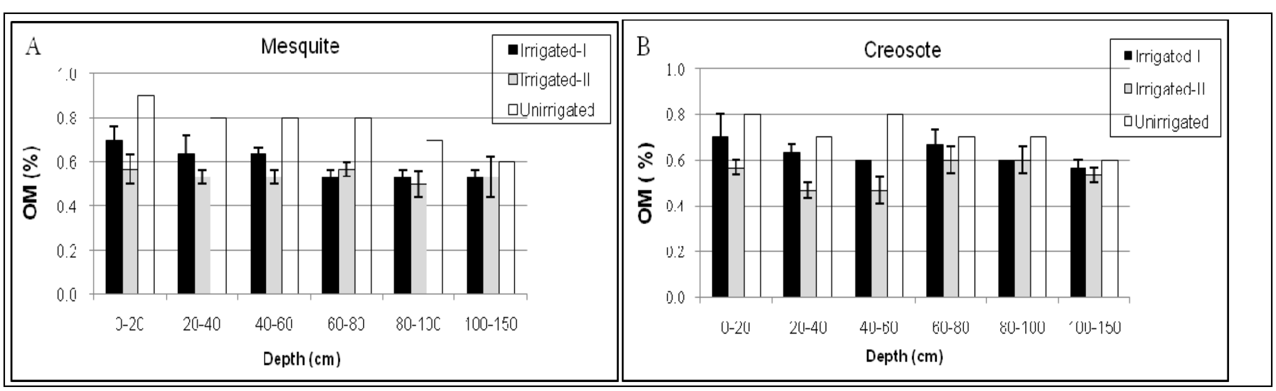


Figure 17: Sodium absorption ratio (SAR) under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

The OM content of soil was higher under vegetation canopies than in the intercanopy areas at 0-20 cm depth of the irrigated plot-I and unirrigated plot (Figs. 18A-C). Higher OM under vegetation canopies was due to the higher deposition of leaf litter under canopies. Differences were detected for OM between mesquite canopies and intercanopy areas, between creosote canopies and intercanopy areas at 20-40, 40-60, 80-100 and 100-150 cm depth of irrigated plot -II (Appendix 9).

The ESP showed similar trend as SAR. Higher ESP was observed under mesquite canopies than creosote and intercanopy areas (Figs. 19A-C). No differences were detected between vegetation canopies and intercanopy in the irrigated plot-I (Appendix 7). Differences in ESP were only detected between creosote canopies and the intercanopy areas at 0-20 and 60-80 cm in irrigated plot-II (Appendix 9). However, no differences for ESP were found between irrigated plot-I and irrigated plot-II at most depths (Appendix 11).



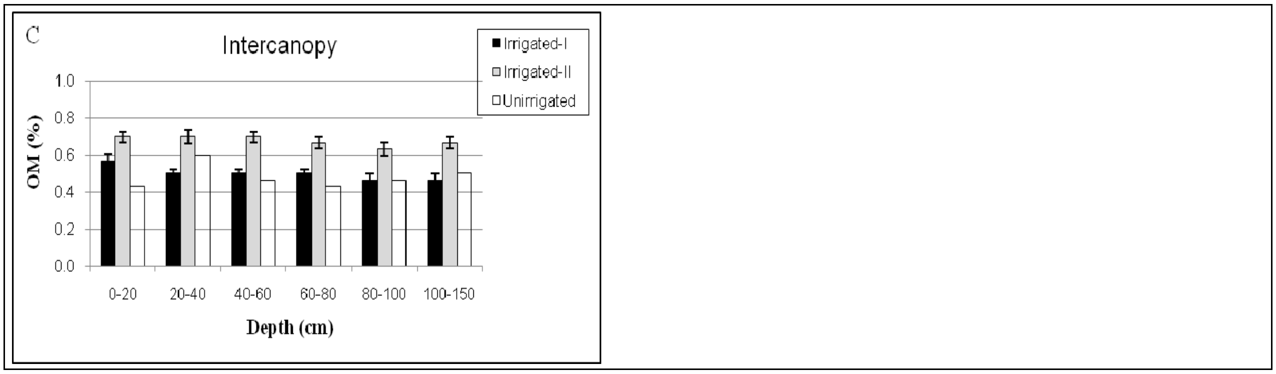


Figure 18: Organic matter (OM) content under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

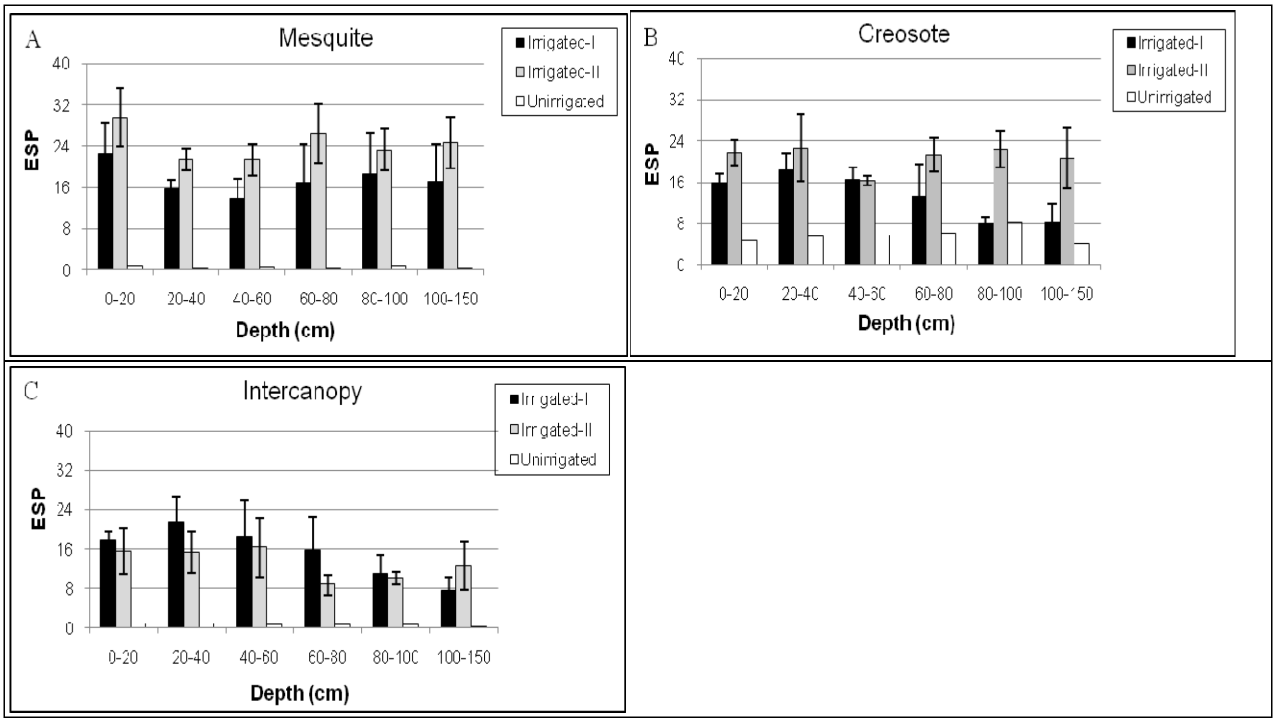


Figure 19: Exchangeable sodium percentage (ESP) under the canopies of (A) mesquite, (B) creosote, and (C) intercanopy area

Correlation analysis

For the combined data from two irrigated plots at 0-20 cm depth, there were significant correlations (P<0.05) among 14 pairs of the 136 soil attribute pairs (Appendix 14). Sand content showed significant negative correlation with AWC (r = -0.67, P = 0.002) and silt content (-0.67, P =0.002); clay content with NO_3^- (0.80, P <0.0001) and Cl^- (0.51, P =0.032); BD with FC (-0.60, P =0.008), NO_3^- (-0.54, P =0.02) and Cl^- (0.51, P =0.032). NO_3^- showed significant positive correlations with EC (0.76, P <.0002) and Cl^- (0.75, P <.0002) pH with EC (0.61, P =0.007) and Na^+ (0.71, P <.0001), EC with Cl^- (0.87, P <.0001) and ESP with SAR. Significant correlations were observed among 15 pairs of 136 soils attributes at 20-40 cm depth in irrigated plots (Appendix 15). Significant positive correlations were observed between silt content and BD; NO_3^- with pH, SAR, ESP; pH with Na^+; EC with Na^+, Cl^-, SAR; Cl^- with SAR and ESP. Conversely, silt content showed significant negative correlation with clay content, θd with AWC and FC with sand content.

For the combined data from all three plots, there were significant correlations among 36 pairs of the total 136 soil attribute pairs at 0-20 cm depth in all three plots (Appendix 16). Significant positive correlations were observed for FC with pH, EC, Na^+, Cl^-, SAR and ESP; pH with EC, Na^+, Cl^-, SAR and significant negative correlation for sand with clay content, EC, Na^+, Cl^-, SAR and ESP; clay content with BD; and K_s with pH, EC , Na^+, Cl^- , SAR and ESP. At 20-40 cm depth for combined data, there were 43 significant correlations among 136 soil attributes pairs (Appendix 17). Significant positive correlation were observed among NO_3^- with pH, EC, Na^+, Cl^-, SAR and ESP; pH with EC, Na^+, Cl^-, SAR, and ESP; EC with Cl^- and Na^+ with Cl^-. Negative significant correlations were observed between sand content and silt content, between K_s and Na^+, and between BD and FC (Appendix 17).

Descriptive statistics

Skewness was positive for most of the variables ranging from 0 to 1.23 but negative for some variables ranging from -0.03 to -1.79 at 0-20 cm depth in irrigated plots (Table 8). Chemical and physical properties values were concentrated in the left tail and the mean was lower than the median where negative skewness occurred. Similarly, where positive skewness occurred, values were concentrated in the right tail and mean was greater than the median.

Negative and positive kurtosis were also observed for soil chemical and physical properties values at both 0-20 and 20-40 cm depth in irrigated and all three plots. Positive kurtosis ranged from 0.28 to 4.84 and negative kurtosis ranged from -0.11 to -1.01 at 0-20 cm depth in irrigated plots (Table 8). Positive values for the kurtosis indicated peakedness of normal distribution and values were closer to the mean. The negative values of kurtosis indicated smaller peaks and values were far from the mean. The K_s, NO_3^-, EC, Na^+, Cl^-, SAR, and ESP were the most variable soil physical and chemical properties with CV>0.35 in irrigated plots and all three plots at 0-20 cm depth. Similarly silt, AWC, FC, θd, and OM were moderately variable with CV <0.35 and CV>0.15 and sand and clay contents, BD and pH were least variable with CV< 0.15 in irrigated plots at the depth of 0-20 cm (Table 8). At 20-40 cm depth in irrigated plots K_s, EC, Cl^-, and SAR were most variable, AWC, FC, θd, OM, NO_3^-, and Na^+ is moderately variable, sand, clay, BD and pH were least variable (Table 9).

At 0-20 cm depth in all irrigated plots silt, AWC, FC were moderately variable and sand, clay, BD, and pH were least variable (Table 10). Similarly at 20-40 cm depth K_s, EC, Na^+, Cl^-, SAR, and ESP were most variable, silt, AWC, FC, θd, OM, and NO_3^- were moderately variable and sand, clay, BD, and pH were least variable (Table 11).

Principal component analysis

Measured soil attributes were assigned to a PC according to their eigenvalues. At 0-20 cm depth of irrigated plots, the first PC explained 28% of variance with high positive loading on Cl^- (r=0.94), NO_3^- (0.87), and EC (0.81) (Tables 12 and 13). It also had negative loadings for clay (r = -0.66), thus this PC consisted of important components of soil salinity. The second PC explained 19% of variance with high positive loading on SAR (0.97) and ESP (0.97) and primarily consisted of factors related to soil sodicity. The third PC explained 16% of variance with high positive loading on pH (0.89) and EC (0.84) and negative loading on K_s (-0.58) and OM (-0.18) and contained factors influencing water transport through the soil profile. The fourth PC explained 11% of variance with high negative loading on sand content (-0.91) and positive loading on silt (0.88), AWC (0.74) and θd (0.12) and explained variability associated with soil texture. The fifth PC explained 8% of variance with negative loading on BD (-0.70) and high positive loading on FC (0.91) and could explain the water storage within the soil (Tables 12 and 13). The rotated factor pattern and the communality estimates (portion of variance explained by PCs for measured attributes) showed that the five PCs explained more than 98% of variability in EC, SAR, θd, and ESP; more than 92% in sand, silt, AWC, FC, OM, pH, clay, BD, Na^+, NO_3^- and Cl^-; and more than 89% in K_s at 0-20 cm depth in irrigated plots (Table 13). A higher communality estimate suggests that a higher portion of variance is explained by the PC and is preferred over low communality estimate (Johnson and Wichern, 1992).

In the irrigated plots at 20-40 cm depth, the first PC explained 27% of variance with positive loadings on NO_3^- (r = 0.85), Cl^- (0.63), SAR (0.86), and ESP (0.87) (Table 14 and 15). The second PC explained 16% of variance with positive loading on pH (0.80), EC (0.75), Na^+ (0.83), FC (0.20), and low negative loadings in K_s (-0.09). These two factors contained all the components responsible for soil salinity and sodicity. The third PC explained 13% of variance with negative loadings in sand content (-0.75) and positive loading in clay content (0.77) and was associated with soil texture. The fourth PC explained 10% of variance with negative loading in AWC (-.79) and OM (-0.10) and positive loading in θd (0.85) and was associated with the water storage capacity of soil. The fifth PC explained 8% of variance with positive loading in silt (0.77) and BD (0.86) (Tables 14 and 15). The communality estimates showed that five PCs explained more than 93% variability in silt, K_s, θd, EC, Na^+, and ESP; more than 90% in BD, AWC, FC, and SAR; and more than 80% in clay, OM, pH, and Cl^- (Table 15).

Table 8: The descriptive statistics including mean, standard error (SE), median, mode, standard deviation (SD), coefficient of variance (CV), kurtosis, skewness, maximum, and minimum of both irrigated plots at (0-20) cm depth.

Variable	Mean	SE	Median	Mode	SD	CV	Kurtosis	Skewness	Minimum	Maximum
Sand	88.82	0.31	88.66	88.28	1.31	0.01	2.00	0.72	86.28	92.28
Silt	3.73	0.28	3.88	4.00	1.20	0.32	4.84	-1.79	0.00	5.00
Clay	7.39	0.14	7.60	7.72	0.60	0.08	0.58	-0.19	6.20	8.72
Ks	11.75	1.13	12.45	-	4.79	0.41	-0.95	-0.04	4.20	20.70
BD	1.53	0.01	1.52	-	0.04	0.03	-0.76	0.00	1.45	1.60
AWC	2.21	0.10	2.17	-	0.44	0.20	0.85	-0.50	1.10	2.84
FC	0.18	0.01	0.18	-	0.03	0.16	0.79	0.28	0.13	0.25
θd	0.12	0.01	0.12	-	0.02	0.20	-1.01	0.26	0.09	0.17
OM	0.63	0.03	0.60	0.60	0.11	0.17	0.75	0.80	0.50	0.90
NO_3^-	50.93	7.84	39.86	22.14	33.25	0.65	0.54	1.23	13.29	124.00
pH	9.69	0.07	9.70	10.00	0.32	0.03	1.09	-0.80	8.90	10.20
EC	1.31	0.11	1.37	-	0.49	0.37	-0.11	0.30	0.49	2.35
Na^+	29.37	2.64	29.74	-	11.20	0.38	-0.59	-0.03	9.17	48.74
Cl^-	121.59	18.76	115.00	-	79.59	0.65	1.66	1.05	5.80	328.70
SAR	19.18	2.12	16.48	-	9.00	0.47	0.28	0.94	8.34	39.67
ESP	20.52	1.83	18.73	-	7.76	0.38	-0.41	0.57	9.95	36.41

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

Table 9: The descriptive statistics including mean, standard error (SE), median, mode, standard deviation (SD), coefficient of variance (CV), kurtosis, skewness, maximum, and minimum of both irrigated plots at 20-40 cm depth.

Variable	Mean	SE	Median	Mode	SD	CV	Kurtosis	Skewness	Minimum	Maximum
Sand	88.82	0.19	88.84	88.28	0.79	0.01	1.27	0.06	87.03	90.64
Silt	3.74	0.13	3.52	3.50	0.56	0.15	4.99	1.81	3.00	5.50
Clay	7.72	0.14	7.77	7.97	0.59	0.08	0.77	0.15	6.61	8.97
Ks	7.17	0.87	7.00	-	3.70	0.52	-0.21	0.54	1.20	14.40
BD	1.55	0.01	1.55	-	0.05	0.03	-0.62	-0.47	1.45	1.63
AWC	1.72	0.10	1.82	-	0.43	0.25	-0.13	-0.66	0.82	2.40
FC	0.19	0.01	0.19	-	0.03	0.18	-0.59	0.06	0.13	0.25
θd	0.13	0.01	0.12	-	0.04	0.28	-1.40	0.16	0.08	0.20
OM	0.59	0.02	0.60	0.50	0.09	0.16	-0.53	0.60	0.50	0.80
NO_3^-	19.93	1.49	17.71	17.71	6.31	0.32	-0.60	-0.07	8.86	31.00
pH	9.68	0.04	9.60	9.60	0.18	0.02	-1.13	0.31	9.40	10.00
EC	1.28	0.11	1.22	0.80	0.47	0.36	-0.41	0.62	0.62	2.26
Na^+	33.28	2.42	33.11	-	10.25	0.31	-0.62	-0.16	14.87	48.74
Cl^-	150.62	21.01	129.65	-	89.15	0.59	-0.63	0.65	37.50	331.80
SAR	17.56	1.83	14.66	-	7.77	0.44	1.85	1.44	8.47	37.86
ESP	19.19	1.59	16.92	-	6.74	0.35	0.77	1.08	10.10	35.31

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

Table 10: The descriptive statistics including mean, standard error (SE), median, mode, standard deviation (SD), coefficient of variance (CV), kurtosis, skewness, maximum, and minimum of all three plots at 0-20 cm depth.

Variable	Mean	SE	Median	Mode	SD	CV	Kurtosis	Skewness	Minimum	Maximum
Sand	89.01	0.25	89.17	89.28	1.29	0.01	0.71	0.11	86.28	92.28
Silt	3.80	0.20	4.00	3.00	1.04	0.27	5.93	-1.87	0.00	5.00
Clay	7.20	0.15	7.36	7.72	0.77	0.11	0.38	-0.53	5.22	8.72
Ks	12.89	1.03	12.60	9.60	5.35	0.42	0.75	0.62	4.20	27.30
BD	1.54	0.01	1.54	-	0.04	0.03	1.23	0.57	1.45	1.67
AWC	2.04	0.09	2.03	-	0.49	0.24	0.18	-0.34	0.94	2.84
FC	0.16	0.01	0.16	-	0.04	0.23	-0.51	0.16	0.10	0.25
θd	0.12	0.00	0.12	-	0.02	0.20	-0.92	0.20	0.09	0.17
OM	0.62	0.03	0.60	0.60	0.15	0.24	-0.22	-0.05	0.30	0.90
NO_3^-	41.33	5.88	31.00	22.14	30.53	0.74	2.18	1.67	8.86	124.00
pH	9.28	0.13	9.60	10.00	0.66	0.07	-1.16	-0.52	8.10	10.20
EC	1.00	0.12	0.95	0.44	0.61	0.61	-0.72	0.43	0.14	2.35
Na^+	19.94	3.15	19.52	-	16.37	0.82	-1.34	0.12	0.32	48.74
Cl^-	83.67	16.25	77.70	10.00	84.43	1.01	1.39	1.19	5.50	328.70
SAR	13.27	2.16	12.60	-	11.24	0.85	-0.18	0.67	0.10	39.67
ESP	14.25	2.13	14.77	0.31	11.06	0.78	-0.91	0.27	0.31	36.41

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

Table 11: The descriptive statistics including mean, standard error (SE), median, mode, standard deviation (SD), coefficient of variance (CV), kurtosis, skewness, maximum, and minimum of all three plot at 20-40 cm depth.

Variable	Mean	SE	Median	Mode	SD	CV	Kurtosis	Skewness	Minimum	Maximum
Sand	89.02	0.18	88.89	88.28	0.92	0.01	1.83	0.77	87.03	91.64
Silt	3.60	0.11	3.50	3.50	0.58	0.16	3.79	0.86	2.25	5.50
Clay	7.57	0.13	7.72	7.36	0.66	0.09	-0.06	-0.18	6.36	8.97
Ks	8.78	0.78	8.80	9.90	4.07	0.46	-1.01	0.03	1.20	15.35
BD	1.56	0.01	1.56	-	0.05	0.03	-0.27	-0.66	1.45	1.63
AWC	1.65	0.09	1.68	-	0.45	0.27	-0.50	-0.47	0.68	2.40
FC	0.17	0.01	0.16	-	0.04	0.25	-0.77	0.14	0.10	0.25
θd	0.13	0.01	0.13	-	0.04	0.26	-1.15	0.24	0.08	0.20
OM	0.57	0.03	0.60	0.50	0.14	0.24	0.16	0.41	0.30	0.90
NO_3^-	20.67	1.29	17.71	17.71	6.73	0.33	-0.83	-0.17	8.86	31.00
pH	9.28	0.12	9.50	9.60	0.62	0.07	-0.93	-0.79	8.10	10.00
EC	0.97	0.11	0.86	0.80	0.58	0.60	-0.55	0.52	0.14	2.26
Na^+	22.54	3.39	25.83	-	17.59	0.78	-1.48	-0.11	0.28	48.74
Cl^-	103.02	19.15	87.20	10.00	99.51	0.97	-0.29	0.86	5.50	331.80
SAR	12.11	1.94	12.22	-	10.10	0.83	0.34	0.71	0.18	37.86
ESP	13.49	1.92	14.36	0.65	9.96	0.74	-0.52	0.27	0.06	35.31

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

The fourth PC explained 8% of variance with positive loadings in K_s (0.85) and θd (0.10) and negative loading in BD (-0.71) and can be termed as a water transmission factor. The fifth PC explained 7% of variance with positive loadings in clay content (0.96) (Tables 16 and 17). The communality estimates showed that five PCs explained more than 98% of variability in clay, FC, θd, SAR, and ESP; more than 90% in sand, silt, K_s, BD, OM, NO_3^-, pH, EC, Na^+, and Cl^-; and about 79% in AWC all three plots at 0-20 cm depth (Table 17).

Table 12: The retained principal components (PCs) obtained from soil physical and chemical properties for both irrigated plot at 0-20 cm depth.

PCs	Eigenvalue[a]	Difference	Proportion	Cumulative
1	4.46	1.46	0.28	0.28
2	3.00	0.42	0.19	0.47
3	2.58	0.74	0.16	0.63
4	1.84	0.48	0.11	0.74
5	1.36	0.40	0.08	0.83

[a] eigenvalue <1 are not presented in the table

Table 13: Rotated principal components (PCs), communality estimates (CE), and contribution of each soil physical and chemical properties in soil variation for both irrigated plots at 0-20 cm depth.

Variables	PC1	PC2	PC3	PC4	PC5	CE
Sand	0.05	0.28	0.02	**-0.91**	0.00	0.94
Silt	0.03	0.26	-0.19	**0.88**	-0.04	0.95
Clay	**-0.66**	-0.42	0.36	-0.07	-0.21	0.93
K_s	0.17	0.56	**-0.58**	0.06	0.32	0.89
BD	-0.49	-0.10	0.14	0.03	**-0.70**	0.92
AWC	0.10	-0.14	0.07	**0.74**	0.24	0.94
FC	0.20	-0.19	0.00	0.08	**0.91**	0.96
θd	0.02	0.10	-0.09	**0.12**	-0.04	0.98
OM	-0.11	**-0.18**	**-0.18**	0.03	-0.07	0.96
NO_3^-	**0.87**	0.31	0.03	0.00	0.16	0.95
pH	0.11	0.19	**0.89**	-0.06	0.20	0.96
EC	**0.81**	0.08	0.52	-0.10	0.15	0.98
Na^+	0.29	0.10	**0.84**	-0.07	-0.27	0.93
Cl^-	**0.94**	-0.11	0.18	0.07	0.12	0.96
SAR	0.09	**0.97**	0.10	-0.06	-0.10	0.98
ESP	0.11	**0.97**	0.13	-0.08	-0.08	0.99

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage.

Table 14: The retained principal components (PCs) obtained from soil physical and chemical properties for both irrigated plots at 20-40 cm depth.

PCs	Eigenvalue	Difference	Proportion	Cumulative
1	4.34	1.77	0.27	0.27
2	2.56	0.56	0.16	0.43
3	2.00	0.37	0.13	0.56
4	1.63	0.28	0.10	0.66
5	1.35	0.39	0.08	0.74

[a] eigenvalue <1 are not presented in the table

Table 15: Rotated principal components (PCs), communality estimates (CE), and contribution of each soil physical and chemical properties in soil variation for both irrigated plots at 20-40 cm depth.

Variables	PC1	PC2	PC3	PC4	PC5	CE
Sand	-0.17	-0.23	**-0.75**	0.32	0.16	0.86
Silt	0.05	-0.02	-0.32	-0.16	**0.77**	0.93
Clay	0.07	0.11	**0.77**	0.24	-0.32	0.82
K_s	-0.03	**-0.09**	-0.08	-0.08	-0.07	0.97
BD	0.15	-0.08	-0.15	0.03	**0.86**	0.91
AWC	-0.02	0.23	0.01	**-0.79**	0.13	0.91
FC	0.19	**0.20**	-0.06	-0.13	-0.06	0.91
θd	-0.03	0.07	0.01	**0.85**	0.01	0.93
OM	-0.09	-0.06	-0.06	**-0.10**	-0.04	0.86
NO_3^-	**0.85**	-0.10	-0.35	-0.13	0.01	0.91
pH	-0.12	**0.80**	-0.04	-0.04	-0.10	0.83
EC	0.54	**0.75**	0.14	0.03	-0.19	0.94
Na^+	0.18	**0.83**	0.31	-0.11	0.10	0.93
Cl^-	**0.63**	0.55	0.14	-0.01	-0.05	0.81
SAR	**0.86**	0.16	0.27	0.04	0.14	0.92
ESP	**0.87**	0.15	0.22	0.04	0.14	0.93

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

At 20-40 cm depth for the combined dataset for all three plots, first PC explained about 41% of variance with positive loadings in pH (r = 0.83), EC (0.92), Na^+ (0.91), Cl^-(0.88), SAR (0.90), and ESP (0.91), and negative loading in K_s (-0.45) and consisted of components causing soil salinity and sodicity (Tables 18 and 19). The second PC explained 15% of variance with positive loadings in θd (0.84), negative loadings in silt (-0.62) and AWC (-0.27). The third PC explained 11% of variance with positive loadings in sand (0.86) and OM (0.14) and negative loadings in clay content (-0.78). The fourth PC explained 8% of variance with positive loadings in BD (0.92) and the fifth PC explained 6% of variance with positive loading in NO_3^-(0.95) (Tables 18 and 19). The communality estimates showed that five PCs explained more than 94% in K_s, BD, AWC, OM, NO_3^-, EC, and Na^+; more than 90% in sand, θd, SAR and ESP; and more than 80% in silt, clay, FC, pH, and Cl^-(Table 19).

Table 16: The retained principal components (PCs) obtained from soil physical and chemical properties for all three plots at 0-20 cm depth.

PCs	Eigenvalue	Difference	Proportion	Cumulative
1	6.35	3.96	0.40	0.40
2	2.39	0.48	0.15	0.55
3	1.91	0.60	0.12	0.67
4	1.31	0.18	0.08	0.75
5	1.13	0.34	0.07	0.82

[a] eigenvalue <1 are not presented in the table

Table 17: Rotated principal components (PCs), communality estimates (CE), and contribution of each soil physical and chemical properties in soil variation for all three plots at 0-20 cm depth.

Variables	PC1	PC2	PC3	PC4	PC5	CE
Sand	0.06	-0.11	**-0.85**	0.11	-0.35	0.92
Silt	0.04	-0.10	**0.91**	0.14	-0.17	0.90
Clay	0.13	-0.07	0.08	-0.16	**0.96**	0.98
K_s	-0.07	-0.11	0.05	**0.85**	-0.33	0.91
BD	-0.09	-0.48	-0.03	**-0.71**	-0.16	0.94
AWC	0.15	0.34	**0.48**	0.06	0.13	0.79
FC	0.36	**0.38**	0.05	0.00	0.00	0.98
θd	-0.04	-0.04	0.03	**0.10**	-0.06	1.00
OM	-0.03	-0.04	**-0.16**	0.11	-0.12	0.93
NO_3^-	0.34	**0.82**	0.05	0.27	-0.24	0.95
pH	**0.71**	0.42	0.03	-0.26	0.25	0.96
EC	0.49	**0.82**	-0.07	-0.04	0.08	0.96
Na^+	**0.66**	0.54	-0.06	-0.29	0.24	0.93
Cl^-	0.27	**0.90**	0.05	-0.04	0.00	0.94
SAR	**0.96**	0.23	0.03	0.09	0.00	0.98
ESP	**0.94**	0.27	0.01	0.05	0.01	0.98

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage

Table 18: The retained principal components (PCs) obtained from soil physical and chemical properties for all three plots at 20-40 cm depth.

PCs	Eigenvalue	Difference	Proportion	Cumulative
1	6.64	4.32	0.41	0.41
2	2.32	0.54	0.15	0.56
3	1.78	0.54	0.11	0.67
4	1.24	0.28	0.08	0.75
5	1.01	0.24	0.06	0.81

[a] eigenvalue <1 are not presented in the table

Table 19: Rotated principal components (PCs), communality estimates (CE), and contribution of each soil physical and chemical properties in soil variation for all three plots at 20-40 cm depth.

Variables	PC1	PC2	PC3	PC4	PC5	CE
Sand	-0.30	0.22	**0.86**	0.12	-0.02	0.91
Silt	0.33	**-0.62**	0.29	0.49	0.07	0.83
Clay	0.24	0.23	**-0.78**	-0.24	0.06	0.82
K_s	**-0.45**	-0.06	0.07	-0.05	0.16	0.97
BD	-0.14	0.07	0.23	**0.92**	0.13	0.94
AWC	0.17	**-0.27**	-0.02	0.07	0.09	0.96
FC	**0.70**	-0.54	0.04	-0.23	0.01	0.85
θd	0.02	**0.84**	0.14	0.11	-0.15	0.92
OM	0.12	-0.08	**0.14**	0.04	-0.06	0.99
NO_3^-	0.02	-0.13	-0.06	0.13	**0.95**	0.97
pH	**0.83**	-0.11	-0.12	-0.07	-0.30	0.89
EC	**0.92**	0.08	-0.13	-0.08	0.04	0.94
Na^+	**0.91**	-0.12	-0.16	-0.02	-0.23	0.96
Cl^-	**0.88**	0.12	-0.15	-0.01	0.13	0.88
SAR	**0.90**	-0.15	-0.15	0.04	0.13	0.91
ESP	**0.91**	-0.16	-0.17	0.03	0.13	0.93

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio and ESP is exchangeable sodium percentage.

DISCUSSION

Sprinkler distribution uniformity

The application of treated wastewater in the study site is not uniform. It is due to temporal fluctuation in volume of tenant-generated wastewater as well as due to the high evaporation losses from the wastewater holding pond during the peak summer months. A Christiansen's uniformity coefficient of 80 is considered acceptable and a uniformity coefficient of 90 is considered good (Zoldoske et al., 1994; Rochester, 1995). According to Solomon (1990), high wind breaks up the water droplets and blows the resulting droplets around. Frequent change of wind direction causes areas to receive low or high precipitation. The CU in this study was 49.34% for plot-I and 61.57% for plot-II. Wind speed during the sprinkler uniformity test in plot-I was about 31.5 km h^{-1} and wind direction was variable. Sprinkler uniformity for plot-II was higher (61.57%), the wind speed was lower (5.6 km h^{-1}) and wind direction was less variable than during the uniformity test in the irrigated plot-I. In addition, spacing of sprinklers in irrigated plot-II was more uniform than in the irrigated plot-I. Thus, variable wind speed, variable wind direction, and sprinkler spacing were some of the factors possibly contributing to the lower sprinkler uniformity in irrigated plot-I than plot-II.

Treated wastewater quality

The SAR, EC, and ion concentrations are the principal water quality criteria for irrigation water. Results of water analysis showed high Na^+, EC, and SAR in the treated wastewater (Table 1). Irrigation with water having higher Na^+ concentrations may cause an accumulation of exchangeable Na^+ on soil colloids and affect the sustainability of the vegetation (Jalali and Merrikhpour, 2008). EC tolerance limit for mesquite is 9.36 dS m^{-1} (Felker et al., 1981) and creosote is 7.51 dS m^{-1} (Al-Jibury, 1972). The highest measured EC from 2002 -2007 was 4.93 dS m^{-1}. Thus, with regard to EC of treated wastewater, there is no immediate danger for the sustainability of native shrubs in the area. However, shallow rooted annual and perennial weed like desert daisy, snakeweed, pigweed, spiderling, sagebrush, and chinchweed may be threatened due to higher SAR. The average SAR of irrigation water was 32.97, EC 3.90 dS m^{-1} and pH 9.7, where SAR content >15 and pH > 8.5 are considered sodic and strongly alkaline. Scianna (2007) reported that there is a combined effect of EC and SAR of the irrigating water on infiltration rate. Irrigation water containing SAR of 20-40 and EC < 2.9 dS m^{-1} will be considered severe, 2.9-5.0 dS m^{-1} slight to moderate, and >5 no influence on the infiltration rate of soil. Usually wastewater generated from meat and dairy processing industry contains elevated concentrations of Na^+, with SAR ranging between 4 and 50 (Menner et al., 2001). Application of highly alkaline and sodic treated wastewater at a rate much less than the plant water demand has exacerbated the sodicity on West Mesa soil. Visual observations during field visits showed signs of stress including leaf burn in creosote and wilting in the mesquite.

Soil physical properties

There are several attributes of wastewater that can affect the soil physical properties. Wastewater decreases the hydraulic conductivity by filling up the soil voids with suspended solids (Abedi-Koupai et al., 2006). Application of high Na^+ content wastewater increases sodicity, which causes swelling and dispersion of clays, changes pore geometry, and reduces hydraulic conductivity (Halliwell et al., 2001). In addition, soil containing higher amounts of SAR, Na^+ ions and the lower EC could decrease soil hydraulic conductivity and the infiltration rate due to swelling and dispersion of clays (Sparks, 2003). The hydraulic conductivity is lower in irrigated plots than in the unirrigated plots at 0-20 and 20-40 cm depths and are in accord with high SAR, Na^+ and low EC at these depths (Tables 4; 5 and Appendix 6). Clay dispersion at the soil surface can also increase hydraulic conductivity of soils, generally in sandy soils with large soil pores that allow the clay particles to pass straight through (Abedi-Koupai et al., 2006). However, research conducted by Agassi and others (2003) in Israel found no adverse impact on the hydraulic parameters while applying standard domestic effluents to soil. It is also reported that application of wastewater rich in organic matter can change the soil texture by aggregating the soil particles onto the cementing agents present in the wastewater and can also alter the soil physical properties (Ibrahim et al., 2005). In this study, K_s under mesquite canopy was generally higher than under creosote canopy and intercanopy areas (Table and 5; and Appendix 3) and was in accord with the lower Na^+ content under mesquite canopies than under the creosote canopies and intercanopy area. Mesquite canopies were on coppice dunes with slightly higher sand content and slightly lower (although not statistically) clay content (Tables 4 and 5) and that may also have contributed to the increases in the K_s.

Field observation showed white coatings on the intercanopy areas, which was likely due to the reprecipitation of salt during evaporation and could have caused reductions in the K_s of the intercanopy areas. No significant differences were detected for K_s between irrigated plot-I and irrigated plot-II although irrigated plot-I had slightly higher values of K_s (Appendix 2 and Table 4). In addition, differences in K_s between vegetation canopies might be due to the differences in morphological structure of the vegetation, difference in particle size, and interception of treated wastewater by vegetation canopies. Chorom and others (1994) also reported that increases in soil pH facilitate the increase of net negative charge and clay dispersion, especially in Alfisols and Aridisols. According to USDA soil survey (Web Soil Survey, USDA, NRCS, 2007), soil in irrigated plot -I was classified as Entisols and in irrigated plot -II as Aridisols with thermic moisture regime. Although the soil order is different, no differences were observed in pH and texture between plots. When exchange sites of clay particles in soil aggregates are occupied chiefly by Na^+, spontaneous dispersion of these particles can occur when they are in contact with electrolyte-free water (Chorom et al., 1994). So high soil pH with some salt precipitation in the West Mesa soils may have affected the clay dispersion.

Porosity can change due to the blockage of the inter-soil spaces by suspended materials such as colloidal clay and algal cell particles (Berend, 1967; Bouwer and Chaney, 1974; Abedi-Koupai et al., 2006). Similarly, pore size distribution (Al-Haddabi et al., 2004), and permeability (Coppola et al., 2003; Al-Haddabi et al., 2004, Carroll et al., 2006) can decrease, and available water content (Ibrahim et al., 2005) and field capacity (Ibrahim et al., 2005) can increase due to the application of wastewater. In this study, results presented in Appendix 3, showed high AWC at 0-20 cm depth and low drainable porosity. Drainable porosity was lower in the irrigated field at upper depths compared to the unirrigated plot. This could be the art effect of soil macroporosity changing into microporosity likely due to the constituents of treated wastewater and organic matter from vegetation settling in the soil macropores.

Land application of solid organic residuals can increase the OM content and enhance soil moisture retention (Magesan and Wang, 2003). However, soil OM was lower in irrigated plots than in the unirrigated plot. This showed that there was not enough contribution of wastewater to OM addition to the soil. The possible reason of higher bubbling pressure in the unirrigated plot was due to the higher BD in the unirrigated plot. Soil moisture content variations under vegetation and intercanopy areas in different plots expressed as standard errors were generally low at most suctions for vegetation canopies as well as in intercanopy areas in unirrigated plot than in irrigated-I and irrigated-II plots at 0-20 cm depth (Figs. 9, 10 and 11).

Irrigated plot-I comprised of bluepoint loamy sand, which is somewhat excessively drained and irrigated plot-II was on Onite-Pajarito association, which is a well drained soil. No differences were found in most physical properties (particle size, K_s, BD, AWC, FC) and chemical properties between irrigated plot-I and irrigated plot–II, although the soil series is different. An earlier study conducted only on the irrigated plot-I also did not detect differences in several soil physical properties such as K_s, BD, AWC, and FC due to the application of wastewater (Babcock, 2006).

Soil chemical properties

Soil microorganisms and plants prefer a near neutral pH range of 6 to 7 for better performance (Sylvia et al., 2005). Irrigation with wastewater with pH 9.70 ± 0.10 raised the soil pH to >9 at upper depths, and may have decreased the performance of microorganisms and the decomposition of OM deposited under the canopies especially under creosote in the irrigated plots. As the soil pH increases, the availability of certain micronutrients, particularly iron (Fe) and manganese (Mn), decreases (Scianna, 2007). Although mesquite and creosote are deep rooted bushes and it is difficult to assess the exact influence of high surface pH on their survival, such a high pH can certainly have an effect on survival and growth of the shallow rooted native perennial and herbal vegetation.

Application of treated wastewater having high EC and SAR raised soil SAR and EC in both irrigated plots. Irrigation with salty water generally tended to increase EC with soil depth except at very shallow (2.5-5 cm) depths because of the evaporation at the soil surface (Costa et al., 1991). Similar patterns of increases in EC were observed except under mesquite canopies in irrigated plot-II. These values were lower in 2007 than those reported in 2005 (Babcock, 2006). This might be due to the time of the sampling, amount of treated wastewater application, and precipitation. Samples were collected during July 2007 after several rainfall events and no application of treated wastewater was made since March 2007. Whereas in 2005, samples were collected during December and treated wastewater was continuously applied from September onwards with no precipitation recorded during the past three months. The values of EC, pH, Na^+ and SAR were higher in irrigated plots than in unirrigated plot. Usually at upper depths, these chemical parameters increase the osmotic potential of the soil, which can prevent the flow of water through the soil at low bubbling pressure.

The Cl^- and NO_3^- are weakly held anions and have high possibility to leach to the groundwater with percolating water. Soil Cl^- accumulation was observed between 60 and 150 cm depth under creosote and intercanopy areas. However, a lower level of Cl^- under mesquite might be the effect of higher K_s that has already leached the Cl^- below the sampling depths. In contrast, a previous study done on the same site reported high Cl^- content in the upper profile (0-15cm) of intercanopy areas due to treated wastewater ponding that was partially supported by this study and the white precipitate observed in the intercanopy areas were mostly Na^+.

The SAR under vegetation canopies and intercanopy areas was >15 within 0-100 cm depth which is characterized by reduced nutrient and micronutrient availability (Brady and Weil, 2002). The primary vegetation in the study area is mesquite and creosote with rooting depths of about 12 m and 3 m, respectively. A majority of mesquite roots are distributed within 0-100 cm depth (Heitschmidt et al., 1988) and creosote within 0-25 cm depth (Baynham, 2004). Therefore, high SAR and Na^+ content would affect the survival of mesquite and creosote bushes along with other perennial vegetation.

Dawes and Goonetilleke (2004) observed significant changes in exchangeable Ca^{2+}, Mg^{2+}, Na^+, as well as in pH, EC, and CEC due to the application of sewage effluent. In this study, significant differences were observed for most chemical properties except CEC among irrigated and unirrigated plots. Higher Na^+ was observed under creosote canopies and intercanopy areas at 0-20 cm depth of the irrigated plot than under mesquite canopies. As stated earlier, it might be the due to lower K_s under creosote canopies and intercanopy areas than under mesquite canopies. According to Amoozegar and Niewoehner (1998), excessive amounts of Na^+ on exchange sites prevents the neutralization of all the negative charges on clay particles causing the soil particles to repel one another and substantially decrease infiltration and hydraulic conductivity.

The alkalinity, total dissolved cations (TDC), and total dissolved anions (TDA) during 2007 were lower in the influent (9.07, 15.50, and 5.42 $mol_c\ m^{-3}$) than effluent (34.97, 55.36 and 22.15 $mol_c\ m^{-3}$, respectively) (Appendix 12). Mesquite, a leguminous crop, can fix nitrogen and modify soil fertility (Ansley et al., 1997). In this study, higher NO_3^- contents were found under mesquite canopies even in the unirrigated plot than under creosote canopies and intercanopy areas. Mesquites are deep-rooted plants that can survive with less moisture (Mooney et al., 1977; Ansley et al., 1997) and can store soil nitrogen 3 to 7 times greater beneath its canopies than in the interspaces between species (Shearer et al., 1983; Tiedemann and Klemmedson, 1986). The mass balance for NO_3^- and Cl^- showed that about 30.98 kg ha^{-1} of NO_3^- and 1609.41 kg ha^{-1} of Cl^{-1} were added to the soil by the treated wastewater (Appendix 13). The mass balance showed a surplus of about 22.15 kg ha^{-1} of NO_3^- and 1276.80 kg ha^{-1} of Cl^{-1}. The Plant NO_3^- content was 12.94 kg ha^{-1} more for shrubs in irrigated than unirrigated plot. Thus, about 9.21 kg ha^{-1} of NO_3^- was leached below the sampling depth. Since Plant Cl^{-1} uptake was not available, 1276.8 kg ha^{-1} Cl^- represents the total chloride that was absorbed by plants and leached below the sampling depth. In general, the level of Cl^- and NO_3^- presented in Figs 12 and 13 also show positive values for these anions at 150 cm depth, and that could be interpreted as the evidence of leaching below sampling depth.

The knowledge of variability in soil physical and chemical properties is essential for designing site-specific management practices. In this study for both datasets, positive skewness was observed for most soil properties. Where positive skewness was observed median values were either equal to or smaller than the mean and where negative skewness was observed, median values were greater than the mean. Positive kurtosis was observed for most of the soil properties value at 0-20 cm depth and negative kurtosis for most of the soil properties at 20-40 cm depth in all three plots. Positive kurtosis indicates a more acute peak with fat tails while negative kurtosis value indicates a smaller peak with thin tails. In this study, mean and median values for most soil physical and chemical properties were either equal or smaller than the mean and outliers did not dominate the measures of central tendency (Cambardella et al., 1994).

The CV for physical properties and chemical properties varied from low to high in both irrigated fields and for the combined dataset for all three plots at each of the 0-20 and 20-40 cm depths. Lowest CV (<15%) for soil properties was associated with sand, BD, and pH; moderate (<35) was associated with clay, AWC, FC, θd, and OM; and most (>35%) was associated with K_s, NO_3^-, EC, Na^+, Cl^-, SAR, and ESP. The high variability of K_s, NO_3^-, EC, Na^+, Cl^-, SAR, and ESP was due to the nonuniform application of treated wastewater. Other physical properties like clay content, AWC, FC, θd, and OM were moderately variable, which suggested that the effect of treated wastewater on these properties was low and the effect on sand content, BD, OM and pH were the least.

The linear correlation analysis of 16 soil attributes at 0-20 cm depth of the irrigated plots showed more significant correlation pairs within all three plots than in the irrigated plots. Significant positive correlations were observed between the soil chemical attributes, for example, NO_3^-, with EC; EC with Na^+, Cl^-; SAR with NO_3^-indicating the treated wastewater application with high electrolyte concentration will increase the values of soil chemical properties including SAR. The negative significant correlation between soil physical properties for BD and silt content and K_s and clay content showed the important influence of clay and silt content on reductions in K_s. Halliwell and others (2001) observed that application of high Na^+ content treated wastewater increases sodicity causing swelling and dispersion of clays, changes pore geometry, and reduces hydraulic conductivity. In this study K_s was also negatively correlated with Na^+ indicating that as Na^+ content of soil increases soil K_s decreases.

Brejda and others (2000a) used 20 soil attributes for PC analysis and reduced their dimensions to five PCs: soil texture, soil organic matter, soil acidity, soil color, and soil mehlich factor. Shukla and others (2004a) used 20 soil attributes and reduced their dimensions into four PCs: bulk density, water infiltration, aggregate size, and nitrogen factor for reclaimed minesoils in Southern Ohio. Shukla and others (2004b) used PCA on 16 soil attributes and reduced their dimensions into four PCs: water retention, water infiltration, water transport, and soil texture. Similarly, 11 soil attributes were grouped into three PCs: soil carbon factor, soil nitrogen factor, and soil texture factor (Garten et al., 2007). In this study, the PCA grouped the 16 measured soil attributes for both irrigated and all three plots for both 0-20 and 20-40 cm depths into five factors: soil salinity, soil sodicity, water transport, soil texture, and water storage. All five factors contribute to one or more soil functions and, therefore, can be called soil quality indicators. The five factors influence the change caused by treated wastewater application in the study site. The Cl^- and NO_3^-, clay and EC were the most dominating soil properties in irrigated plot at 0-20 cm depth. These properties are the important component of soil salinity. SAR, ESP, and OM were found to be the second most dominating soil properties in the irrigated plots at 0-20 cm depth. These soil properties are the important component of soil sodicity. This study was different than others reported in the literature because it was conducted on native desert ecosystem irrigated with treated industrial effluent where salinity (EC >3.90 dS/m) and sodicity are a problem (SAR>32.97). Other reported studies were conducted on agriculture fields (Brejda et al., 2000a; b; Shukla et al., 2006) and reclaimed minelands (Shukla et al., 2004a) with no problem of soil salinity. The PCA analysis grouped the measured attributes into components of sodicity, salinity, and soil texture for the desert soils irrigated with treated industrial treated wastewater.

This research was mainly concentrated in three plots within a 36-ha area with a large number of samples collected from two irrigated plots and one unirrigated plot. The study showed some statistical differences between irrigated and unirrigated plots for some physical (AWC, K_s) and chemical (pH, EC, SAR, ESP, Na^+, Cl^- and NO_3^-) properties of soil. The study also showed that soil physical and chemical properties could be different under different canopies as well as bare soil. Further research on spatial variability of soil properties vis-a–vis wastewater application is necessary to fully understand the influence of treated wastewater application in the entire 36-ha area and to develop statistical models for site specific management that can also be easily applied to other areas with similar soil environment. Overall, treated wastewater application with high EC and SAR has raised soil SAR and EC in both the irrigated plots.

CONCLUSIONS

Application of treated wastewater was usually higher during winter and lower during the summer months when the crop water demand was higher. Chemical parameters were higher in the treated effluent than in the influent probably due to evaporation in the holding pond. Necessary steps should be taken to schedule uniform application of wastewater year round and measures should be taken to reduce the evaporation in the holding pond. Low sprinkler uniformity in both irrigated plots was observed primarily due to the nonuniform sprinkler distances, wind velocities, and treated wastewater interception by vegetation canopies. Application of treated wastewater containing high EC, SAR, and Na^+ content affected the $K_{s,}$ of the West Mesa soil. The amount of NO_3^- was higher at upper depths of irrigated plots. Higher sodium content (>693 mg kg^{-1}) and pH (>9) at upper depths of the irrigated plots threaten the survival of annual and perennial forbs and grass in the intercanopy areas.

Principal Component Analysis grouped various measured soil attributes into five PCs: soil salinity, soil sodicity, water transmission, soil texture, and water storage factors at both 0-20 and 20-40 cm depths. The CV showed that attributes related to soil salinity and sodicity were most variable (CV>0.35) in irrigated plots at both depths. Further efforts could be made to identify the most dominant attribute within each PC using redundancy analysis techniques. Soil salinity and sodicity causing soil properties were associated with the treated wastewater chemical properties, so measures should be taken to reduce the chemical constituent like EC, Cl^-, NO_3^-, SAR, ESP and Na^+ in the treated wastewater. Treated wastewater application in the site must take into account the relative differences and importance of intercanopy and under the canopy soils. Although exact influence of SAR and EC on native shrubs and perennial vegetation are unknown, the soil SAR and EC levels are high enough to imitate management practices toward controlling soil salinity and sodicity in the West Mesa site. Success of this project at the West Mesa is important for the area because increasing demands on limited water resources have made wastewater reclamation for irrigation an attractive option for extending water supply and several other New Mexico municipalities are considering development of land application sites.

RECOMMENDATIONS

There are several recommendations that can be made for a better understanding of the influence of treated wastewater on native shrubs and other vegetation in the West Mesa site. Since uniformity of water application was low and highly variable, influence of treated wastewater on soil properties may also be highly variable. Therefore, a detailed study on spatial variability of soil physical and chemical properties including total soil alkalinity, and plant sodium and chloride content is needed to map the areas with very high and low salinity and sodicity. These hot and cold spots then can be utilized for scheduling irrigations as well as initiating control measures. We also suggest that irrigation in the West Mesa should also take into account variable shrub density and types. Since soil EC and SAR levels have increased significantly, further research should be carried out to establish crop coefficients of the herbaceous vegetation so that a realistic compromise can be made in meeting ET of the diverse population. A detailed analysis should be done to determine the total salt load and salt balance for the study area. A separate study may be undertaken to determining the total depth of leaching of the applied salts. Since most effluent chemical parameters were higher than influent, immediate attention should be paid to reducing evaporation from the holding ponds.

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APPENDICES

Appendix 1: Mean and standard errors of treated wastewater chemistry during summer and winter season from 2003 to 2006

	2003		2004	
	Summer	Winter	Summer	Winter
TDS (mg L^-)	2395.00 ± 165.00	1870.00 ± 185.20	1840.00 ± 260.00	1836.66± 136.42
Cl^- (mg L^-)	345.00 ± 25.00	316.00 ± 24.68	236.00 ± 40.00	250.33± 26.77
NO_3^- (mg L^-)	8.86 ± 8.04	6.69 ± 2.06	14.25 ± 7.75	3.57± 1.47
Na^+ (mg L^-)	758.00 ± 34.00	579.00 ± 75.01	590.00 ± 92.00	607.00 ± 48.09
EC	3.74 ± 0.26	2.92 ± 0.29	2.87± 0.41	2.86 ± 0.21
SAR	29.65 ± 0.11	23.74 ± 3.44	27.93± 6.48	28.22 ± 3.00
	2005		2006	
TDS (mg L^-)	2695.00± 615.00	2420.00 ± 500.00	4230.00 ± 0.00	2625.00 ± 1255.00
Cl^- (mg L^-)	327.50 ± 57.50	330.50 ± 100.50	706.00 ± 0.00	439.00 ± 249.00
NO_3^- (mg L^-)	0.13 ± 0.12	2.12 ± 2.13	0.01± 0.00	4.52 ± 4.42
Na^+ (mg L^-)	929.50 ± 190.50	877.00 ± 223.00	1320.00.± 0.00	1103.00 ± 227.00
EC	4.21 ± 0.96	3.78± 0.78	6.60 ± 0.00	4.10 ± 1.96
SAR	47.76 ± 9.77	37.17± 8.16	44.56± 0.00	39.93 ± 7.02

Where TDS is total dissolved solids, Cl^- is chloride, NO_3^- is nitrate, Na^+ is sodium, EC is electrical conductivity, and SAR is sodium adsorption ratio

Appendix 2: One-way ANOVA contrasts between vegetation canopies and intercanopy areas for particle size, bulk density (BD), and hydraulic conductivity (K_s) at 0-20 and 20-40 cm depth.

1-way ANOVA contrasts	Sand	Silt	Clay	BD	K_s
Irrigated plot-I					
0-20 cm depth	---------------------------P-value---------------------				
Mesquite vs. Creosote	0.309	0.210	0.695	0.053	**<0.001**
Mesquite vs. Intercanopy	**0.046**	0.708	0.714	0.372	**0.004**
Creosote vs. Intercanopy	0.081	0.091	0.871	0.214	0.093
20-40 cm depth					
Mesquite vs. Creosote	0.124	0.076	0.939	0.063	0.085
Mesquite vs. Intercanopy	0.163	0.459	0.413	0.236	0.754
Creosote vs. Intercanopy	0.164	0.436	0.417	0.753	0.231
Unirrigated					
0-20 cm depth					
Mesquite vs. Creosote	0.085	0.585	0.706	**0.003**	**0.045**
Mesquite vs. Intercanopy	0.156	0.557	0.174	0.087	0.084
Creosote vs. Intercanopy	0.190	0.818	0.232	0.553	0.312
20-40 cm depth					
Mesquite vs. Creosote	0.088	0.289	0.054	0.666	0.094
Mesquite vs. Intercanopy	0.778	0.553	0.767	0.679	0.264
Creosote vs. Intercanopy	0.469	0.188	0.675	0.967	0.798
Irrigated plot-II					
0-20 cm depth					
Mesquite vs. Creosote	0.0792	**0.024**	0.215	0.573	**<0.001**
Mesquite vs. Intercanopy	0.644	0.484	0.524	0.204	**<0.003**
Creosote vs. Intercanopy	0.112	**<0.001**	0.186	0.143	**<0.001**
20-40 cm depth					
Mesquite vs. Creosote	**0.015**	0.109	0.057	0.854	0.392
Mesquite vs. Intercanopy	0.895	0.563	0.746	0.283	0.485
Creosote vs. Intercanopy	0.063	0.214	0.234	0.073	0.724

P-values less than $\alpha = 0.05$ are significantly different and are bolded

Appendix 3: One-way ANOVA contrasts between vegetation canopies and intercanopy areas for available water content (AWC), field capacity (FC), and drainable porosity (θd) at 0-20 and 20-40 cm depths

One –Way ANOVA contrasts	AWC	FC	θd	AWC	FC	θd
	0-20 cm depth			20-40 cm depth		
	-----------------------------P-value--------------------------					
	-------------------------Irrigated plot-I------------------------					
Mesquite vs. Creosote	0.618	0.552	0.480	0.441	0.877	0.849
Mesquite vs. Intercanopy	0.990	0.422	0.372	0.485	0.505	0.349
Creosote vs. Intercanopy	0.697	0.213	0.392	0.697	0.213	0.392
	-----------------------Unirrigated plot-------------------------					
Mesquite vs. Creosote	0.422	0.325	0.885	0.442	0.593	0.270
Mesquite vs. Intercanopy	0.072	0.178	0.336	**0.006**	**0.037**	0.710
Creosote vs. Intercanopy	0.523	0.926	0.935	0.385	0.075	0.687
	-------------------------Irrigated plot-II------------------------					
Mesquite vs. Creosote	0.951	0.059	0.421	0.652	0.288	0.293
Mesquite vs. Intercanopy	0.578	0.169	0.666	0.467	0.443	0.254
Creosote vs. Intercanopy	0.523	0.926	0.935	0.385	0.075	0.687

P-values less than α = 0.05 are significantly different and are bolded

Appendix 4: One-way ANOVA contrasts for different suction between vegetation canopies and intercanopy areas at 0-20 cm depth in irrigated plot-I and unirrigated plot

1-way ANOVA contrasts	0 MPa	0.003 MPa	0.006 MPa	0.03 MPa	0.1 MPa	0.3 MPa	1 MPa	1.5 MPa
Irrigated plot-I								
0-20 cm depth	---------P-value---------							
Mesquite vs. Creosote	0.248	0.520	0.920	0.552	0.720	0.555	0.413	0.876
Mesquite vs. Intercanopy	0.816	0.870	0.380	0.422	0.115	0.242	0.093	0.112
Creosote vs. Intercanopy	0.637	0.638	0.342	0.213	0.060	0.130	**0.018**	0.077
20-40 cm depth								
Mesquite vs. Creosote	0.896	0.807	0.940	0.897	0.302	0.459	0.454	**0.025**
Mesquite vs. Intercanopy	0.895	0.120	0.166	0.505	0.149	0.142	0.205	<**0.001**
Creosote vs. Intercanopy	0.966	0.838	0.342	0.213	0.060	0.130	**0.018**	0.077
Unirrigated								
0-20 cm depth								
Mesquite vs. Creosote	**0.008**	**0.028**	0.240	0.325	0.313	0.306	0.792	0.774
Mesquite vs. Intercanopy	**0.010**	**0.009**	0.340	0.178	0.483	0.228	0.244	0.108
Creosote vs. Intercanopy	0.554	0.941	0.515	0.926	0.739	0.875	0.872	0.894
20-40 cm depth								
Mesquite vs. Creosote	0.868	0.657	0.258	0.593	0.730	0.913	0.726	0.531
Mesquite vs. Intercanopy	0.267	0.334	0.639	**0.037**	0.480	0.325	0.653	0.839
Creosote vs. Intercanopy	0.641	0.473	0.914	**0.075**	0.065	0.006	0.070	0.097

P-values less than $\alpha = 0.05$ are significantly different and are bolded

Appendix 5: One-way ANOVA contrasts for different suction between vegetation canopies and intercanopy areas at 0-20 cm depth in irrigated plot-II

1-way ANOVA contrasts	0 MPa	0.003 MPa	0.006 MPa	0.03 MPa	0.1 MPa	0.3 MPa	1 MPa	1.5 MPa
Irrigated plot-II								
0-20 cm depth								
Mesquite vs. Creosote	0.962	0.068	0.520	0.059	**0.003**	**0.003**	0.005	**0.021**
Mesquite vs. Intercanopy	0.309	0.724	0.726	0.169	**0.026**	0.066	0.058	0.127
Creosote vs. Intercanopy	0.554	0.941	0.515	0.926	0.739	0.875	0.872	0.894
20-40 cm depth								
Mesquite vs. Creosote	0.865	0.806	0.452	0.288	**0.029**	0.229	**0.039**	0.092
Mesquite vs. Intercanopy	0.930	0.660	0.639	0.443	0.954	0.976	0.718	0.759
Creosote vs. Intercanopy	0.641	0.47	0.914	0.075	0.065	0.064	0.070	0.097

P-values less than α = 0.05 are significantly different and are bolded

Appendix 6: Mean and standard errors for electrical conductivity (EC), pH, nitrate (NO_3^-), and chloride (Cl^-) in both irrigated and unirrigated plots

	Depth	---------------------Irrigated-I---------------------			------------------Unirrigated-----------------			------------------Irrigated-II--------------------		
	cm	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy
pH	0-20	9.50±0.32	9.63±0.18	9.76±0.14	8.18±0.14	8.56±0.17	8.66±0.14	9.60±0.12	9.83±0.18	9.80±0.09
	20-40	9.63±0.14	9.66±0.12	9.60±0.10	8.26±0.08	8.70±0.18	8.39±0.10	9.66±0.12	9.73±0.06	9.76±0.09
	40-60	9.53 ±0.27	9.40±0.26	9.20±0.01	8.03±0.13	8.10±0. 50	8.00±0 00	9.50±0.10	9.76±0.03	9.50±0.12
	60-80	9.63±0.21	8.73±0.38	8.73±0.23	8.05±0.09	8.62±0.14	8.10±0.18	9.40±0.17	9.60±0.25	9.36±0.19
	80-100	9.53±0.51	8.53±0.35	8.46±0.14	7.91±0.06	8.52±0.26	8.12±0.26	9.33±0.17	9.40±0.35	9.06±0.12
	100-150	9.02±0.55	8.56± 0.14	8.33±0.33	7.93±0.05	8.22±0.11	8.32 ±0.19	9.23±0.22	9.30±0.40	8.96±0.28
EC	0-20	1.16±0.23	1.36±0.20	0.89±0.24	0.45±0.13	0.36±0.02	0.28±0.08	1.06±0.20	2.03±0.20	1.36±0.20
dS m^{-1}	20-40	1.14±0.17	1.70±0.35	1.03±0.36	0.35±0.06	0.46±0.48	0.22±0.06	0.92±0.08	1.60±0.26	1.24±0.21
	40-60	1.09±0.21	1.40±0.16	1.20±0.43	0.35±0.08	0.41±0.02	0.21±0.05	0.94±0.09	1.40±0.28	1.19±0.23
	60-80	1.12±0.29	1.04±0.37	1.48±0.51	0.71±0.18	0.30±0.05	0.20±0.03	0.89±0.11	1.46±0.28	0.93±0.18
	80-100	1.26±0.18	2.14±0.61	1.78±0.62	1.56±0.31	0.39±0.04	0.18±0.05	0.96±0.13	1.38±0.20	0.93±0.15
	100-150	1.38±0.22	2.50±0.53	1.58±0.54	1.38±0.21	0.38±0.06	0.23±0.08	0.92±0.13	1.58±0.50	1.08±0.05
NO_3^-	0-20	45.74±2.85	35.42±1.52	25.06±1.76	24.1±0.32	15.63±0.23	7.97±0.10	106.28±3.51	63.46±3.84	29.49±1.20
mg kg^{-1}	20-40	25.06±3.27	19.17±0.33	19.1±0.88	12.88±0.06	8.10±0.08	5.97±0.38	23.60±0.66	20.63±0.66	11.78±0.66
	40-60	14.74±1.92	13.28±0.58	19.17±1.85	10.93±0.35	7.92±0.10	3.36±0.14	19.17±0.88	14.74±0.33	8.85±0.00
	60-80	16.20±0.33	8.85±0.00	20.63±2.18	11.83±0.18	4.16±0.03	2.96±0.18	20.63±1.20	17.71±1.00	8.85±0.00
	80-100	19.17±0.64	11.78±0.66	16.20±0.88	8.32±0.08	4.42±0.00	6.86±0.23	23.60±2.85	13.28±0.58	10.31±0.33
	100-150	29.49±1.20	8.85±0.00	14.74±0.66	12.17±0.13	3.94±0.05	4.29±0.05	22.14±1.15	11.78±0.33	11.78±0.33
Cl^-	0-20	95.33±12.30	140.93±13.32	52.66 ±37.76	6.68±0.92	7.87±0.39	6.10±0.92	76.33±25.25	258.00±39.30	106.30±25.63
mg kg^{-1}	20-40	146.46±22.44	233.93±50.25	124.63±77.43	5.84±1.07	7.36±1.32	4.4 ±1.37	80.40±23.05	212.66±58.06	105.6 ± 19.25
	40-60	99.43±13.33	199.13±42.41	182.06 ±102.72	12.58±3.10	6.76±2.23	3.53±0.40	89.36±36.06	198.43±62.54	126.00±10.18
	60-80	85.30±21.33	501.43±174.16	263.90±108.96	51.16±11.59	6.42±0.96	5.53±1.24	81.7±47.17	195.40±79.38	96.96±26.85
	80-100	103.73±17.75	530 .26±266.56	460.36±229.76	119.23±22.82	18.40±2.92	5.26 ± 1.13	112.36±54.44	168.66±69.22	124.53±48.15
	100-150	175.43±45.59	661.01±330.90	429.23±242.19	100.32±23.65	34.3±2.89	5.83±0.77	92.93±53.65	181.76±99.73	162.30±16.85

Appendix 7: Mean and standard errors for sodium adsorption ratio (SAR), sodium (Na), calculated exchangeable sodium percentage (ESP), and organic matter (OM) in both irrigated and unirrigated plots

		---------------------Irrigated-I-------------------			-------------Unirrigated[a]-------------			----------------Irrigated-II---------------------		
	Depth	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy
SAR	0-20	21.40 ± 6.42	13.74 ± 1.58	15.76 ± 1.66	0.32	4.15	0.33	30.53 ± 7.31	19.80 ± 2.53	13.84 ± 4.59
	20-40	13.57 ± 1.59	16.41 ± 3.21	20.09 ± 6.28	0.64	4.82	0.29	19.57 ± 2.30	22.13 ± 8.01	13.59 ± 4.11
	40-60	12.16 ± 3.40	16.56 ± 2.22	18.57 ± 7.35	1.21	5.02	0.39	19.49 ± 3.27	14.04 ± 0.82	14.90 ± 5.44
	60-80	15.95 ± 6.95	12.07 ± 5.75	14.67 ± 6.71	0.57	5.32	0.42	26.43 ± 7.83	19.52 ± 3.82	7.44 ± 1.60
	80-100	17.91 ± 14.38	6.74 ± 1.11	9.60 ± 3.39	0.35	6.81	0.49	21.97 ± 4.63	20.87 ± 4.16	8.50 ± 1.13
	100-150	16.11 ± 6.91	7.12 ± 2.81	6.51 ± 2.28	0.58	3.73	1.06	16.11 ± 6.91	7.11 ± 2.80	6.51 ± 2.28
Na^+ mg kg^{-1}	0-20	533.33 ±167.73	507.66 ± 59.17	693.33±216.85	9	151	10	539.33±100.40	824.00 ± 83.70	955.67 ± 91.52
	20-40	693.33 ±183.97	710.33 ± 67.33	671.60±167.60	20	266	9	624.00 ± 43.11	905.00 ± 98.32	982.33 ±195.66
	40-60	666.00 ±197.45	584.67 ± 92/26	497.00 ±95.47	38	262	12	710.67 ± 67.10	827.67 ± 73.31	837.33 ±219.87
	60-80	655.47 ±235.09	489.67 ±232.39	389.67 ±94.74	25	212	12	676.67 ±78.86	828.00 ± 103.52	641.00 ±213.93
	80-100	651.33 ±269.50	361.67± 80.32	285.33± 69.29	8.08	156.62	11.19	608.67±132.95	756.67 ±137.14	476.33 ± 160.54
	100-150	496.33 ±197.90	271.33 ± 64.71	223.33 ± 52.90	13.26	85.81	24.49	450.67 ± 98.26	566.00± 148.08	383.67 ± 138.46
Calculated ESP	0-20	22.37 ± 6.08	15.90 ± 1.62	17.95 ± 1.64	0.40	4.64	0.77	29.59 ± 5.67	21.71 ± 2.35	15.55 ± 4.56
	20-40	15.72 ± 2.85	18.43 ± 3.05	21.33 ± 5.29	0.42	5.53	0.84	21.52 ± 2.14	22.71 ± 6.49	15.39 ± 4.13
	40-60	13.97 ± 3.71	16.56 ± 2.22	18.57 ± 7.35	0.53	5.79	0.69	21.34 ± 2.96	16.27 ± 0.85	16.37 ± 5.96
	60-80	16.97 ± 7.35	13.30 ± 6.18	15.82 ± 6.77	0.43	6.18	0.65	26.43 ± 5.75	21.300 ± 3.35	8.76 ± 2.04
	80-100	18.51 ± 8.18	7.95 ± 1.38	11.09 ± 3.78	0.75	8.08	0.55	23.32 ± 4.12	22.46 ± 3.59	10.09 ± 1.37
	100-150	17.17 ± 7.22	8.19 ± 3.44	7.53 ± 2.78	0.41	4.07	0.31	24.64 ± 4.97	20.61 ± 5.91	12.48 ± 4.86

Appendix 7: (continued) Means and standard errors for sodium adsorption ratio (SAR), sodium (Na), calculated exchangeable sodium percentage (ESP), and organic matter (OM) in both irrigated and unirrigated plots

		----------------------Irrigated-I-------------------			---------------Unirrigated[1]--------------			--------------------Irrigated-II---------------------		
	Depth	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy	Mesquite	Creosote	Intercanopy
OM (%)	0-20	0.70 ± 0.06	0.70 ± 0.10	0.57 ± 0.03	0.9	0.8	0.6	0.67 ± 0.12	0.57 ± 0.12	0.43 ± 0.09
	20-40	0.63 ± 0.09	0.63 ± 0.03	0.50 ± 0.00	0.8	0.7	0.7	0.69 ± 0.12	0.47 ± 0.12	0.60 ± 0.60
	40-60	0.63 ± 0.03	0.60 ± 0.00	0.50 ± 0.00	0.8	0.8	0.7	0.53 ± 0.13	0.47 ± 0.17	0.47 ± 0.12
	60-80	0.53 ± 0.03	0.67 ± 0.07	0.50 ± 0.00	0.8	0.7	0.7	0.50 + 0.13	0.60 ± 0.06	0.43 ± 0.13
	80-100	0.53 ± 0.03	0.60 ± 0.00	0.47 ± 0.03	0.7	0.7	0.7	0.43 ± 0.13	0.60 ± 0.06	0.47 ± 0.12
	100-150	0.53 ± 0.03	0.57 ± 0.03	0.47 ± 0.03	0.6	0.6	0.8	0.40 ± 0.10	0.53 ± 0.07	0.50 ± 0.15

[1]only one sample was analyzed

Appendix 8: One-way ANOVA contrasts for different chemical properties in irrigated plot-I

Depth (cm)	Contrasts	NO_3^-	pH	EC	Cl^-	SAR	Na^+	CEC	ESP	OM
		----------------	----------------	----------------	----------------	P-value	----------------	----------------	----------------	----------------
0-20	Mesquite vs. Creosote	0.137	0.346	**0.027**	**0.018**	0.245	0.901	0.091	0.269	0.981
	Mesquite vs. Intercanopy.	0.130	0.288	0.363	0.452	0.753	0.375	0.073	0.720	0.123
	Creosote vs. Intercanopy	**0.009**	0.886	0.080	**0.032**	0.386	0.444	0.956	0.445	0.123
20-40	Mesquite vs. Creosote	0.230	0.868	0.225	0.187	0.683	0.933	0.722	0.653	0.972
	Mesquite vs. Intercanopy	0.879	0.725	0.472	0.109	0.598	0.847	0.882	0.631	**0.049**
	Creosote vs. Intercanopy	0.624	0.842	0.129	**0.049**	0.357	0.684	0.678	0.359	**0.049**
40-60	Mesquite vs. Creosote	0.725	0.743	0.321	0.088	0.484	0.684	**0.046**	0.450	0.454
	Mesquite vs. Intercanopy	0.638	0.298	0.831	0.470	0.747	0.662	0.359	0.890	**0.039**
	Creosote vs. Intercanopy	0.530	0.501	0.697	0.885	0.314	0.404	0.370	0.374	**0.009**
60-80	Mesquite vs. Creosote	**0.008**	0.156	0.125	0.077	0.647	0.513	0.273	0.650	**0.049**
	Mesquite vs. Intercanopy	0.674	0.298	0.832	0.470	0.757	0.690	0.359	0.755	**0.018**
	Creosote vs. Intercanopy	0.290	0.920	0.423	0.312	0.879	0.301	0.163	0.885	0.594
80-100	Mesquite vs. Creosote	0.152	0.186	0.236	0.186	0.105	0.214	0.077	0.114	0.271
	Mesquite vs. Intercanopy	0.579	0.118	0.463	0.197	0.662	0.736	0.386	0.622	**0.040**
	Creosote vs. Intercanopy	0.417	0.870	0.700	0.852	0.216	0.123	**0.023**	0.254	0.270
100-150	Mesquite vs. Creosote	**0.018**	0.333	0.122	0.258	0.229	0.234	0.819	0.585	0.626
	Mesquite vs. Intercanopy	0.072	0.253	0.746	0.361	0.932	0.795	0.945	0.280	0.159
	Creosote vs. Intercanopy	0.116	0.556	0.298	0.672	0.195	0.155	0.510	0.117	0.337

P-value less than $\alpha = 0.05$ are significantly different and are bolded

Appendix 9: One-way ANOVA contrasts for different chemical properties in irrigated plot-II

Depth (cm)	Contrasts	NO_3^-	pH	EC	Cl^-	SAR	Na^+	CEC	ESP	OM
		----------	----------	----------	----------	P-value	----------	----------	----------	----------
0-20	Mesquite vs. Creosote	0.137	0.346	**0.027**	**0.018**	0.283	0.095	0.091	0.286	0.091
	Mesquite vs. Intercanopy	0.130	0.288	0.363	0.452	0.290	**0.037**	0.073	0.288	0.176
	Creosote vs. Intercanopy	0.010	0.886	0.086	0.032	0.571	0.349	0.956	0.059	0.176
20-40	Mesquite vs. Creosote	0.518	0.653	0.068	0.102	0.338	0.058	0.363	0.339	0.593
	Mesquite vs. Intercanopy	0.898	0.588	0.227	0.430	0.847	0.136	0.640	0.867	**0.048**
	Creosote vs. Intercanopy	0.702	0.820	0.365	0.158	0.419	0.899	0.301	0.424	**0.018**
40-60	Mesquite vs. Creosote	0.349	0.034	0.083	0.219	0.579	0.361	0.586	0.581	0.147
	Mesquite vs. Intercanopy	0.616	0.859	0.356	0.433	0.519	0.638	0.114	0.536	**0.038**
	Creosote vs. Intercanopy	0.057	0.163	0.512	0.317	0.734	0.970	0.686	0.758	**0.002**
60-80	Mesquite vs. Creosote	0.692	0.573	0.132	0.267	0.403	0.310	0.897	0.407	0.594
	Mesquite vs. Intercanopy	0.116	0.855	0.781	0.716	0.844	0.820	**0.029**	0.844	0.295
	Creosote vs. .Intercanopy	0.091	0.512	0.200	0.313	0.381	0.460	0.090	0.382	0.126
80-100	Mesquite vs. Creosote	0.467	0.880	0.162	0.557	0.934	0.483	0.790	0.425	0.098
	Mesquite vs. Intercanopy	0.374	0.367	0.878	0.875	0.875	0.572	0.560	0.262	**0.040**
	Creosote vs. Intercanopy	0.355	0.430	0.154	0.628	**0.046**	0.255	0.205	**0.044**	**0.040**
100-150	Mesquite vs. Creosote	0.012	0.898	0.276	0.472	0.542	0.553	0.744	0.552	0.337
	Mesquite vs. Intercanopy	0.950	0.582	0.338	0.265	0.808	0.715	0.173	0.785	**0.011**
	Creosote vs. Intercanopy	0.124	0.568	0.379	0.587	0.607	0.420	0.898	0.596	0.068

P-value less than $\alpha = 0.05$ are significantly different and are bolded

Appendix 10: One-way ANOVA contrasts for different chemical properties in the unirrigated plot

Contrasts	NO_3^-	pH	EC	Cl^-
0-20 cm depth	-------------------------P-value-----------------------			
Mesquite vs. Creosote	0.136	0.345	**0.027**	**0.017**
Mesquite vs. Intercanopy	0.129	0.287	0.363	0.451
Creosote vs. Intercanopy	**0.009**	0.886	0.086	**0.031**
20-40 cm depth				
Mesquite vs. Creosote	0.518	0.653	0.067	0.101
Mesquite vs. Intercanopy	0.897	0.587	0.227	0.429
Creosote vs. Intercanopy	0.701	0.820	0.364	0.157
40-60 cm depth				
Mesquite vs. Creosote	0.348	**0.033**	0.082	0.219
Mesquite vs. Intercanopy	0.616	0.859	0.356	0.432
Creosote vs. Intercanopy	0.057	0.163	0.511	0.316
60-80 cm depth				
Mesquite vs. Creosote	0.691	0.573	0.131	0.267
Mesquite vs. Intercanopy	0.116	0.855	0.780	0.716
Creosote vs. Intercanopy	0.090	0.512	0.200	0.312
80-100 cm depth				
Mesquite vs. Creosote	0.466	0.879	0.162	0.557
Mesquite vs. Intercanopy	0.374	0.367	0.878	0.875
Creosote vs. Intercanopy	0.354	0.430	0.153	0.628
100-150 cm depth				
Mesquite vs. Creosote	**0.012**	0.897	0.276	0.471
Mesquite vs. Intercanopy	0.950	0.582	0.337	0.264
Creosote vs. Intercanopy	0.124	0.568	0.379	0.586

P-value less than $\alpha = 0.05$ are significantly different and are bolded

Appendix 11: One-way ANOVA contrasts for different chemical properties in three plots

Depth (cm)	Contrasts 0-20 cm	NO_3^-	pH	EC	Cl^-	SAR	Na^+	CEC	ESP	OM
		-----------	-----------	-----------	-----------	P-value	-----------	-----------	-----------	-----------
0-20	Irri-I vs. Unirrigated	0.113	**<0.001**	**<0.001**	**<0.001**	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	**<0.001**	**<0.001**	**<0.001**	**<0.001**	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.110	0.463	0.026	**0.014**	0.213	0.199	0.310	0.251	0.269
20-40	Irri-I vs. Unirrigated	0.358	0.550	0.971	0.546	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	0.563	0.986	0.986	0.991	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.728	0.550	0.986	0.553	0.666	0.225	0.144	0.693	0.757
40-60	Irri-I vs. Unirrigated	0.129	**<0.001**	**<0.001**	**0.001**	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	**0.011**	**<0.001**	**<0.001**	**<0.001**	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.237	**0.028**	0.306	0.753	0.914	0.088	0.109	0.869	0.205
60-80	Irri-I vs. Unirrigated	0.075	**<0.001**	**<0.001**	**<0.001**	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	0.057	**<0.001**	**0.008**	0.089	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.886	0.069	0.052	**0.020**	0.469	0.176	0.082	0.462	0.229
80-100	Irri-I vs. Unirrigated	**0.027**	**0.002**	**<0.001**	**0.004**	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	**0.017**	**<0.001**	0.200	0.325	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.990	0.067	**0.026**	**0.035**	0.148	0.181	0.191	0.113	0.744
100-150	Irri-I vs. Unirrigated	**<0.001**	**0.036**	**0.001**	**0.006**	NA	NA	NA	NA	NA
	Irrri-II vs. Unirrigated	**0.001**	**0.001**	0.187	0.374	NA	NA	NA	NA	NA
	Irri-I vs. Irri-II	0.308	0.077	**0.026**	**0.038**	0.067	0.213	0.646	0.693	0.404

P-value less than α = 0.05 are significantly different and are bold

Appendix 12: Alkalinity, total dissolved cations (TDC), and total dissolved anions (TDA) in the influent and effluent during 2007

Parameters	Influent	Effluent
	----------mol$_c$ m^{-3}----------	
Alkalinity [a]	9.07	34.97
TDC[b]	15.50	55.35
TDA[c]	5.42	22.15

[a] Alkalinity as calcium carbonate at pH 4.5; [b] TDC total dissolved mean of sodium , calcium, magnesium, and potassium cations; [c] TDA is total dissolved mean of nitrate and chloride anions

Appendix 13: Nitrate (NO_3^-) and chloride (Cl^{-1}) balance during 2007

Parameter	Initial soil concentration (Unirrigated0	Final soil concentration (Irrigated)	Added by treated wastewater	Storage
	----------kg ha^{-1}----------			
NO_3^{-1}	68.49	99.47	53.14	22.15
Cl^{-1}	1374.57	2983.98	2886.21	1276.80

[a] plant uptake not included

Appendix 14: The Pearson correlation coefficient and p-values (data in italics is p-value only for significant pairs) among soil physical and chemical properties of both irrigated plots at 0-20 cm depth. (P-value less than α = 0.05 significantly correlated)

Variable	Sand	Silt	Clay	Ks	BD	AWC	FC	θd	OM	NO_3^-	pH	EC	Na^+	Cl^-	SAR	ESP
Sand	1.00															
Silt	**-0.67** ***<.002***	1.00														
Clay	-0.02	-0.16	1.00													
Ks	0.08	0.25	**-0.60** ***0.008***	1.00												
BD	-0.06	-0.04	0.46	-0.47	1.00											
AWC	**-0.67** ***<.002***	0.50	0.01	0.09	-0.36	1.00										
FC	-0.12	-0.05	-0.33	0.18	**-0.60** ***0.008***	0.18	1.00									
θd	-0.14	0.20	0.10	0.26	-0.09	0.28	-0.22	1.00								
OM	-0.01	0.01	0.33	-0.14	-0.15	0.31	-0.22	0.10	1.00							
NO_3^-	0.12	0.07	**-0.80** ***<.0001***	0.39	**-0.54** ***0.02***	0.08	0.25	0.04	-0.37	1.00						
pH	0.10	-0.18	0.05	-0.30	0.04	-0.06	0.24	-0.12	-0.47	0.28	1.00					
EC	0.18	-0.12	-0.38	-0.06	-0.42	0.06	0.26	-0.05	-0.22	**0.76** ***<.0002***	**0.61** ***0.007***	1.00				
Na^+	0.10	-0.21	0.08	-0.44	0.13	-0.08	-0.16	-0.23	-0.21	0.26	**0.71** ***<.0001***	**0.61** ***0.007***	1.00			
Cl^-	-0.05	0.02	**-0.51** ***0.03***	0.05	-0.51	0.21	0.28	-0.04	-0.04	**0.75** ***<.0002***	0.24	**0.87** ***<.0001***	0.36	1.00		
SAR	0.31	0.16	-0.44	0.45	-0.02	-0.21	-0.24	0.16	-0.27	0.38	0.29	0.20	0.21	-0.02	1.00	
ESP	0.33	0.14	-0.45	0.44	-0.01	-0.24	-0.21	0.09	-0.31	0.40	0.33	0.23	0.24	0.00	**0.99** ***<.0001***	1.00

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio, and ESP is exchangeable sodium percentage.

Appendix 15: The Pearson correlation coefficient and p-values (data in italics is p-value only for significant pairs) among soil physical and chemical properties of both irrigated plots at 20-40 cm depth. (P-value less than α = 0.05 are significantly correlated)

Variable	Sand	Silt	Clay	Ks	BD	AWC	FC	θd	OM	NO_3^-	pH	EC	Na^+	Cl^-	SAR	ESP
Sand	1.00															
Silt	0.30	1.00														
Clay	-0.45	**-0.56** ***0.02***	1.00													
Ks	0.10	-0.07	-0.13	1.00												
BD	0.21	**0.52** ***0.03***	-0.29	-0.08	1.00											
AWC	-0.09	0.20	-0.09	0.04	0.02	1.00										
FC	-0.24	0.36	-0.19	0.18	-0.27	-0.04	1.00									
θd	0.30	-0.31	0.26	-0.22	0.09	**-0.47** ***0.04***	**-0.51** ***0.03***	1.00								
OM	0.21	0.05	0.00	-0.07	-0.04	0.38	-0.13	0.00	1.00							
NO3-	0.11	0.11	-0.17	0.12	0.27	0.08	0.14	-0.09	-0.02	1.00						
pH	-0.25	-0.05	0.11	-0.25	-0.13	0.01	0.18	-0.09	-0.15	-0.16	1.00					
EC	-0.38	-0.16	0.28	-0.21	-0.15	0.15	0.16	0.07	0.03	0.27	0.47	1.00				
Na+	-0.46	0.02	0.20	0.09	-0.07	0.30	0.33	-0.13	-0.10	-0.01	**0.56** ***0.01***	**0.69** ***0.001***	1.00			
Cl-	-0.35	0.00	0.26	-0.22	0.00	0.19	0.15	0.08	0.05	0.39	0.22	**0.89** ***<.0001***	**0.51** ***0.03***	1.00		
SAR	-0.35	0.14	0.18	-0.08	0.11	-0.06	0.32	-0.12	-0.20	**0.56** ***0.01***	0.12	**0.55** ***0.02***	0.43	**0.53** ***0.03***	1.00	
ESP	-0.35	0.14	0.12	-0.09	0.13	-0.10	0.33	-0.12	-0.21	**0.58** ***0.01***	0.12	**0.54** ***0.02***	0.41	**0.52** ***0.03***	**0.99** ***<.0001***	1.00

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio, and ESP is exchangeable sodium percentage

Appendix 16: The Pearson correlation coefficient and p-values (data in italics is p-value only for significant pairs) among soil physical and chemical properties of all three plots at 0-20 cm depth. (P-value less than α = 0.05 are significantly correlated)

Variable	Sand	Silt	Clay	Ks	BD	AWC	FC	θd	OM	NO_3^-	pH	EC	Na^+	Cl^-	SAR	ESP
Sand	1.00															
Silt	**-0.61** ***0.0008***	1.00														
Clay	**-0.39** ***0.02***	-0.08	1.00													
Ks	0.18	0.22	**-0.46** ***0.01***	1.00												
BD	0.12	-0.07	-0.02	-0.36	1.00											
AWC	**-0.42** ***0.02***	0.26	0.11	-0.01	**-0.44** ***0.02***	1.00										
FC	-0.18	-0.09	0.04	-0.21	**-0.51** ***0.006***	**0.45** ***0.02***	1.00									
θd	0.08	0.13	-0.17	0.31	0.02	0.07	-0.21	1.00								
OM	0.28	-0.05	-0.21	0.22	-0.21	0.30	0.00	**0.39** ***0.04***	1.00							
NO_3^-	-0.02	0.04	-0.27	0.16	**-0.58** ***0.005***	0.31	**0.48** ***0.01***	-0.04	-0.13	1.00						
pH	-0.21	-0.11	0.35	**-0.45** ***0.02***	-0.26	0.36	**0.74** ***<.0001***	-0.20	-0.14	**0.48** ***0.01***	1.00					
EC	-0.05	-0.15	0.09	-0.19	**-0.49** ***0.009***	**0.41** ***0.03***	**0.65** ***0.0002***	-0.12	0.02	**0.78** ***<.0001***	**0.81** ***<.0001***	1.00				
Na^+	-0.12	-0.19	0.30	**-0.44** ***0.02***	-0.24	0.37	**0.58** ***0.001***	-0.20	0.03	**0.50** ***0.009***	**0.90** ***<.0001***	**0.84** ***<.0001***	1.00			
Cl^-	-0.17	-0.05	-0.01	-0.17	**-0.52** ***0.005***	**0.43** ***0.02***	**0.62** ***0.0006***	-0.11	0.04	**0.80** ***<.0001***	**0.64** ***0.0002***	**0.91** ***<.0001***	**0.69** ***<.0001***	1.00		
SAR	-0.01	0.03	0.09	-0.05	-0.28	0.25	**0.48** ***0.01***	-0.02	-0.05	**0.55** ***0.002***	**0.76** ***<.0001***	**0.65** ***0.002***	**0.71** ***<.0001***	**0.48** ***0.01***	1.00	
ESP	0.00	-0.01	0.11	-0.09	-0.30	0.32	**0.55** ***0.002***	-0.09	-0.04	**0.57** ***0.002***	**0.80** ***<.0001***	**0.70** ***<.0001***	**0.76** ***<.0001***	**0.53** ***0.005***	**0.99** ***<.0001***	1.00

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio, and ESP is exchangeable sodium percentage

Appendix 17: The Pearson correlation coefficient and p-values (data in italics is p-value only for significant pair) among soil physical and chemical properties of all three plots 20-40 cm depth. (P-value less than α = 0.05 are significantly correlated)

Variable	Sand	Silt	Clay	Ks	BD	AWC	FC	θd	OM	NO_3^-	pH	EC	Na^+	Cl^-	SAR	ESP
Sand	1.00															
Silt	0.10	1.00														
Clay	**-0.60** ***0.008***	-0.32	1.00													
Ks	0.14	-0.16	-0.25	1.00												
BD	0.37	0.34	**-0.40** ***0.03***	0.03	1.00											
AWC	-0.10	0.28	0.02	-0.16	0.05	1.00										
FC	-0.33	0.43	0.15	-0.33	-0.28	0.33	1.00									
θd	0.33	-0.37	0.10	-0.13	0.11	**-0.54** ***0.003***	**-0.47** ***0.01***	1.00								
OM	0.18	0.23	-0.16	-0.15	0.09	0.26	0.11	-0.15	1.00							
NO3-	-0.11	0.19	0.02	0.24	0.20	0.21	0.06	-0.27	-0.10	1.00						
pH	-0.33	0.27	0.33	**-0.63** ***0.0005***	-0.26	0.15	**0.62** ***0.0005***	-0.03	0.13	-0.25	1.00					
EC	**-0.40** ***0.03***	0.20	0.34	**-0.53** ***0.004***	-0.21	0.32	**0.60** ***0.0005***	-0.05	0.18	0.04	**0.76** ***<.0001***	1.00				
Na+	**-0.41** ***0.03***	0.31	0.33	**-0.48** ***0.01***	-0.22	0.33	**0.71** ***<.0001***	-0.14	0.19	-0.15	**0.89** ***<.0001***	**0.87** ***<.0001***	1.00			
Cl-	**-0.39** ***0.04***	0.24	0.36	**-0.51** ***0.005***	-0.15	0.28	**0.55** ***0.003***	-0.02	0.16	0.11	**0.68** ***0.0001***	**0.93** ***<.0001***	**0.78** ***<.0001***	1.00		
SAR	**-0.39** ***0.04***	0.33	0.31	**-0.49** ***0.009***	-0.12	0.14	**0.66** ***0.0006***	-0.14	0.12	0.11	**0.76** ***<0.0001***	**0.80** ***<.0001***	**0.82** ***<.0001***	**0.78** ***<.0001***	1.00	
ESP	**-0.41** ***0.03***	0.33	0.33	**-0.52** ***0.005***	-0.13	0.18	**0.69** ***<.0006***	-0.15	0.13	0.13	**0.80** ***<.0001***	**0.81** ***<.0001***	**0.84** ***<.0001***	**0.78** ***<.0001***	**0.98** ***<.0001***	1.00

Where K_s is hydraulic conductivity, BD is bulk density, AWC is available water content, FC is field capacity, θd is drainable porosity, OM is organic matter, NO_3^- is nitrate, EC is electrical conductivity, Na^+ is sodium, Cl^- is chloride, SAR is sodium adsorption ratio, and ESP is exchangeable sodium percentage