VARIATION OF SOIL CHEMICAL PROPERTIES IN IRRIGATED AND NON-IRRIGATED AREAS OF THE LAGUNA REGION OF MEXICO

Variación de las Propiedades Químicas del Suelo en Áreas Irrigadas y no Irrigadas de La Región Lagunera, México

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SUMMARY

Since approximately 1840, irrigation has been required for agriculture in the Laguna Region. This activity might have changed soil chemical properties throughout time. The objective of this work was to compile soil chemical data of irrigated soils in order to document the nature and changes of soil properties. Data of organic matter, pH, electrical conductivity and cation exchange capacity from irrigated areas and non-irrigated areas of 1975 and 1997 were compared. Also, digitized soil information of the Mexican Durango and Coahuila states was examined using a Geographic Information System to obtain soil maps of the region and to locate soil sample sites. Means comparison analysis was used to statistically contrast soil parameters from non-irrigated areas against irrigated areas. Also, histograms and graphs of soil data *versus* depth were used to display the ranges of soil properties. The results showed that organic matter diminished by 50 percent in irrigated soils in 1997 compared with 1975; pH values increased by 6% in irrigated soils; cation exchange capacity decreased 11% in soils under irrigation; and the electrical conductivity did not show statistical changes.

Index words: *geographic information system, organic matter, pH, cation exchange capacity, electrical conductivity*.

RESUMEN

Desde aproximadamente 1840, la agricultura en la Región Lagunera ha sido con riego. Esta continua práctica podría haber cambiado las principales propiedades químicas del suelo a través del tiempo. Considerando lo anterior, se realizó un análisis de datos del suelo para la materia orgánica, el pH, la conductividad eléctrica y la capacidad de intercambio catiónico en áreas irrigadas y áreas no irrigadas de 1975 y 1997, y así poder comprobar la hipótesis de si la práctica del riego pudo haber producido cambios significativos en las propiedades químicas de los suelos irrigados con respecto a los no irrigados. Se utilizó un sistema de información geográfica para localizar geográfica-mente los sitios de muestreo en el área de estudio a partir de información digitalizada de suelos de los estados mexicanos de Durango y Coahuila. Se realizaron análisis de comparación de medias para confrontar estadísticamente los parámetros del suelo de las áreas irrigadas con las no irrigadas a través de los años. También se usaron histogramas y gráficas de datos de suelo para mostrar los intervalos de las variables del suelo estudiadas. Los resultados mostraron que el contenido de materia orgánica en los suelos disminuyó 50% en los suelos irrigados para 1997, en comparación con 1975; los valores de pH se incrementaron 6% en las áreas de riego, la capacidad de intercambio catiónico disminuyó 11% en suelos irrigados, y la conductividad eléctrica en los suelos no presentó cambios estadísticos en el estudio.

Palabras clave: *sistema de información geográfica, materia orgánica, pH, capacidad de intercambio catiónico, conductividad eléctrica.*

INTRODUCTION

The Laguna Region has a desertic environment with an annual rainfall of less than 240 mm and an annual evaporation rate of more than 2500 mm. Thus, the agricultural areas of the region must be irrigated in order to obtain economically viable agriculture. Studies of long-term changes in soil properties are important because they provide direct evidence of

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the effects of changes in land-use or climate pollution on soils. Soil characteristics such as organic matter (SOM), soil salinity (EC), pH, and cation exchange capacity (CEC) could have changed with irrigation practices through time (Lado *et al*., 2004; Presley *et al*., 2004). It is important to quantify how soil properties were modified, to know the environmental soil changes and then take the adequate future decisions to preserve soil resources. The goal of this paper was to investigate how soil characteristics (i.e., organic matter, pH, electrical conductivity, and cation exchange capacity) have changed through time with irrigation in the Laguna Region. To determine soil property changes for irrigation, soil organic matter, soil electrical conductivity, soil pH, and cation exchange capacity were considered by comparing data of irrigated and non-irrigated areas of the years 1975 and 1997.

MATERIALS AND METHODS

The study area is located in the Laguna Region between 24° 22' and 26° 23' N, and 102° 22' and 104° 47' W (SAGARPA, 2002). The study area included the counties of Gómez Palacio, Lerdo, Tlahualilo, and Mapimí, all located in the Mexican Durango State. This area is the oldest portion of the Laguna practicing irrigation on agricultural lands. The soil sampling sites were distributed over almost the entire Gómez Palacio area with 177 soil sites, the southern part of Tlahualilo with 50 sites, the northern portion of Lerdo with 37 sites, and, finally, the southeastern part of Mapimí with 21 sites. In total, 285 soil sites were sampled during 1975 and 1997.

The soil samples were analyzed according to the methods reported by Richards (1977) to determine: soil organic matter, SOM (Walkley and Black method); pH, (Potentiometric method); electrical conductivity, EC (Saturation paste extract method, dS m^{-1}); and cation exchange capacity, CEC (Ammonium acetate method pH 7, $cmol_c$ kg^{-1}). Most of the 285 sampling sites were sampled at three or more soil depths (0-30), (30-60), (60-90), and (90-120 cm). The data of 1975 were reported in the Cartas Edafológicas (Soil Maps) of INEGI (1978). The data of 1997 in the Laguna Region were reported by CNA [Comisión Nacional del Agua (1998)].

The soil sample sites of 1975 were georeferenced using the Cartas Edafológicas (Soil Maps) of INEGI. The soil sample sites of 1997 were georeferenced by the CNA data using a Global Positioning System (GPS). Also, the Carta de Uso del Suelo y Vegetación (Soil Land Use and Vegetation Maps) of INEGI (1981) and the report of CNA (1998) were used to classify the soil sample sites as non-irrigated (ni) or irrigated (i) areas. The Geographic Information System (ARC\VIEW) was used to locate, geographically, the 285 soil samples in the study area. An overlay process using GIS with the digital soil maps of Durango and Coahuila states and the digital map of the Laguna counties was made. The digital soil maps for the states were obtained by digitalization of the Cartas Edafológicas (Soil Maps) of INEGI by the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). The procedure permitted the geographic location of the sampling sites. In addition, a Tukey statistical analysis of mean comparisons was performed to average the data for each soil variable under study.

RESULTS AND DISCUSSION

Soil Organic Matter

The analysis of the SOM histograms of Figure 1 (1975) and Figure 2 (1997) revealed that the amount of SOM in the soil has changed significantly from 1975 to 1997 in irrigated areas. For irrigated areas in 1975, 90 percent of the SOM values were in the range from 0.0 to 1.4, and the remaining 10 percent values ranged from 1.5 to 1.9. However, the SOM histogram in Figure 2 shows that 90 percent of the SOM values for 1997 ranged from 0.2 to 0.55 and the remaining 10 percent ranged from 0.56 to 0.64 for irrigated areas. Thus, SOM decreased from irrigated areas in 1975 to irrigated areas in 1997 as an effect of the irrigation practices. Comparison between the amount of SOM in non-irrigated areas in 1975, illustrated in Figure 1, and the amount of SOM in irrigated areas in 1997, shown in Figure 2, implies that the SOM concentration decreased in irrigated areas. Figure 1 displays that 96 percent of the data in non-irrigated areas in 1975 had SOM values in the range from 0.0 to 1.2 percent; while Figure 2 shows that 100 percent of the data in irrigated areas in 1997 had SOM values from 0.20 to 0.64 percent. Therefore, the SOM content in the irrigated soils in 1997 was significantly lower than that of the non-irrigated areas in 1975. Finally, according to the SOM histogram in Figure 2, the range from 0.09 to 1.55 percent for non-irrigated areas in 1997 has a relative frequency of 0.94, while for irrigated areas in 1997, 90 percent of

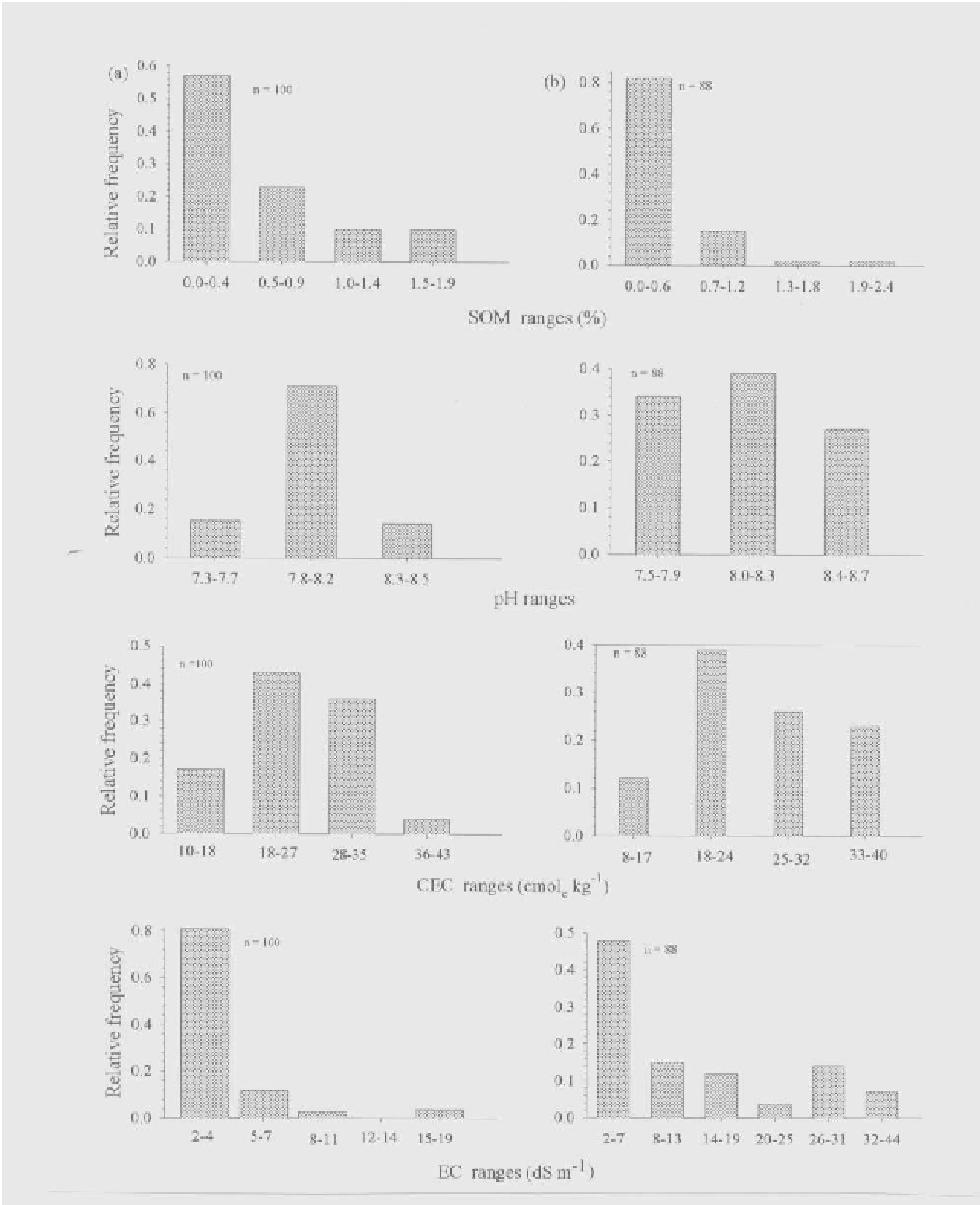

Figure 1. Soil variable ranges for the entire profile in 1975: (a) irrigated and (b) non-irrigated soils.

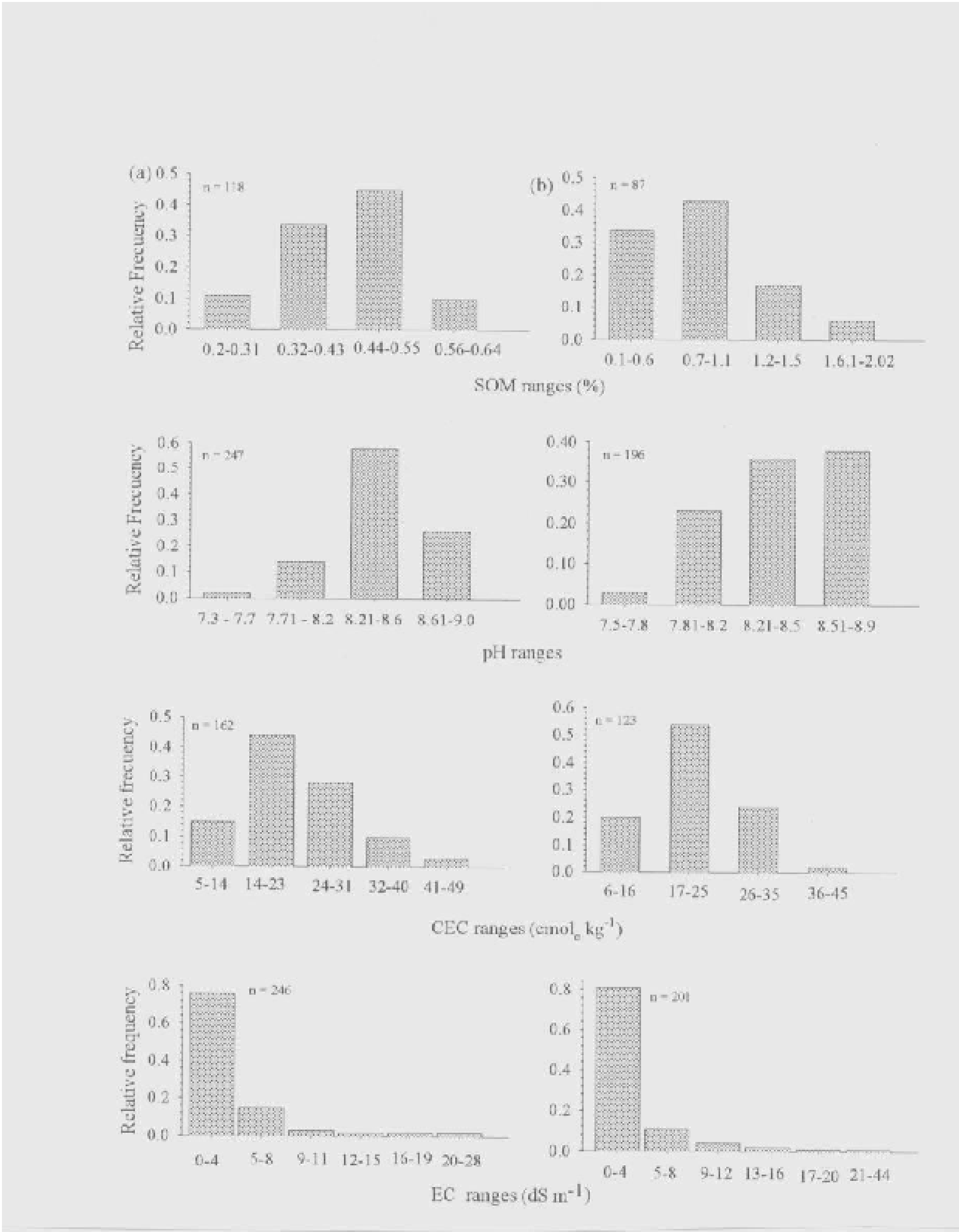

Figure 2. Soil variable ranges for the entire profile in 1997: (a) irrigated and (b) non-irrigated soils.

the SOM values were in the range from 0.2 to 0.55 (Figure 2), significantly lower than for non-irrigated areas. This means that in 1997 for this soil variable non-irrigated areas contained more SOM than irrigated areas. The results agree with Ortega *et al.* (2002) and Sainju *et al.* (2002), with the reduction of SOM under wet and dry soil conditions because they cause an increase in microbial activity (Presley *et al.*, 2004).

Soil pH

When pH data from irrigated areas in 1975 are compared with pH data from 1997 in irrigated areas, we consider that the pH values did increase from 1975 to 1997 with irrigation practices. The histogram of pH, included in Figure 1, shows that in 1975 pH ranged from 8.3 to 8.5 representing only 29 percent of the total pH values; however, in 1997 for irrigated areas, the highest pH ranged from 8.21 to 9.0 showing 84 percent of the total soil samples (Figure 2).

When the pH data for non-irrigation areas in 1975 are compared with the pH values obtained for the irrigated areas in 1997, we deduced that the pH values have been raised in the latter data set. Figure 1 shows that the 8.0 to 8.7 pH values for non-irrigated areas in 1975 represented 66 percent of the total pH values, however, Figure 2 shows, for a similar range, 8.2 to 9.0, a percentage of 84 of the total pH data for irrigation areas in 1997. So, the pH ranges cited increased from 1975 to 1997 because the irrigation practices increased the salt content in soil of mainly calcium, magnesium, potassium, and sodium (Paliwal and Gandhi, 1973). In addition, the pH range from 8.2 to 8.9 represented 74 percent of the pH data for non-irrigated areas in 1997. According to Figure 2, the same pH range for the irrigated areas in the same year represented 84 percent. The values for this parameter were higher for the irrigated areas than for the non-irrigated areas in the same year. This was caused by the application of additional amounts of soluble salts in the soil profile with irrigation water.

Cation Exchange Capacity

A comparison between Figure 1 and Figure 2 shows that CEC values of 1975 are slightly higher than the CEC values of 1997. CEC ranged from 10.3 to 35.7 $cmol_c\ kg^{-1}$ in 1975, as shown in Figure 1, and 96 percent of the CEC values were in this range. However, CEC values from 5.8 to 31.9 $cmol_c\ kg^{-1}$ in 1997, displayed in Figure 2, had 87 percent of the CEC values in the latter range. Therefore, this soil variable decreased in a significant form over time. An explanation is that SOM is responsible for the variable charge of the soil particles. Thus, because SOM diminished, CEC decreased as well. A comparison of CEC ranges between non-irrigation areas in 1975 and irrigation areas in 1997 can be made. For non-irrigation areas in 1975, 88 percent of the total CEC values were included in the range from 16.8 to 40.3. In a similar CEC range from 14.6 to 40.6 $cmol_c\ kg^{-1}$ in irrigated areas a percentage of 82 was shown. In other words, the soils in non-irrigated areas could be slightly higher in their capacity to absorb cations. This was caused by the SOM depletion through time from 1975 in non-irrigated soils to 1997 in irrigated areas.

Electrical Conductivity

The comparison of Figure 1 and Figure 2 shows that EC values of 1975 are slightly higher than the EC values of 1997. The EC range from 2.0 to 4.0 dS m^{-1} in Figure 1 for irrigated areas in 1975 has 80 percent of occurrence, however, for similar EC range from 0.3 to 4.2 dS m^{-1} in Figure 2 for irrigated soils in 1997 shows 76 percent of occurrence. The interpretation for this specific result is that the EC values diminished from 1975 to 1997 in the irrigated areas because the soil rehabilitation plans carried on for the irrigation district of the Laguna. This land reclamation has permitted the reduction of the saline areas. Similar conclusion is obtained when EC values for non-irrigated areas in 1975 and data of irrigated areas in 1997 were compared. EC ranges from 2.0 to 7.0 dS m^{-1} in 1975, shown in Figure 1, has 48 percent of the EC values, however, the EC range from 0.3 to 8.0 dS m^{-1} in 1997, displayed in Figure 2, has 92 percent of the EC values. This means that the non-saline to moderate saline areas increased from non-irrigated areas in 1975 to irrigated areas in 1997, which is explained by the cited land reclamation activities after 1975.

Finally, the value of 81 percent obtained for non-irrigated soils in 1997 in the EC range from 0.3 to 4.3 dS m^{-1} was higher than the 76 percent obtained for the same EC range in irrigated areas for the same year. In other words, in this specific range there were more areas free of salt problems in the non-irrigated areas than in the irrigation areas. This is due to the gradual salt accumulation in the soil profile by the application of water irrigation with high salt content.

Discussion of Soil Properties Changes with Mean Comparison Method

An analysis of the average of the soil variables using a statistical mean comparison analysis by two means of soil variables was done using the T test for Paired Comparisons. Table 1 shows the results of the statistical analysis that was done in the entire profile of the soil parameters. Tables 2 and 3 show the most important results and a hypothesis explanation of the result for each comparison.

CONCLUSIONS

The soil parameters analyzed to evaluate the changes of the soil characteristics showed statistically significant changes between 1975 and 1997. The soil organic matter diminished with 50 percent in the irrigated areas from 1975 to the irrigated areas of 1997. Also, the soil organic matter decreased 30 percent between the non-irrigated areas of 1975 and the irrigated areas of 1997. According to the data of this study, the soil organic matter was affected by the irrigation practices from 1975 to 1997, because under wetting and drying of soils, microbial activity increased and more decomposition of SOM occurred.

- Soil pH increased significantly from irrigated and non-irrigated lands in 1975 to irrigated areas in 1997. The soil pH values of irrigated areas increased 5.6 percent from 1975 to 1997. Also, soil pH values raised 4.1 percent when pH values of non-irrigated soils in 1975 were compared with those of irrigated areas in 1997. In theory, this soil property was raised throughout this time due to the salts deposited by irrigation water.

Table 1. Mean comparison analysis for soil parameters in the study area.

Mean1†	Mean2‡	ρ > | t |	Conclusion
SOM75i = 0.9 (%)	SOM97i = 0.4 (%)	0.0001	**
SOM75ni = 0.6 (%)	SOM97i = 0.4 (%)	0.056	*
SOM75ni =0.6 (%)	SOM97ni = 0.8 (%)	0.06	ns
pH75i = 8.0	pH97i = 8.4	0.00001	**
pH75ni = 8.1	pH97i = 8.4	0.0001	**
pH75ni = 8.1	pH97ni = 8.4	0.0001	**
CEC75i = 23.7 ($cmol_c$ kg^{-1})	CEC97i = 21.2 ($cmol_c$ kg^{-1})	0.01	**
CEC75ni = 25.3 ($cmol_c$ kg^{-1})	CEC97i = 22.7 ($cmol_c$ kg^{-1})	0.01	**
CEC75ni =25.3 ($cmol_c$ kg^{-1})	CEC97ni = 21.2 ($cmol_c$ kg^{-1})	0.0003	**
EC75i = 3.6 (dS m^{-1})	EC97i = 3.9 (dS m^{-1})	0.57	ns
EC75ni =12.6 (dS m^{-1})	EC97i = 3.9 (dS m^{-1})	0.0001	**
EC75i = 3.6 (dS m^{-1})	EC97ni = 3.1 (dS m^{-1})	0.32	ns

† 75 = year 1975, i, ni = irrigated and non-irrigated areas. ‡ 97 = year 1997; ** highly significant at α = 99%; *significant at α = 95%; ns = not significant.

Table 2. Summary and hypotheses of parameters in non-irrigated and irrigated soils.

Results		Hypothesis
1. Non-irrigated soils *versus* irrigated soils in 1975		
a) SOM	Highest value in irrigated.	More biomass production in irrigated areas than arid environment (Bowman *et al.*, 1999).
b) pH	Highest value in non-irrigated.	More soluble salt because leaching occurred in irrigated soils.
c) CEC	Slightly higher value in non-irrigated.	Charge is pH dependent (Bell, 1993).
d) EC	Highest value in non-irrigated.	Before 1975, 10 000 m^3 ha^{-1} water were applied to irrigated soils and the salts were leached (Wienhold and Trooien,1975).
2. Non-irrigated soils *versus* irrigated soils in 1997		
a) SOM	Highest value in non-irrigated.	In irrigated areas optimal microbial conditions are generated. There is more decomposition of SOM than in non-irrigated (Lado *et al.*, 2004).
b) pH	Slightly higher in irrigated.	More salt accumulation with irrigation water.
c) CEC	Slightly higher in irrigated.	Changes because is pH dependent.
d) EC	Highest value in irrigated.	The salt concentration in the soil profile was increased with the irrigation practices (Wienhold and Trooien, 1995).

Table 3. Changes in soil properties after 22 years and hypotheses.

Results		Hypothesis
1. Non-irrigated soils in 1975 *versus* irrigated soils in 1997		
a) SOM	Decreased from 0.6 to 0.4. Significant differences.	Soils under cultivation using irrigation and tillage generate optimal conditions for decomposition of SOM (Ortega *et al*., 2002).
b) pH	Increased from 8.1 to 8.4. Significant differences.	Soluble salt accumulation (rich in carbonates) with the water application through time is one of the causes that increased pH (Paliwal and Gandhi, 1973; Presley *et al*., 2004).
c) CEC	Decreased from 25.3 to 22.7 $cmol_c$ kg^{-1}. Highly significant differences.	One of the mayor components of soil CEC is SOM, which decreased. Thus the CEC values decreased too.
d) EC	Decreased from 12.6 to 3.9 dS m^{-1}. Highly significant differences.	Land reclamation of 1975 decreased salinity levels in irrigation lands. Highly levels of salinity were showed in non-irrigated areas before 1975 because sometimes these soils were only wet.
2. Irrigated soils in 1975 *versus* irrigated in 1997		
a) SOM	Decreased from 0.9 to 0.4 %. Highly significant differences.	Wetting and drying of the soil by irrigation, cultivation and tillage activities increase microbial activity and reducing SOM (Quiroga *et al*., 1998).
b) pH	Increased from 8.0 to 8.4. Highly significant differences.	Irrigation practices have increased the pH level with the increment of soluble salts throughout time (Bordovsky *et al*., 1999).
c) CEC	Decreased from 24.8 to 22.7 $cmol_c$ kg^{-1} Significant differences.	Because SOM decreased, CEC decreased (Bordovsky *et al*., 1999).
d) EC	Increased from 3.6 to 3.9. It does not have significant differences.	The small increment is due to the additional salt applied with irrigation water (Costa *et al*., 1991).
3. Non-irrigated soils in 1975 *versus* non-irrigated soils in 1997		
a) SOM	Slightly increased from 0.6 to 0.8%. It did not have statistical differences.	The small increment is because the arid environment is not adequate for SOM development.
b) pH	Increased from 8.1 to 8.4. Highly significant differences.	Different from expected results because according to EC and SOM results should decrease in 1997 (Billet *et al*., 1990).
c) CEC	Decreased from 25.3 to 21.2 $cmol_c$ kg^{-1}. Highly significant differences.	Different from expected results. Small increase of SOM should increase CEC (Crescimanno *et al*., 1995).
d) EC	Decreased from 12.1 to 3.1 dS m^{1}. Highly significantly differences.	This decrement perhaps was caused by the land reclamation actions in 1975 (SAGARPA, 2002).

- The electrical conductivity did not show consistency in the results. This soil variable did not present significant changes through time for irrigated areas from 1975 to 1997. However, the electrical conductivity values from non-irrigated areas in 1975 were statistically higher than those from irrigated areas in 1997. This conclusion may be explained that after 1975 a rehabilitation of the irrigation district was realized and this included saline and sodic soil reclamation. This explains that the electrical values of non-irrigated lands of 1997 were significantly lower than those of 1975.

- The soil cation exchange capacity parameter showed highly significant differences in mean values from 1975 to 1997. The average value of irrigated areas in 1975 was significant higher than the mean value of irrigated areas in 1997. Also, the values significantly diminished from non-irrigated areas in 1975 to irrigated areas in 1997. The hypothesis that explains both situations is that the organic matter decreased from 1975 to 1997. It is recommended for more precise work to take soil samples through time in the same geographic position in which control plots are compared with treated plots of similar soil types. This would eliminate a significant source of sampling error.

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