Solid Earth Discuss., 7, 91–114, 2015
www.solid-earth-discuss.net/7/91/2015/
doi:10.5194/sed-7-91-2015

Solid Earth
Discussions
Open Access

Evaluating management-induced soil salinization in golf courses in semi-arid landscapes

J. Young[1], T. K. Udeigwe[1], D. C. Weindorf[1], T. Kandakji[1], P. Gautam[1], and M. M. A. Mahmoud[2]

[1]Department of Plant and Soil Science, Texas Tech University, Lubbock, TX 79409, USA
[2]Soil, Water & Environment Research Institute (SWERI), Giza, Egypt

Received: 2 November 2014 – Accepted: 11 November 2014 – Published: 13 January 2015

Correspondence to: T. K. Udeigwe (theo.udeigwe@ttu.edu)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Site-specific information on land management practices are often desired to make better assertions of their environmental impacts. A study was conducted in Lubbock, TX, in the Southern High Plains of the United States, an area characterized by semi-arid climatic conditions, to (1) examine the potential management-induced alteration in soil salinity indicators in golf course facilities and (2) develop predictive relationships for a more rapid soil salinity examination within these urban landscape soils using findings from portable x-ray fluorescence (PXRF) spectrometer. Soil samples were collected from the managed (well irrigated) and non-managed (non irrigated) areas of seven golf course facilities at 0–10, 10–20, and 20–30 cm depths, and analyzed for a suite of chemical properties. Among the extractable cations, sodium (Na) was significantly ($p < 0.05$) higher in the managed zones of all the golf facilities. Soil electrical conductivity (EC), exchangeable sodium percentage (ESP), and sodium adsorption ratio (SAR), parameters often used in characterizing soil salinity and sodicity, were in most part significantly ($p < 0.05$) higher in the managed areas. Water quality report collected over a 22-year period (1991–2013, all years not available) indicated a gradual increase in pH, EC, SAR, total alkalinity, and extractable ions, thus, supporting the former findings. Findings from the PXRF suggested possible differences in chemical species and sources that contribute to salinity between the managed and non-managed zones. PXRF quantified Cl and S, and to a lesser extent Ca, individually and collectively explained 23–85 % of the variability associated with soil salinity at these facilities.

1 Introduction

Soil salinization is a global environmental problem that has gained a lot of research attention over the years (Pitman and Läuchli, 2002; Martinez-Beltran and Manzur, 2005; Herrero and Pérez-Coveta, 2005; Fan, 2012). Site-specific research on soil salinization are often needed because generalization of findings could be misleading.

The Southern High Plains (SHP) of the United States (US), an area characterized by semi-arid climatic conditions (Peel et al., 2007), is noted for complex environmental challenges such as drought, dust, wind erosion, soil salinization, and nutrient deficiency. Nevertheless, in this region lie very important economic cities, such as Lubbock that substantially contributes to US cotton production (USDA-NASS, 2014). Lubbock, located in the northwestern part of Texas, among other environmental challenges is currently plagued by extreme water scarcity, attributed to low precipitation (a 30 year average annual precipitation of approximately 470 mm) and the declining local aquifer, the Ogallala. Recent observations have also shown an increasing pollutant concentration in well waters (Scanlon et al., 2005), therefore, a concern over the water quality of the aquifer. Thus, the intensification of agricultural and municipal activities could have a substantial impact on water quantity and soil quality in this region.

Given the chemical properties of soils in the semi-arid and arid regions, which are typified by high pH (> 7.0) and the relatively higher level of soluble salts (IUSS Working Group, 2006), poor management practices could lead to soil salinization. As can be evidenced from most semi-arid and arid regions of the world, the unavailability of sufficient rainfall is often associated with impaired soil quality as salts tend to accumulate in the soil as a result of limited leaching. This could result to soil salinization; a process where salts build up in the soil to a potentially toxic level (Pitman and Lauchli, 2002; Rengasamy, 2006). Such altered chemical properties could affect the soil hydraulic properties and its susceptibility to erosion (Morgan, 2009), environmental fate of soil pollutants (Du et al., 2009), and nutrient availability to agronomic crops (Havlin et al., 2005). Poor quality irrigation water could also worsen such scenarios as more contaminants from the water are continuously added; a typical case being the declining Ogallala aquifer, which has been noted as a potential source of arsenic (As) and nitrate (NO_3^-) to irrigated agricultural soils in the SHP (Hudak, 2000; Scanlon et al., 2005). Although a common topic, but there are still very limited scientific reference materials on soil salinization in agricultural and urban landscapes in the study area.

The first approach to addressing environmental degradations resulting from contaminations is usually the identification of the major contributors. Evidently, in this region, management (irrigation)-induced soil salinization has received less attention, particularly within urban landscape facilities such as golf courses, despite its severity. Golf courses are major users of irrigation water per unit area; a typical 18-hole golf facility in Southwest region could use an average of approximately 1200 mm yr^{-1} of water (USGA, 2012) compared to 600 mm yr^{-1} for a fully irrigated cotton in the same region (Snowden et al., 2013). Thus, in assessing the potential impact of impaired water quality on soil and other environmental media in any setting, it will be logical to examine the contributions of major irrigation water users in that given region of interest. With the increasing severity of environmental degradation in the SHP region, it will be of great interest to attempt to extend the applications of modern tools such as the portable x-ray fluorescence (PXRF) for a more rapid investigation of environmental contamination, particularly relating to soil salinization in golf course facilities. This tool is gaining importance in the fields of soil and environmental sciences (Weindorf et al., 2012; McWhirt et al., 2012; Gardner et al., 2013; Hu et al., 2014; Weindorf et al., 2014). Swanhart et al. (2015) demonstrated the utility of using PXRF for soil salinity determination. This approach was further refined by Aldabaa et al. (2015) who coupled PXRF data with visible near infrared diffuse reflectance spectra as well as hyperspectral satellite data for improved measurement of salinity in playas of West Texas, USA. The proposed study serves as an attempt to extend the application of the PXRF to soil salinization prediction in urban landscapes of the semi-arid climates. Already, PXRF has been extended to gypsum determination (Weindorf et al., 2013) in arid environments

We hypothesize that there will be significant differences in key chemical properties between managed and non-managed areas of golf course facilities. This was deduced from the fact that in addition to the unique management practices of golf course facilities such as perennial monoculture, less soil pulverization, and extended irrigation window, the managed zones are frequently irrigated and would reflect the state of the irrigation water quality. Given the semi-arid climatic condition of the study area and the characteristically alkaline nature of the soils, these hypothesized differences could be more obvious in their salinity and/or sodicity properties. Thus, the objective of this study were to (1) examine the possible management-induced changes in soil chemical properties, particularly those significant to salinization, within golf course facilities in a semi-arid climate, and (2) develop predictive relationships for a more rapid soil salinity examination within these urban landscape soils using findings from PXRF.

2 Materials and methods

2.1 Study site description

This study was conducted in Lubbock, Texas, USA. Lubbock lies within 33°34′ N, 101°53′ W and sits on an elevation of 990 m a.s.l. (USGS, 2014). To achieve our objectives, seven golf course facilities spread all over the city were selected for this study. Figure 1 shows the locations of the selected facilities, which are designated as A, B, C, D, E, F, and G. Using web soil survey, soil types at the sites were broadly identified to belong to the Amarillo series (Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) and Acuff series (Fine-loamy, mixed, superactive, thermic Aridic Paleustolls). The average golf course contains 10 to 12 ha of irrigated fairways. All managed fairways were planted with hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) while the non-managed areas were composed of poorly managed grass cover, native vegetation, or bare soil.

2.2 Soil sampling and handling

The fairways which are consistently irrigated were designated as the “managed areas”, whereas adjacent areas of similar soil types that are not irrigated or managed were designated as the “non-managed areas” in each facility. In each area, core samples were randomly collected using a 30 cm long × 6 cm wide (diameter) core sampler and then separated into three depths of 0–10, 10–20, and 20–30 cm, then samples from same depth were combined to get a representative sample. Collected soil samples were then transported to the lab, air dried, ground and passed through a 2 mm sieve.

2.3 Soil characterization

Soil samples were analyzed for a suite of chemical properties. Soil electrical conductivity (EC) and pH were measured in a 1 : 2 solid (soil) to water suspension (Rhoades, 1996). Total carbon (C) and nitrogen (N) were analyzed using a TruSpec C/N analyzer (LECO, St Joseph, MI). Organic matter (OM) was determined using a modified Walkley and Black method (Nelson and Sommers, 1996), using sodium (Na) dichromate and read on Gilford unit. Percent calcium carbonate ($CaCO_3$) was determined by the tensimeter approach (Soil Survey Staff, 1996); a modification of the pressure calcimeter approach (Loeppert and Suarez, 1996). Exchangeable Na, calcium (Ca), magnesium (Mg) and potassium (K) were measured in ammonium acetate extract (Soil Survey Staff, 2009) using atomic absorption spectrometer (AAS) (Spectra AA 220, Varian, Palo Alto, California). Exchangeable sodium percentage (ESP) was calculated using measured exchangeable cation values (Sparks, 2003). Sodium adsorption ratio (SAR) was determined using the established relationship between ESR and SAR of saturated extract developed by US Salinity Laboratory (Richards, 1954; Sparks, 2003). For the purpose and scope of this study, water-extractable chloride (Cl^-) and bicarbonate (HCO_3^-) were measured in 1 : 5 soil water extract and Cl^- concentration determined by titration with 0.005 M silver nitrate ($AgNO_3$) standard following Mohr titration approach (Soil Survey Staff, 1996), and HCO_3^- by titration with 0.01 M sulfuric acid (H_2SO_4) (Soil Survey Staff, 1996).

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀◀ ▶▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

2.4 PXRF scanning

Collected samples were scanned using a PXRF (DP-6000 Delta Premium, Olympus, Waltham, MA, USA) equipped with a Rh-X-ray tube which is operated at 10–40 kV with integrated silicon drift detector (165 eV) (USEPA, 2007). The tool was operated in the Soil Mode to measure a suite of elements, among which only Cl, K, S, and Ca were selected for our purpose. Importantly, PXRF is not able to quantify Na, given its small, stable electron cloud. Soil mode consist of three beams operating sequentially, each set to scan for 30 s for a total scan time of 90 s per sample. Calibration of the instrument was conducted before sample analysis using a 316 alloy chip fitted to the aperture. Each soil sample was scanned in triplicate and the average value reported. The data on elemental concentration and limit of detection (LOD) (three times the standard error) were obtained and compiled.

2.5 Water quality

Water quality reports were obtained from the various golf course facilities, where available. Since the facilities pump from the same groundwater source, the available reports were enough to achieve the objectives of this study. In summary, 12 years (1991–2013, not all years were included) of data were provided by one of the facilities, 2 years by another (2009–2010), 1 year each (2011 and 2013) by the remaining 2 facilities. The data sets broken down by water sources were: well (12 years of data), retention pond (3 years) and recycled wastewater (1 year). Water quality parameters reported include, EC, pH, SAR, Na, Mg, K, Ca, HCO_3^-, S in SO_4^{2-}, Cl^-, and total alkalinity.

2.6 Statistical analyses

All statistical analyses were performed using the Statistical Analysis Software (SAS 9.3, SAS Institute, Cary, NC). Differences among means were examined using PROC

GLM. Single and multiple linear regression analyses using the stepwise technique were performed using the PROC REG procedure to establish the relationships among parameters.

3 Results and discussions

3.1 Soil pH, $CaCO_3$, and OM

Table 1 summarizes the differences in soil pH, % $CaCO_3$ and % OM between the managed and non-managed areas of each golf course facility. Salinity parameters will be discussed separately (see Sect. 3.2). The results indicated little differences in mean pH (range = 7.7–8.8, mean = 8.25, $n = 42$) between managed and non-managed areas of all the courses examined (Table 1). The differences in means between managed and non-managed areas at each facility ranged between 0.1–0.3 pH units and there was no consistent trend observed between the areas. However, these differences were significant ($p < 0.05$) in three (B, C and F) of the seven facilities. Percent $CaCO_3$ (range = 0.09–15.7 %, mean = 3.01, $n = 42$) showed no definite trend with depth and no consistent differences between managed and non-managed areas (Table 1). Although not significantly different, % $CaCO_3$ was higher in the non-managed zones of 4 (D, E, F, and G) of the 7 courses examined. Organic matter (range = 0.2–3.3 %, mean = 0.9, $n = 42$) tended to be higher in the managed areas as was observed in 6 (A, B, C, D, F and G) out of the 7 sites, although these were not statistically significant. The higher values observed in the managed zones could be attributed to more biomass (Havlin et al., 2005) resulting from better management. The exact same trend observed for soil OM also reflected in the soil TC as well as TN which could be influenced by N fertilizer additions and N in irrigation water. Apart from OM, TC, and TN, there was no consistent trend between managed and non-managed areas at these set of facilities examined. The lack of significant differences between managed and non-managed zones for most of the examined soil properties reported here somewhat indicates there are no major external sources of these introduced through irrigation or other management activities.

3.2 Extractable ions and salinity parameters

Table 2 summarizes the differences in selected extractable ions and some salinity indicators between managed and non-managed sites at each golf course. Among the extractable cations (Ca, K, Mg, and Na), Na (range = 37–407 $\mathrm{mg\,kg^{-1}}$, mean = 167 $\mathrm{mg\,kg^{-1}}$, $n = 42$) was significantly higher ($p < 0.05$) in the managed zone of each facility. This finding could somewhat be attributed to the Na contained in the irrigation water originating mainly from groundwater sources (see Sect. 3.3) because Na is not typically added through fertilization. Exchangeable Ca (range = 1360–5477 $\mathrm{mg\,kg^{-1}}$, mean = 2968 $\mathrm{mg\,kg^{-1}}$, $n = 42$) was higher in the non-managed zones of six (A to F) of the seven facilities, and this finding was significant ($p < 0.05$) at 3 of the facilities. This observed difference could be attributed to the possible leaching of Ca (possibly in the form of sulfates and chlorides) from the more frequently irrigated areas. Extractable Mg (range = 145–1381 $\mathrm{mg\,kg^{-1}}$, mean = 738 $\mathrm{mg\,kg^{-1}}$, $n = 42$) and K (range = 215–1491 $\mathrm{mg\,kg^{-1}}$, mean = 587 $\mathrm{mg\,kg^{-1}}$, $n = 42$) were found to be higher in the irrigated areas of six of the seven and five of the seven examined facilities, respectively, with significant differences ($p < 0.05$) observed in some facilities (Table 2). The higher levels of these elements in the managed areas is likely due to their addition to the soil from irrigation water (see Sect. 3.3) because they are not typically added through fertilization in this region. In general, the chloride salts of Ca are more soluble than those of Mg and K, while the sulfate salts of Mg and K are more soluble than those of Ca, and carbonate salts are generally insoluble (Clugston and Flemming, 2000). Thus, using their solubility characteristics, it could be inferred that Na, Mg, and K in these soils could be more of carbonate salts because they will be less soluble and thus mildly leached by irrigation water. Conversely, Ca which tended to be more susceptible to leaching from these irrigated zones could be predominantly in the form of chloride salts of Ca. The slight positive relationship ($R^2 = 0.65$, $p < 0.05$, $n = 42$) observed between Na and Cl^- could suggests the presence of chloride salts of Na as well.

The water extractable anions examined revealed that HCO_3^- (range = 77.6–326 mg kg^{-1}, mean = 170, $n = 42$) and Cl^- (range = 0–604 mg kg^{-1}, $n = 42$) were mostly higher in the managed areas compared to the non-managed areas, some of which were significantly different (Table 2). The only exception was HCO_3^- in facility F. The higher levels of these anions in the managed zones of these facilities could be attributed to their addition to the soil from irrigation water sources. The dominant anions in the soil solution of most semi-arid salty soils are Cl^-, SO_4^{2-}, HCO_3^- (at pH values of 6.0–8.0) and some NO_3^- (Dierickx, 2013). Thus, significant increases in these ions could reflect a shift toward soil salinization. In this study, less emphasis was placed on soil SO_4^{2-}, NO_3^-, and PO_4^{3-} concentrations because these are commonly added through fertilization and thus, possible contribution from irrigation sources would not be easily quantified.

The potential contribution of the management practices to salinity and sodicity could be evidenced from the examination of the soil EC (range = 0.15–2.28 dS m^{-1}, mean = 0.643, $n = 42$), ESP (range = 0.80–7.10 %, mean = 3.20 %, $n = 42$) and SAR (range = 1.40–6.04, mean = 3.12, $n = 42$) values. It is apparent that the practices at the facilities and possibly irrigation water tended to increase the salinity and sodicity properties of these soils. This is supported by the significantly higher EC, ESP and SAR values generally observed in the managed areas of these facilities (Table 2). A comparison was made among depths to examine the distribution of EC, ESP, and SAR between all managed and non-managed sites (Fig. 2). When all the managed zones were grouped and compared against the non-managed zone, at each depth, the salinity parameters were significantly higher in the managed zones, suggesting the effects were similar within all the depths examined. Besides irrigation, this shift toward salinization is further supported by the semi-arid condition of the study site, characterized by low rainfall and less leaching of the soluble salts, leading to their build up in the top soil.

3.3 Influence of local aquifer water quality

The water quality reports obtained from the facilities are summarized in Table 3. Of interest, the concentration of each parameter examined (with the exception of pH) was on the average approximately 2-folds higher in the well water compared to the retention pond, which is mainly a collection of runoff and rain water (Table 3). These differences could be most likely attributed to the possible settling of pollutants at the bottom of the pond and likely uptake by vegetation in the reservoir. The concentrations of the examined parameters in the effluent treated water were 2–11 folds higher than those of the well water. Using the water quality information, pollutant addition to soil from the water sources could be estimated. For instance, using the average values of contaminants in the well water, approximately 5.60 g Cl^-, 7.60 g SO_4^{2-}, 9.0 g HCO_3^- and 3.80 g Na^+ will be added to 1.0 kg of the receiving soil over a 10-year period if a field receives approximately 120 cm year^{-1} of irrigation water from well sources in this area. The limited rainfall and thus minimal leaching of salts in the semi-arid and arid areas could make the situation described above more realistic.

The well water quality, which is a better representation of that of the local aquifer was further examined. The available data were grouped into three sets: 1991–1993, 2004–2008, and 2009–2013, and the average values for each parameter in a set calculated. A striking feature observed was the gradual increase in pH, EC, SAR, total alkalinity, Na, K, HCO_3^- and Cl^- over the years (Fig. 3), suggesting that the declining aquifer (Terrel et al., 1999, 2002) could be associated with an increase in contaminant concentration, particularly salts. Using the mean values, the $Na^+ : Ca^{2+}$ ratio of approximately 2 : 1 in the well water sources justifies the higher SAR and ESP in the managed areas that are irrigated using water from well sources. This ratio is higher than those of recycled wastewater (1.5 : 1) and ditch water (1 : 1) reported by Qian and Mecham (2005) that still impacted higher SAR in soils after years of irrigation in Denver and Fort Collins, Colorado. Thus, our findings suggest that continuous irrigation with well water could increase the salt contents of the receiving soils overtime, a situation that is already apparent in the managed zones of the facilities examined in this study as discussed under Sect. 3.2. The water quality data and the observed differences in salinity parameters between managed (irrigated) and non-managed (non-irrigated) areas establish a possible influence of the aquifer water quality on soil quality at these facilities.

3.4 Application of PXRF to salinity prediction

The PXRF quantified Ca, Cl, K, and S were individually and collectively used to explain the variability associated with salinity, approximated using EC. The findings are presented in Table 4. As evidenced from the R^2 values, when all the sites were considered ($n = 42$), approximately 70 % of the variability associated with salinity was explained by the Cl alone, 82 % by Cl and S, and 85 % by Cl, S, and K. The findings here suggest the likely contributions of salts of Cl^- and SO_4^{2-} to soil salinity within these facilities. When studied individually, the strengths of these relationships were notably higher within the managed area ($n = 21$) compared to the non-managed area ($n = 21$) (Table 4) as evidenced from R^2 average of 0.72 (managed) vs. 0.29 (non managed) for all the relationships examined. The stronger relationships observed within the managed group support part of our hypothesis that salinity (EC) is influenced by anthropogenic sources, thus, the more the input of these cation and anion-forming elements through irrigation, fertilization, etc., the higher the salinity. The weaker relationships observed within the non-managed group suggest a limited influence of the anthropogenic sources of the elements (particularly Cl and S), further suggesting that salinity could be controlled by other parameters that were not accounted for by the PXRF. From this information, it can be inferred that the chemistry of salinity, i.e., the elemental species contributing to it, could be different within the managed and the non-managed groups. This is an important piece of information that was rapidly obtained using the PXRF.

Overall, the relationships developed when all data points (managed and non-managed) were collectively considered suggest that the PXRF could be used for rapid in situ prediction of salinity in the semi-arid urban soils, an application that could be extended to other semi-arid regions. Although, it is important to note that the capability of this tool is still limited since the contributions of some elements such as Na, and anions such as HCO_3^- and CO_3^{2-} cannot be ascertained yet.

4 Conclusions

The impacts of management practices on environmental quality could vary with climate and thus, site-specific investigations are often desired because extrapolation of findings among practices and locations could be misleading. Thus, this study, serves as an initial probe into the potential management-induced changes in soil chemical properties with a focus on salinity parameters of golf courses in Lubbock, TX, located in the SHP of the USA. This is an area characterized by semi-arid climatic conditions, typified by drought, wind erosion, salinization, etc. Evaluation of soil chemical properties of managed (irrigated) and non-managed (non-irrigated) areas at seven different golf course facilities and information on well water quality revealed possible differences in soil properties. The major findings are summarized as thus: (1) among the exchangeable cations, Na was significantly higher in all the managed and well irrigated zones of all the seven golf courses in the semi-arid region of the USA, suggesting the addition of Na salts (possibly in the forms of carbonates and chlorides) to irrigated soils from irrigation water sources. (2) Irrigation tended to increase the salinity and sodicity properties of the soils as evidenced from the significantly higher Soil EC, ESP and SAR observed in majority of the managed areas compared to the non-managed areas. This finding was supported by the water quality data of the local aquifer which showed an increase in pH, EC, SAR, total alkalinity, and extractable ions over the years. (3) The PXRF quantified Cl and S, and to a lesser extent Ca, individually and collectively explained most of the variability associated with salinity within the soils of these facilities. The strengths of the relationships were generally higher in the managed area.

Although in the SHP and other semi-arid and arid regions, the emphasis is more on water quantity; however, it is important to point out that salt build up can affect water quantity, by altering the hydrological properties of soils such as hydraulic conductivity, infiltration, permeability, water holding capacity and thus water availability to crops. This study was an initial investigation into an observed environmental issue and findings will support future research effort in the subject area.

Author contributions. J. Young and T. K. Udeigwe planned and implemented the study. T. Kandakji and P. Gautam assisted in field and laboratory activities. M. A. Mahmoud suggested ideas and assisted in various aspect of the project as needed.

References

Aldabaa, A. A. A., Weindorf, D. C., Chakraborty, S., Sharma, A., and Li, B.: Combination of proximal and remote sensing methods for rapid soil salinity quantification, Geoderma, 239–240, 34–46, 2015.
Clugston, M. and Flemming, R.: Advanced Chemistry, Oxford University Press, Oxford, UK, 2000.
Dierickx, W.: The salinity and alkalinity status of arid and semi-arid lands, Land Use, Land Cover and Soil Sciences V, 163–189, 2013.
Du Laing, G., Rinklebe, J., Vandecasteele, B., Meers, E., and Tack, F. M. G.: Trace metal behaviour in estuarine and riverine floodplain soils and sediments: a review, Sci. Total Environ., 407, 3972–3985, 2009.
Fan, X., Pedroli, B., Liu, G., Liu, Q., Liu, H., and Shu, L.: Soil salinity development in the yellow river delta in relation to groundwater dynamics, Land Degrad. Dev., 23, 175–189, 2012.
Gardner, D., Weindorf, D. C., and Flynn, M.: Presence of chromium, copper, and arsenic in schoolyard soils, Soil Horizons, 54, 1–5, doi:10.2136/sh12-12-0032, 2013.
Havlin, J. L., Beaton. J. D., Tisdale, S. L., and Nelson, W. L.: Soil fertility and fertilizers: an introduction to nutrient management, Vol. 515, Pearson Prentice Hall, Upper Saddle River, NJ, 2005.
Herrero, J. and Pérez-Coveta, O.: Soil salinity changes over 24 years in a Mediterranean irrigated district, Geoderma, 125, 287–308, 2005.

Hu, W., Huang. B., Weindorf, D. C., and Chen, Y.: Metals analysis of agricultural soils via portable X-ray fluorescence spectrometry, B. Environ. Contam. Tox., 92, 420–426, 2014.

Hudak, P. F.: Distribution and sources of arsenic in the southern high plains aquifer, Texas, USA, J. Environ. Sci. Heal. A, 35, 899–913, 2000.

IUSS Working Group WRB: World Reference Base for Soil Resources, 2nd edn., World Soil Resources Reports No. 103, FAO, Rome, ISBN 92-5-105511-4, 2006.

Loeppert, R. H. and Suarez, D. L.: Carboante and gypsum, in: Methods of Soil Analysis, Part 3, Chemical Methods, edited by: Bartels, J. M. and Bigham, J. M., Soil Science Society of America, Inc., Madison, USA, SSSA Book Series 5, 437–474, 1996

Martinez-Beltran, J. and Manzur, C. L.: Overview of salinity problems in the world and FAO strategies to address the problem, in: Proceedings of the international salinity forum, Riverside, California, 311–313, 2005

McWhirt, A., Weindorf, D. C., and Zhu, Y.: Rapid analysis of elemental concentrations in compost via portable x-ray fluorescence spectrometry, Compost Sci. Util., 20, 185–193, 2012.

Morgan, R. P. C.: Soil Erosion and Conservation, Blackwell Publishing, Oxford, UK, 2009

Nelson, D. W. and Sommers, L. E.: Total carbon, organic carbon, and organic matter, in: Methods of Soil Analysis, Part 3, Chemical Methods, edited by: Sparks D. L., Soil Science Society of America Book Ser. 5, SSSA and ASA, Madison, Wis., 961–1010, 1996.

Peel, M. C., Finlayson, B. L., and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 11, 1633–1644, doi:10.5194/hess-11-1633-2007, 2007.

Pitman, M. G. and Läuchli, A.: Global impact of salinity and agricultural ecosystems, in: Salinity: Environment-Plants-Molecules, Springer Netherlands, Part A, 3–20, doi:10.1007/0-306-48155-3_1, 2002.

Qian, Y. L. and Mecham, B.: Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways, Agron. J., 97, 717–721, 2005.

Rengasamy, P.: World salinization with emphasis on Australia, J. Exp. Bot., 57, 1017–1023, 2006.

Rhoades, J. D.: Salinity: electrical conductivity and total dissolved solids, in: Methods of Soil Analysis, III, Chemical Methods, edited by: Sparks, D. L., SSSA, Madison, WI, 417–435, 1996.

Richards, L. A.: Diagnosis and Improvement of Saline and Sodic Soils, USDA Agric. Handb. 60, USDA, Washington, DC, 1954.

Scanlon, B. R., Nicot, J. P., Reedy, R. C., Tachovsky, J. A., Nance, S. H., Smyth, R. C., Keese, K., Ashburn, R. E., and Christian, L.: Evaluation of arsenic contamination in Texas, The Univ. of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Commission on Environmental Quality, under umbrella contract no. 582-4-56385 and work order no. UT-08-5-70828, 177, p. 167, 2005.

Snowden, C., Ritchie, G., Cave, J., Keeling, W., and Rajan, N.: Multiple irrigation levels affect boll distribution, yield, and fiber micronaire in cotton, Agron. J., 105, 1536–1544, 2013.

Soil Survey Staff: Chemical analyses, calcium carbonate (4E) HCl treatment (4E1) manometer, electronic (4E1) < 20 mm basis (4E), in: Soil Survey Laboratory Manual, USDA-NRCS SSRI #42, Version 4.0, 269–273, 1996.

Soil Survey Staff: Soil Survey Field and Laboratory Methods Manual, Soil Survey Investigations Report No. 51, Version 1.0, edited by: Burt, R., U.S. Department of Agriculture, Natural Resources Conservation Service, 2009.

Sparks, D. L.: Environmental Soil Chemistry, Academic Press, San Diego, California, 2003.

Swanhart, S., Weindorf, D. C., Chakraborty, S., Bakr, N., Zhu, Y., Nelson, C., Shook, K., and Acree. A.: Measuring soil salinity via portable x-ray fluorescence spectrometry, Soil Sci., in press, 2015.

Terrell, B. L. and Johnson, P. N.: Economic impact of the depletion of the Ogallala aquifer: a case study of the southern high plains of Texas, in: American Agricultural Economics Association annual meeting, Nashville, TN, 8–11 August 1999.

Terrell, B. L., Johnson. P. N., and Segarra, E.: Ogallala aquifer depletion: economic impact on the Texas high plains, Water Policy, 4, 33–46, 2002.

U.S. Environmental Protection Agency: Method 6200: Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment, USEPA, 2007.

USDA-NASS: Cotton ginning 2013 summary, available at: http://usda.mannlib.cornell.edu/usda/current/CottGinnSu/CottGinnSu-05-09-2014.pdf (last access: 9 July 2013), 2014.

USGA: How Much Water Does Golf Use and Where Does It Come From?, available at: http://www.usga.org/uploadedFiles/USGAHome/Course_Care/Golf_and_the_Environment/Water/214418%20Lyman,%20Greg%20-%20How%20Much%20Water%20Does%20Golf%20Use.pdf (last access: 11 April 2014), 2012.

USGS: National Elevation Dataset, available at: http://ned.usgs.gov/ (last access: 28 March 2014), 2014.

Weindorf, D. C., Zhu, Y., Chakraborty, S., Bakr, N., and Huang, B.: Use of portable X-ray fluorescence spectrometry for environmental quality assessment of peri-urban agriculture, Environ. Monit. Assess., 184, 217–227, 2012.

Weindorf, D. C., Herrero, J., Castañeda, C., Bakr, N., and Swanhart, S.: Direct soil gypsum quantification via portable x-ray fluorescence spectrometry, Soil Sci. Soc. Am. J., 77, 2071–2077, 2013.

Weindorf, D. C., Bakr, N., and Zhu, Y.: Advances in portable x-ray fluorescence (PXRF) for environmental, pedological, and agronomic applications, Adv. Agron., 128, 1–45, 2014.

Table 1. Selected soil properties examined at the managed and non-managed areas of the seven golf facilities in Lubbock, TX, USA.

Golf Course	Management	Irrigation Source	pH	$CaCO_3$ %	TC %	TN %	OM %
A	Managed	Well	8.2a	1.1a	1.88a	0.19a	1.5a
	Non-managed		8.1a	0.2b	0.77a	0.07a	0.7a
B	Managed	Well	8.3b	8.8a	2.31a	0.14a	1.0a
	Non-managed		8.4a	4.5a	1.20b	0.07a	0.5a
C	Managed	Well	8.2b	1.9a	1.68a	0.13a	1.2a
	Non-managed		8.5a	1.2a	0.89a	0.07a	0.5a
D	Managed	Well	8.6a	0.5a	0.87a	0.08a	0.8a
	Non-managed		8.6a	0.7a	0.47a	0.03a	0.3a
E	Managed	Well	8.2a	4.6a	2.24a	0.18a	1.1a
	Non-managed		7.9a	6.4a	2.96a	0.22a	1.3a
F	Managed	Well and RW	8.0a	0.7a	1.91a	0.18a	1.3a
	Non-managed		8.1b	1.6a	1.57a	0.13a	0.9a
G	Managed	Surface and Well	8.1a	4.2a	2.86a	0.21a	1.5a
	Non-managed		8.3a	4.7a	1.48a	0.06a	0.7a

TC, total carbon; TN, total nitrogen; OM, organic matter; RW, recycled wastewater. Mean values in a column within a golf course with the same letter are not statistically different (Fisher's LSD, $\alpha = 0.05$).

Table 2. A summary of extractable ions and soil salinity parameters for the managed and non-managed areas of the seven golf facilities in the study in Lubbock, TX, USA.

			$\mathrm{NH_4}$-Acetate Extractable				Water Extractable				
Golf Course	Management	Irrigation Source	Na^{+} mg kg^{-1}	Ca^{2+} mg kg^{-1}	Mg^{2+} mg kg^{-1}	K^{+} mg kg^{-1}	HCO_3^{-} mg kg^{-1}	Cl^{-} mg kg^{-1}	EC µs cm^{-1}	ESP %	SAR
A	Managed	Well	271a	2165a	810a	534a	253a	5.9	445a	5.8a	5.0a
	Non-managed		42.0b	2259a	160b	321b	90.3b	nd	199b	1.3b	1.8b
B	Managed	Well	322a	2757b	1058a	633a	170a	307.7	1561a	5.4a	4.7a
	Non-managed		47b	3684a	569b	386b	125a	nd	417b	0.8b	1.4b
C	Managed	Well	309a	2355a	1109a	600a	186a	236.7	1187a	5.7a	5.1a
	Non-managed		68b	2786a	806b	520a	125a	nd	219b	1.3b	1.8b
D	Managed	Well	132a	1610b	657a	380a	160a	88.8	426a	3.9a	3.6a
	Non-managed		65.2b	2328a	293b	253a	125a	nd	221b	1.9b	2.2b
E	Managed	Well	264a	2732b	826a	441b	192a	88.8a	815a	5.1a	4.5a
	Non-managed		107b	5134a	912a	888a	176a	71.0a	699a	1.3b	1.7b
F	Managed	Well and RW	255a	2428a	776a	381b	189a	166a	991a	5.4a	4.7a
	Non-managed		114b	3038a	667a	786a	214a	76.9b	605a	2.1b	2.3b
G	Managed	Surface and Well	270a	4401a	1140a	1272a	230a	59.2	810a	3.3a	3.2a
	Non-managed		78b	3872a	551b	822b	144a	nd	409b	1.3b	1.7b

EC, electrical conductivity; ESP, exchangeable sodium percentage; RW, recycled wasterwater; SAR, sodium adsorption ratio (estimated using calculated exchangeable sodium ratio); nd, not detected. Mean values in a column within a golf course with the same letter are not statistically different (Fisher's LSD, $\alpha = 0.05$).

Table 3. Typical concentrations ranges (mean) of selected water quality indicators from well, lake, and effluent sources summarized from four different golf courses in the city of Lubbock, TX, USA, from 1991–2013 ($n = 15$, 4 and 1 for well, retention pond, and recycledwastewater sources, respectively).

Parameters	Well	Retention pond	Effluent
SAR	2.09–3.18 (2.70)	1.42–1.76 (1.92)	7.87
EC ($\mathrm{dS\,m^{-1}}$)	0.89–2.38 (1.58)	0.49–1.27 (0.74)	8.26
pH	7.03–8.23 (7.78)	7.73–8.67 (8.22)	6.41
Chloride ($\mathrm{mg\,L^{-1}}$)	101–338 (205)	31.2–110 (57.2)	2400
Sulfate ($\mathrm{mg\,L^{-1}}$)	140.8–447 (277)	55.7–196 (98.5)	1329
Bicarbonate ($\mathrm{mg\,L^{-1}}$)	251–426 (330)	178–383 (230)	615
Carbonate ($\mathrm{mg\,L^{-1}}$)	16.8 (16.8)	–	–
Potassium ($\mathrm{mg\,L^{-1}}$)	13.8–21.9 (17.26)	8.60–14.5 (10.17)	47.31
Sodium ($\mathrm{mg\,L^{-1}}$)	79.3–188 (139)	40.5–126 (68.6)	792
Calcium ($\mathrm{mg\,L^{-1}}$)	42.5–111 (77.0)	25.3–43.3 (33.0)	332
Magnesium ($\mathrm{mg\,L^{-1}}$)	37.3–134.3 (75.3)	18.7–71.5 (35.5)	264

Table 4. Regression equation and coefficients for the relationships between electrical conductivity (EC) and the selected PXRF quantified elements within managed and non-managed facilities of the golf courses in Lubbock, TX, USA.

	All facilities ($n = 42$)		Managed ($n = 21$)	
Parameter (s)	Equation	R^2	Equation	R^2
Cl	$EC = 0.0015Cl + 0.2476$	0.70^{c}	$EC = 0.0017Cl + 0.1987$	0.85^{c}
S	$EC = 0.0007S - 0.5716$	0.63^{c}	$EC = 0.0007S - 0.4108$	0.52^{b}
Ca	$EC = 0.00001Ca + 0.3813$	0.23	$EC = 0.00002Ca + 0.5547$	0.43^{b}
K	$EC = 0.0341K + 160.28$	0.06	$EC = 0.0444K + 275.83$	0.09
Cl + S	$EC = 0.001Cl + 0.0004S - 0.3063$	0.82^{c}	$EC = 0.0014Cl + 0.0002S - 0.1399$	0.89^{c}
Cl + K	$EC = 0.0015Cl + 0.00004K - 0.2876$	0.77^{c}	$EC = 0.0017Cl + 0.1987K - 0.1459$	0.88^{c}
Cl + Ca	$EC = 0.0014Cl + 0.000006Ca + 0.1490$	0.75^{c}	$EC = 0.0015Cl + 0.000005Ca + 0.1796$	0.87^{c}
Cl + S + K	$EC = 0.0012Cl + 0.00003S + 0.00003K - 0.5931$	0.85^{c}	$EC = 0.0014Cl + 0.0002S + 0.00002K - 0.4151$	0.91^{c}
Cl + S + Ca	$EC = 0.0010Cl + 0.0004S + 0.000003Ca - 0.3004$	0.83^{c}	$EC = 0.0013Cl + 0.0002S + 0.000004Ca - 0.1250$	0.91^{c}
Cl + Ca + K	$EC = 0.0014Cl + 0.000003Ca + 0.00003K - 0.2085$	0.78^{c}	$EC = 0.0015Cl + 0.0000003Ca + 0.00002K - 0.0718$	0.89^{c}

	Non managed ($n = 21$)	
Parameter (s)	Equation	R^2
Cl	$EC = 0.0003Cl + 0.3598$	0.03
S	$EC = 0.0005S - 0.3238$	0.39^{b}
Ca	$EC = 0.000005Ca + 0.2884$	0.10
K	$EC = 0.0392K - 171.05$	0.26
Cl + S	$EC = 0.00035Cl + 0.000516S - 0.3803$	0.43^{b}
Cl + K	$EC = 0.0004Cl + 0.000004K - 0.2820$	0.33^{a}
Cl + Ca	$EC = 0.00037Cl + 0.000006Ca + 0.2321$	0.15
Cl + S + K	$EC = 0.00042Cl + 0.0004S + 0.00002K - 0.5226$	0.49^{b}
Cl + S + Ca	$EC = 0.0003Cl + 0.0005S - 0.00000007Ca - 0.3946$	0.43^{b}
Cl + Ca + K	$EC = 0.0005Cl + 0.000000008Ca + 0.00004K - 0.2804$	0.33

[a] = Significant at 0.05 probability level; [b] = Significant at 0.01 probability level; [c] = Significant at 0.001 probability level; EC in $dS\,m^{-1}$; Cl, S, Ca, and K in $mg\,kg^{-1}$.

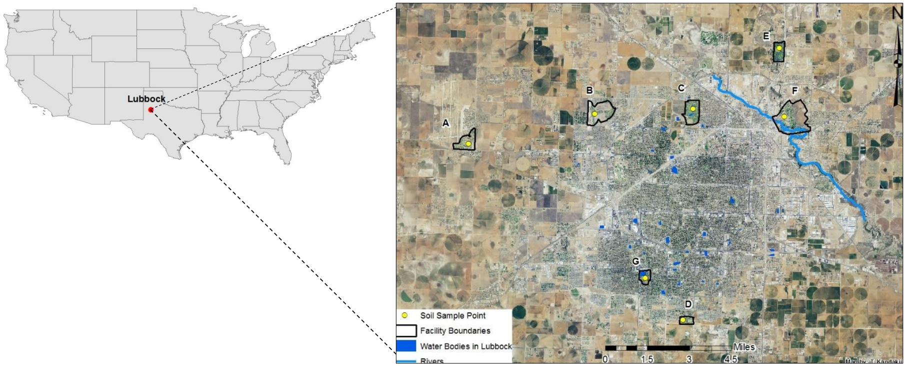

Figure 1. Map showing the study area located in Lubbock, Texas, USA and the locations of the seven golf facilities. The facilities are designated as A, B, C, D, E, F, and G.

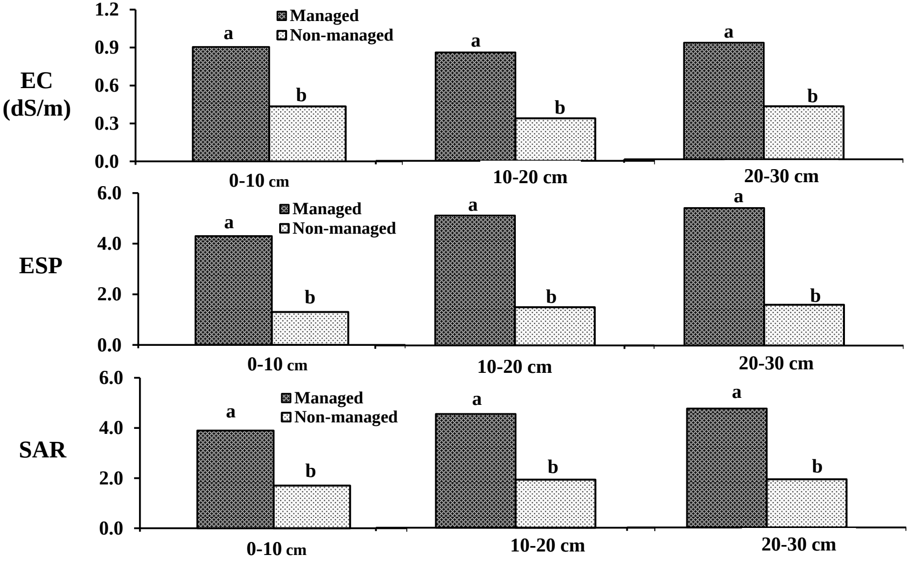

Figure 2. Differences in selected soil chemical properties examined within depths between managed and non-managed zones of all seven golf courses examined in Lubbock, TX, USA. Each data point represents the average of seven points. Mean values within a soil depth with the same letter are not statistically different (Fisher's LSD, $\alpha = 0.05$). EC, electrical conductivity; ESP, exchangeable sodium percentage; SAR, sodium adsorption ratio.

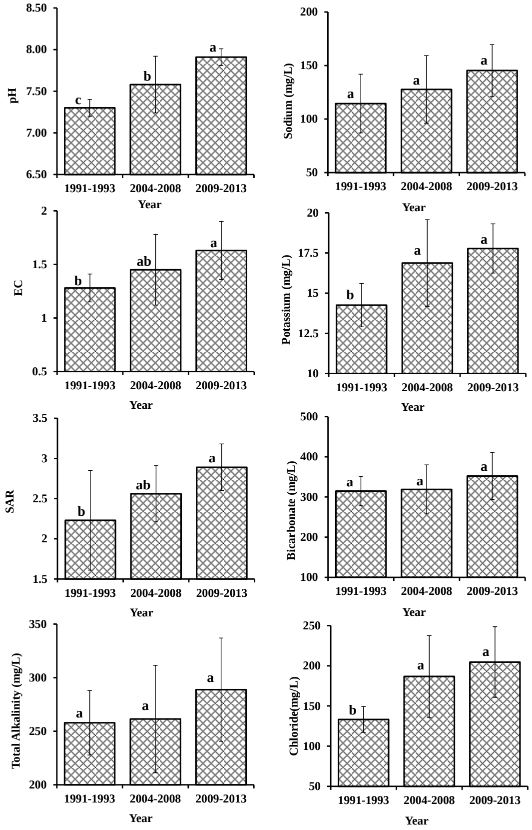

Figure 3. The observed trend in selected water quality parameters from 1991–1993. Water samples were obtained from well sources utilized by a golf course in Lubbock, TX, USA. For each parameter, data were averaged over 1991–1993 ($n = 9$), 2004–2008 ($n = 6$) and 2009–2013 ($n = 6$), error bars are for the SD. Mean values within a parameter with the same letter are not statistically different (Fisher's LSD, $\alpha = 0.05$).