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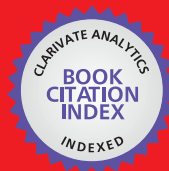Downloads

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Long-Term Effects of Effluent Water Irrigation on Soil Chemical Properties of Sand-Based Putting Greens

Hanan Isweiri and Yaling Qian

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Abstract

The increase of the world's population and the decrease of freshwater resources have led to increased use of alternate water resources to meet the water need. Using treated wastewater (effluent water) for urban landscape irrigation has become a common practice to alleviate freshwater shortage. Golf courses are the leading urban landscape users of effluent water, because intensively managed turf can use nutrients in the wastewater efficiently. The objectives of this study were to assess changes in soil chemical properties of sand-based putting greens, following conversion from freshwater irrigation to effluent water irrigation, and identify potential concerns related to long-term use of effluent water on sand-based greens. Soil samples were collected and analyzed from greens at the Heritage Golf Course in Westminster, Colorado. The course started to use effluent water for irrigation in 2000. Nine out of eighteen (1, 3, 5, 7, 9, 11, 13, 15, 17) greens were selected for soil sample collection. Soil samples (0–10 cm below soil surface) were collected in September of 1999, 2003, and 2009. Soil test data showed that the soil's chemical characteristics changed over time. Soil organic matter (SOM) increased from 0.12 to 1.5%, and cation exchange capacity (CEC) is increased by as much as double over nine years. Extracted phosphates increased by 388% after nine years of effluent water use. Exchangeable calcium, magnesium, potassium, and sodium also increased, by 198, 116, 148, and 452%, respectively, over nine years of effluent water irrigation. In addition, increases over time were found for extractable iron, manganese, copper, zinc, and aluminum. In conclusion, using effluent water for irrigation has both benefits and risks. Increased salinity (EC) and sodium levels are the greatest risks when using effluent water; however, to a certain degree, these can be managed through appropriate cultural practices such as leaching and adding gypsum. Supplemental nutrients and decreased fertilizer costs are the greatest benefits of using effluent water for irrigation. Our results showed that released nitrogen, phosphorus, potassium, and magnesium levels increased in the soil after using effluent water, which would be beneficial for the grass and lowering the fertilizer's cost.

Keywords: treated wastewater, effluent water, irrigation, soil salinity

1. Introduction

The increase of the world's population and the decrease of freshwater resources have led to increased use of alternate water resources. In contrast, as the population increases, wastewater production increases. In many arid and semiarid areas in USA, Australia, and Israel, using freshwater for turfgrass and landscape irrigation has become rare. Consequently, using treated wastewater (effluent water) for irrigation has become a common practice to alleviate freshwater shortage. In addition to the growing concerns of the future water supply, the more stringent wastewater discharge standards make use of effluent water increasingly attractive.

Golf courses are the leading urban landscape users of effluent water. A survey conducted by the National Golf Foundation (NGF) reported that approximately 13% of golf courses in the US use effluent water for irrigation, with 34% of golf courses in the Southwest US doing so [1]. In Colorado, approximately 25% of golf courses are using effluent water for irrigation.

Effluent water is any water after residential and sometimes industrial use that undergoes significant treatment at a sewage treatment plant, to meet standards set by federal or state water laws and regulations. This water is usually suitable for various reuse purposes including irrigation. During treatments, suspended solids are removed, pathogens are disinfected, and partial to substantial reduction in nutrient concentrations occurs, depending on treatment stage [2, 3]. Currently, effluent water used for turf and landscape irrigation must be disinfected [4].

However, using effluent water has some disadvantages. Public health is the first concern due to the pathogens it may contain, but that is less of a concern if used for nonedible plants. Effluent water may contain different levels of dissolved solids, ions, nutrients (NO_3 and P_2O_4), and other elements. Increases in soil salinity and sodium are potential problems associated with using effluent water irrigation. Salinity has harmful effects on nonhalophyte plant growth and development as well as making soil water less available for the plants. Increased sodium level (sodicity) in the soil leads to disaggregation of soil to its components and damages the soil structure. In addition, researchers suggest that using effluent water for irrigation may affect soil chemistry over time [5–9]. Accordingly, the use of effluent water for irrigation requires monitoring and the use of management practices to minimize any potential adverse effects on soil and plants.

On the other hand, using effluent water for irrigation has some advantages. Effluent water contains some nutrients that can be used by plants. Nitrogen (N) and phosphorus (P) as well as some small amounts of micronutrients are found in effluent water. Studies have showed that plant yields increased by using effluent water when compared to freshwater irrigation [10]. This increase is due to the nutrient concentrations such as N and P in effluent water and their effect on plant growth [10]. High-quality effluent water has become available for golf course irrigation, and it decreases the fertilizer cost because of nutrient availability in the water [4]. Also, using effluent water is less expensive when compared to other alternative irrigation resources such as desalinized seawater [11].

Many studies have been published regarding the effect of using effluent water on soils in urban landscapes. However, no research is available regarding the impacts of effluent water irrigation on sand-based root zones on golf course putting greens and sports fields. Research

is needed to determine the effect of using effluent water on sand-based root zones on putting greens. Most golf course putting greens are constructed based on the United States Golf Association (USGA) putting green construction recommendations. USGA putting green consists of 30 cm sand-based root zone that contains 90% sand and 10% organic matter by volume. The sand-based root zone overlays a 10-cm-deep gravel blanket to provide the best soil conditions for turfgrass growth and to minimize compaction and optimize drainage. Sand-based putting greens allow for good aeration and drainage, and that is important to maintain a good playing surface. Sand is suitable for the putting green's function because it is resistant to soil compaction and has good filtration and percolation rates. However, it has low organic matter, which may affect its ability to hold nutrients [12]. Organic matter, typically peat, is often added to improve water and nutrient-holding capacity [13]. With putting green's special nature, using effluent water for irrigation needs to be investigated over the long term to address the impact of effluent water on putting green soil properties.

The objectives of this study were to:

1. Assess changes in soil chemical properties of sand-based greens following conversion from freshwater irrigation to effluent water irrigation.

2. Identify potential concerns related to long-term use of effluent water on sand-based greens.

2. Materials and methods

2.1. Study location

The study was conducted at Heritage Golf Course in Westminster, Colorado, which is located north of metro Denver (39° 53′ 59.34″ N 105° 07′ 00.04″). The course started to use effluent water for irrigation in 2000. Nine out of 18 (1, 3, 5, 7, 9, 11, 13, 15, 17) greens were selected for soil sample collection. Soil samples (0–10 cm below soil surface) were collected in September of 1999, 2003, and 2009.

Soil samples were analyzed for soil pH, extractable salt content (Ca, Mg, K, Na, Fe, Mn, Cu, Zn, P, and B), base saturation percent of Ca, Mg, K, and Na, soil organic matter (SOM), and cation exchange capacity (CEC) by Brookside Laboratories, Inc. (New Knoxville, OH). Soil pH was analyzed using 1:1 H_2O procedure; 1:1 is the most common ratio used for soil-water pH. It is performed by mixing an equal volume of soil and deionized water. Soil samples were extracted using the Mehlich III extract (0.015 M NH_4F + 0.20 M CH_3COOH + 0.25 M NH_4NO_3 + 0.013 M HNO_3 + 0.0005 M EDTA chelating agent) to determine Ca, Mg, K, Na, Fe, Mn, Cu, Zn, B, and P by inductively coupled plasma-emission spectrophotometry instrumentation. Mehlich III is a procedure widely used for extraction of plant available macro- and micro-nutrients in soils that have an acidic or neutral pH, by using a dilute acid-fluoride-EDTA solution with pH 2.5 extracted [14]. Mehlich III extracted Ca, Mg, K, and Na plus soil buffer pH data are used to calculate CEC. Base saturation percent of Ca, Mg, K, and Na was calculated by dividing the extracted Ca, Mg, K, and Na by the calculated CEC, respectively. Base saturation percent of Na is considered the exchangeable sodium percentage (ESP). Soil

organic matter was determined by reaction with $Cr_2O_7^{2-}$ and sulfuric acid. The remaining unreacted $Cr_2O_7^{2-}$ is titrated with $FeSO_4$ using ortho-phenanthroline as an indicator, and oxidizable organic matter was calculated by the difference in $Cr_2O_7^{2-}$ before and after the reaction [15]. Estimated N release is calculated to determine the potential amount of N released annually by SOM decomposition.

2.2. Data analysis

Data were analyzed by analysis of variance (ANOVA) [16] to test the effect of irrigation with effluent water on individual soil chemical properties. Comparisons between years were examined, and means were separated by LSD at 0.95 level of confidence. Regression analysis was used to examine the changes in individual soil parameters over time after the use of effluent water for irrigation.

3. Results and discussion

Effluent water analysis showed that sulfate (182 mg L^{-1}), bicarbonate (125 mg L^{-1}), chloride (120 mg L^{-1}) and sodium (101 mg L^{-1}) are the most dominant elements in the water (**Table 1**).

On average, soil pH was 6.9 at the initiation of the study (**Figure 1**). ANOVA test showed no changes in pH for 9 years after using effluent water (**Figure 1**). These results are similar to the findings in a previous study on the fairways of the same golf course [9]. These results likely were due to the use of sulfur (S) burner units on the golf course irrigation system. After transitioning to effluent water, the Heritage Golf Course installed a sulfur burner. Sulfur burner units heat elemental S to create sulfurous acid for injection into irrigation water to reduce the bicarbonate content and pH [7]. The fact that we did not see an increase in soil pH suggests that the S burner was effective in controlling soil pH associated with effluent water irrigation. Soil pH increases have been observed by others in soils under effluent water irrigation [7, 17]. At this site, soil pH was maintained without change over 9 years by reducing the bicarbonate level in the irrigation water and releasing H^+ into water and soil.

The SOM was significantly different among the sampling years with the means linearly increasing from 1999 to 2009 (**Figure 2**). Comparing before using effluent water (1999) and after 9 years of using effluent water (2009) at the Heritage Golf course, we found that SOM significantly increased ($R^2 = 0.83$). At the initiation of the study in 1999, SOM content was 0.12%, which increased to 1.5% in 2009. The average increase was 0.15% annually. To calculate the total carbon (C) sequestration from SOM, an assumption was made that SOM contains 58% C, and putting greens have 1.6 g cm^{-3} bulk density. The average annual total C sequestration was 1.4 t h^{-1} yr^{-1} during 9 years of using effluent water. Our calculation for this site was higher than the estimation that was reported by Qian and Follett [18] that soil C sequestration rate was 1.1 t h^{-1} yr^{-1} on golf course putting greens. Soil organic matter is a significant component in turfgrass systems; it affects soil porosity, water and nutrients retention, and percolation in the sand-based root zone. In addition, the calculation of C sequestration from SOM could be helpful to understand the role of turfgrass systems in storing C in the soil.

Water quality parameters	
pH	7.4
NH_4–N	0.8 mg L^{-1}
NO_3–N	2.9 mg L^{-1}
Total P	0.6 mg L^{-1}
Total dissolved salts	638
Conductivity	0.99 dS m^{-1}
Sodium absorption ratio (SAR)	3.05
Adjusted SAR	5.74
Na	101 mg L^{-1}
Cl	120 mg L^{-1}
Bicarbonate	125 mg L^{-1}
Ca	67 mg L^{-1}
Mg	11.8 mg L^{-1}
Sulfate	182 mg L^{-1}
B	0.21 mg L^{-1}
Fe	0.31 mg L^{-1}
K	16.9 mg L^{-1}
Total suspended solid (TSS)	9.1 mg L^{-1}

Table 1. Effluent water quality used in Heritage Golf Course (season average).
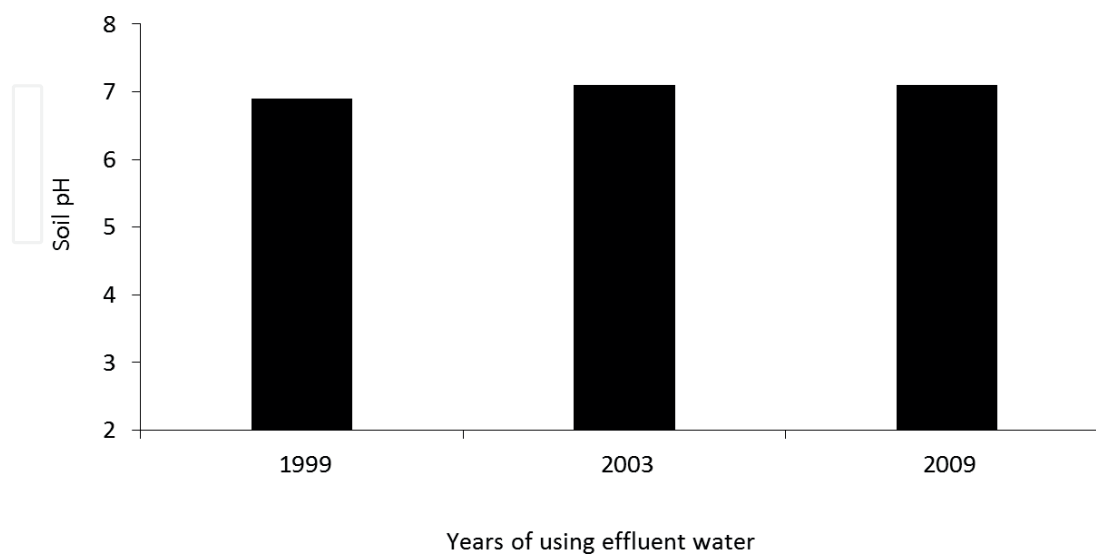
Figure 1. Effect of using effluent water irrigation on soil pH. Different letters indicate significant differences using LSD ($P < 0.05$).
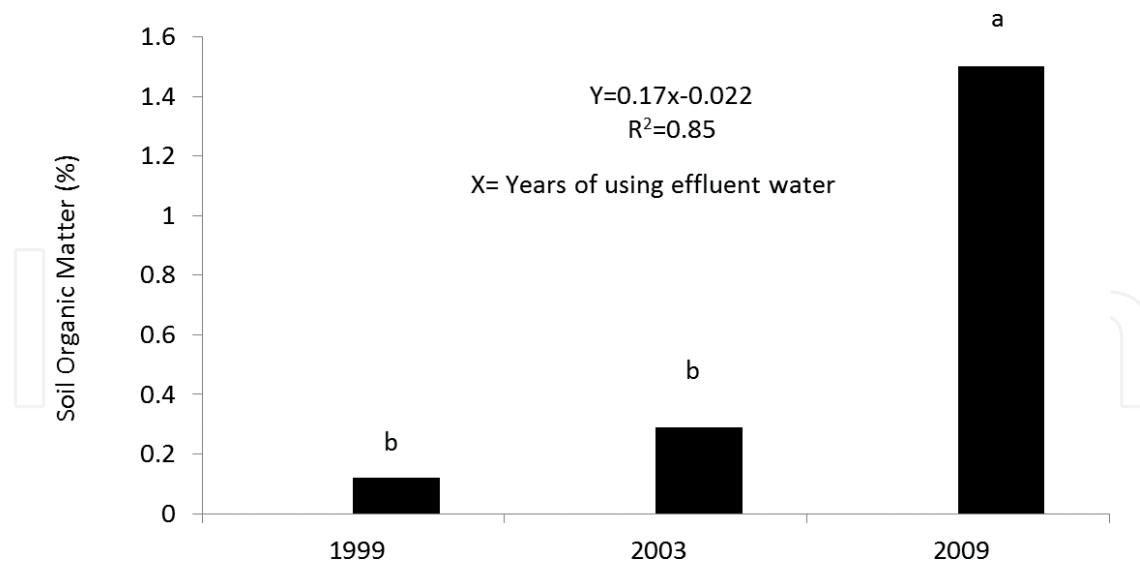
Figure 2. Effect of using effluent water irrigation on soil organic matter. Different letters indicate significant differences using LSD ($P < 0.05$).

Putting greens had low CEC (1.9 $cmol_c$ kg^{-1}) at the beginning of the experiment. This was because it was mostly sand with low SOM and contained low inorganic colloids. Soil CEC is increased by 174% over the course of the experiment ($R^2 = 0.86$) and by an average rate of 0.38 $cmol_c$ kg^{-1} (**Figure 3**). Organic matter has very high CEC. The significant increase in soil CEC observed in this study is likely due to the increase in SOM.

The estimated N release showed a highly significant increase over time ($R^2 = 0.90$), and the percentage increase was 1117%, with an annual rate of 5.6 kg ha^{-1} yr^{-1} compared to the year
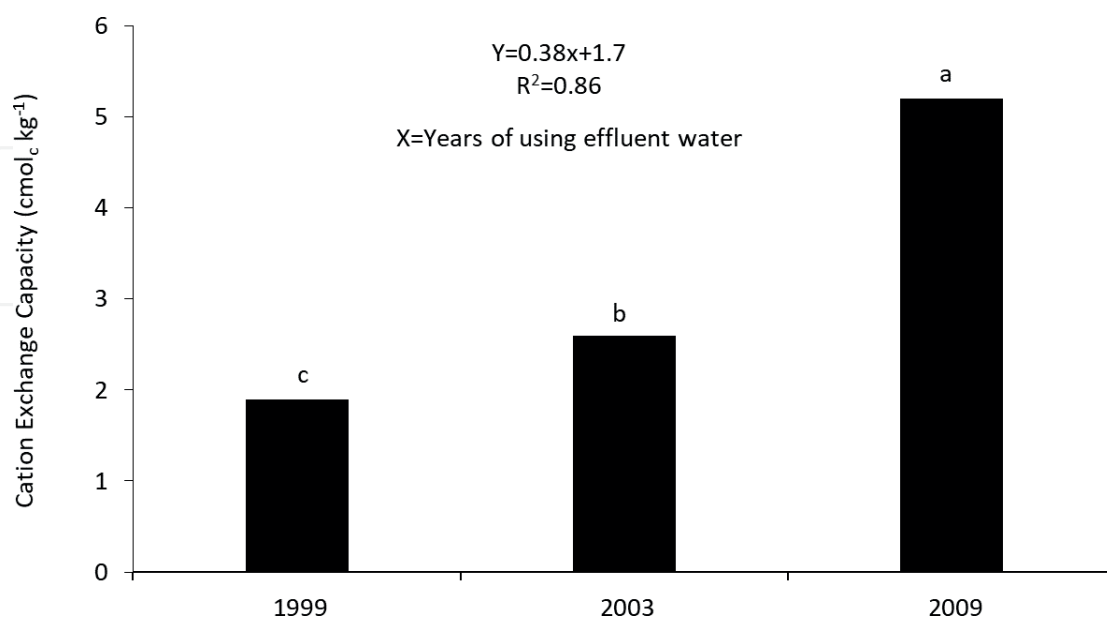

Figure 3. Effect of using effluent water irrigation on cation exchange capacity. Different letters indicate significant differences using LSD ($P < 0.05$).

before using effluent water which was 4.6 kg ha^{-1} (**Figure 4**). Estimated N release is an estimate of N potentially released annually by decomposition of SOM. Estimated N release could be affected by many factors such as soil moisture, temperature, and soil type. This large increase was due to the fertilization and organic matter increase as well as substances added by effluent water because it often contains significant concentrations of organic nutrients, such as N and P [19]. Increases in this category were also a result of increased biomass production that translated to increases in SOM and eventually available N from organic matter decomposition.

Soluble S increased over time ($R^2 = 0.82$; **Figure 5**). The percentage increase during the 9 years of using effluent water was 413%. As mentioned earlier, this increase of S content over time was a result of using S burner to inject elemental S into irrigation water to reduce pH and bicarbonate concentration in effluent water [7]. Turf managers at Heritage Golf Course encountered a problem of increased black layer beneath putting green surfaces since 2003. Black layer is the formation of a layer of metal sulfide [20, 21], which forms when hydrogen sulfide (H_2S) gas reacts with metal elements in the soil. Hydrogen sulfide gas is produced by sulfur-reducing bacteria (SRB). Black layer is typically associated with turfgrass chlorosis, wilting, thinning, and sometimes death.

Soluble S is the substrate for S reduction activity that leads to black layer. Therefore, the use of a S burner under effluent water irrigation might have partially contributed to the increased occurrence of black layer. Further research is needed to address the potential relationship between the incidence of black layer and effluent water irrigation.

In addition, extracted phosphates increased over time ($R^2 = 0.83$; **Figure 6**), and the percentage of increase during 9 years of using effluent water was 388%. This increase was expected because effluent water usually has more soil phosphates than freshwater. Increases in phosphates over years of using effluent water irrigation have been recorded in previous studies [9, 22].
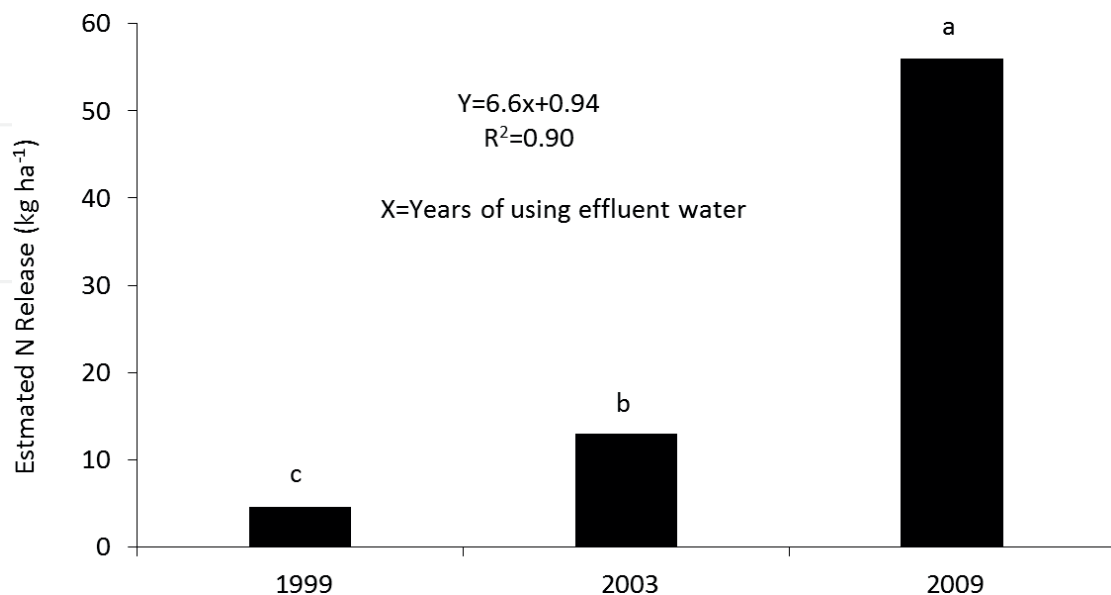

Figure 4. Effect of using effluent irrigation on soil's estimated N release. Different letters indicate significant differences using LSD (P < 0.05).
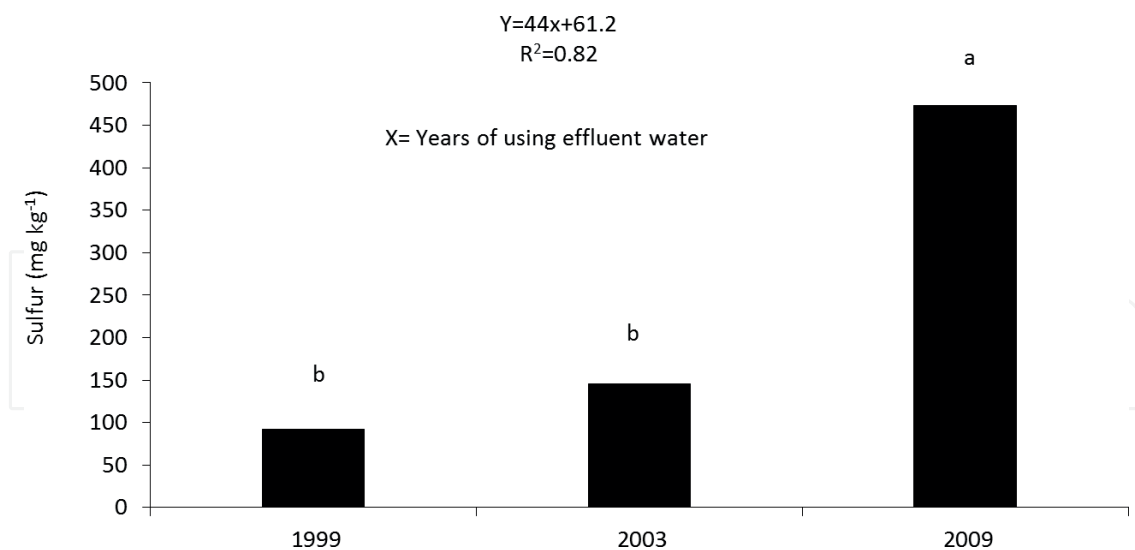
Figure 5. Effect of using effluent irrigation on soil soluble sulfur content. Different letters indicate significant differences using LSD ($P < 0.05$).
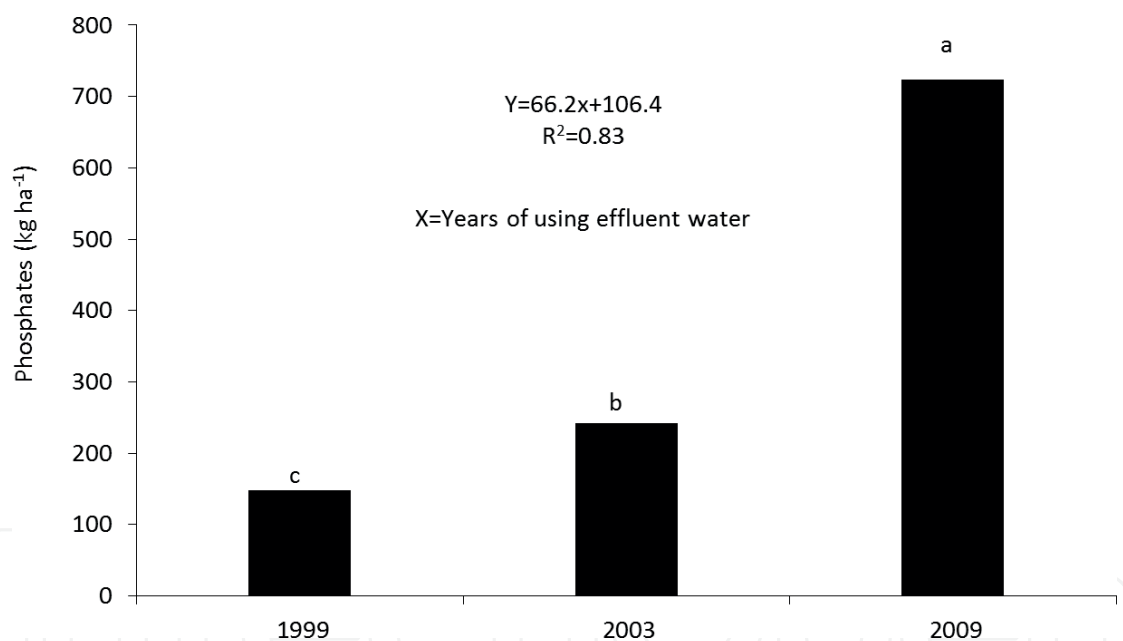

Figure 6. Effect of using effluent irrigation on soil phosphates. Different letters indicate significant differences using LSD ($P < 0.05$).

Similarly, exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) significantly accumulated over time after using effluent water (**Figures 7–10**). The percentage of the increase after nine years of using effluent water was (Ca) 198%, (Mg) 116%, (K) 148%, and (Na) 452%. Exchangeable Na increased to 156 kg ha^{-1} after nine years of using effluent water. This increase could be due to the use of effluent water irrigation as some research has indicated. Soil Na concentration increased almost 5.5 times since the start of using effluent water, and the value (156 kg ha^{-1}) was in the moderate risk range (>210 is in high risk) [23]. A study

done in 2005 found that effluent water provided enough K, Ca, and Mg for plants [24]. The authors suggested that soil with excessive amounts of K could lead to base saturation imbalance, and highly soluble salts tie up other elements such as B, Ca, and Mg. In contrast, higher amounts of Mg appeared to be a problem in clay soil, but it could help stabilize sandy soil. In this study, however, no clear pattern was found over time for potassium base saturation percentage (**Figure 11**).
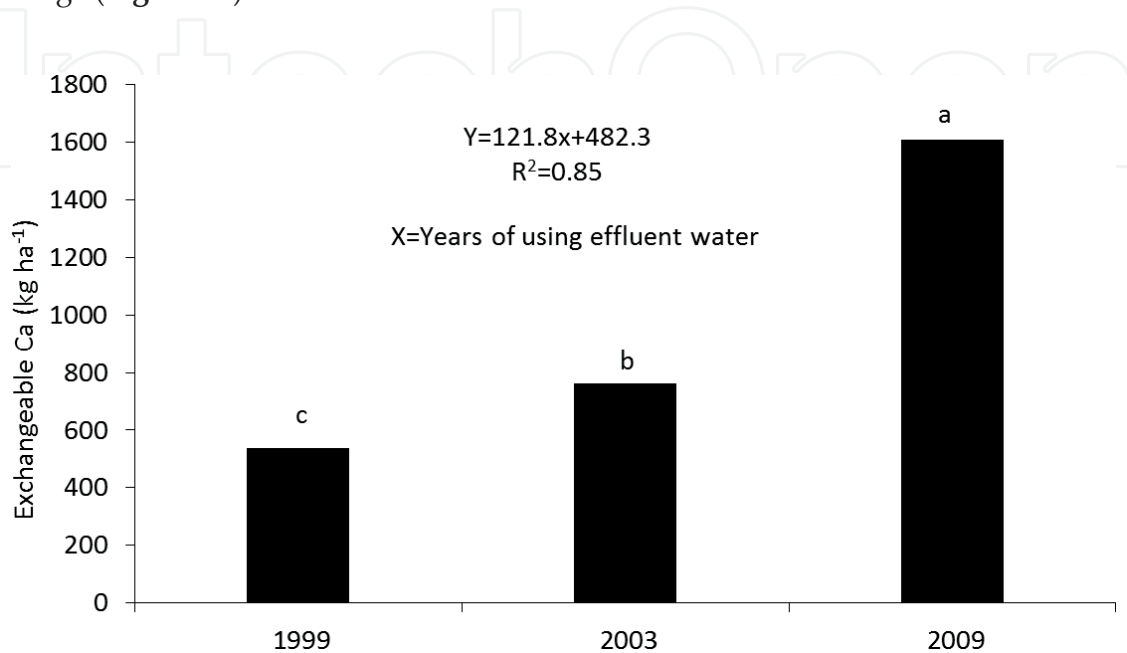

Figure 7. Effect of using effluent irrigation on soil exchangeable calcium. Different letters indicate significant differences using LSD ($P < 0.05$).
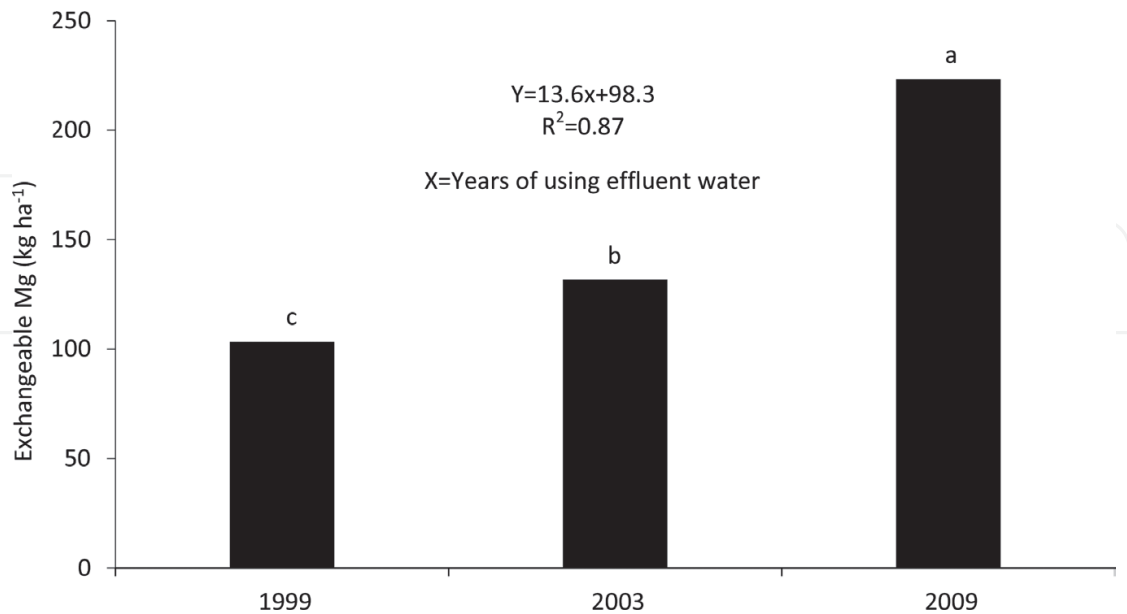

Figure 8. Effect of using effluent irrigation on soil exchangeable magnesium. Different letters indicate significant differences using LSD ($P < 0.05$).
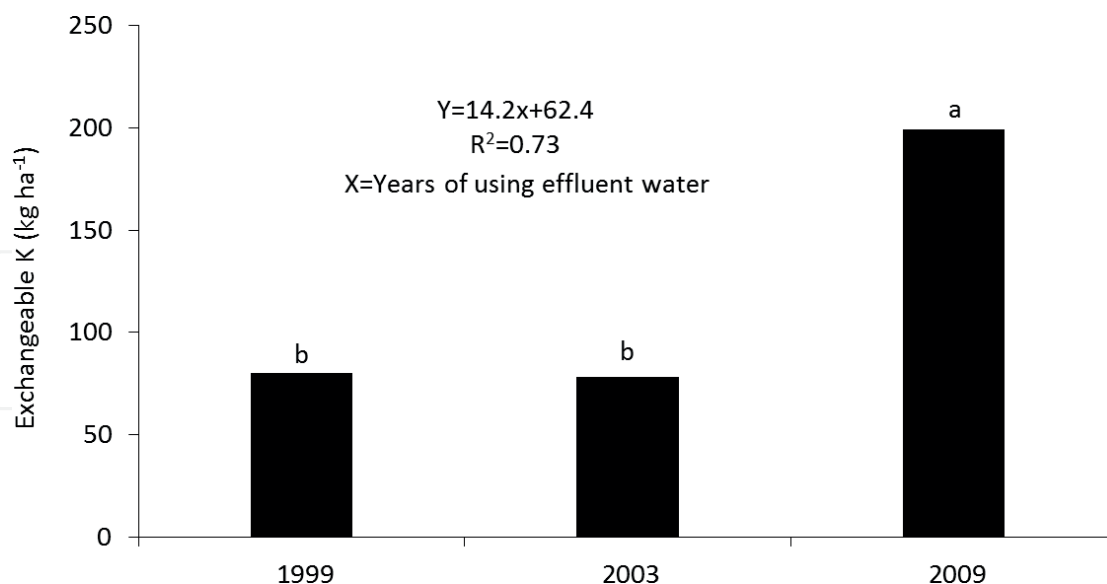
Figure 9. Effect of using effluent irrigation on soil exchangeable potassium. Different letters indicate significant differences using LSD ($P < 0.05$).
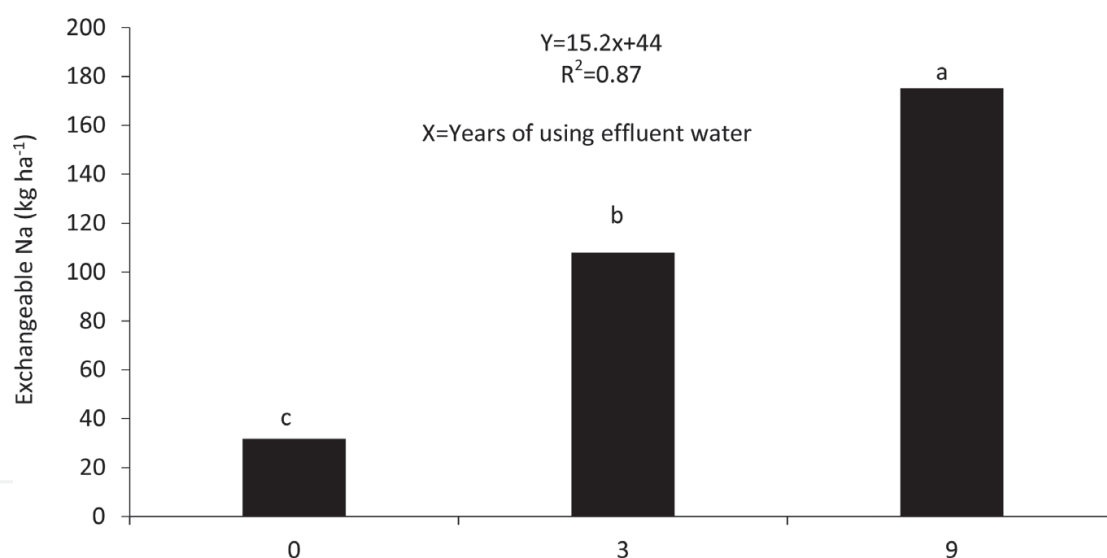

Figure 10. Effect of using effluent irrigation on soil exchangeable sodium. Different letters indicate significant differences using LSD ($P < 0.05$).

Increase in Na base saturation percentage was observed after nine years of effluent water irrigation at an average rate of 0.27% per year (**Figure 11**). Elevating exchangeable sodium percentage (ESP) observed over several years of effluent water irrigation can be of concern with regard to the preservation of water permeability and hydraulic conductivity on putting greens. ESP is a measurement of sodium hazard in soil, and ESP more than 15% can cause sodicity problems. Soil hydraulic conductivity decreases as ESP increases. However, sodicity depends on soil type. Soil with high clay content is affected more by ESP. Effluent water can cause Na build up over time in the soil. High concentrations of Na can affect the ability of water to move through the soil, that is, decrease infiltration.
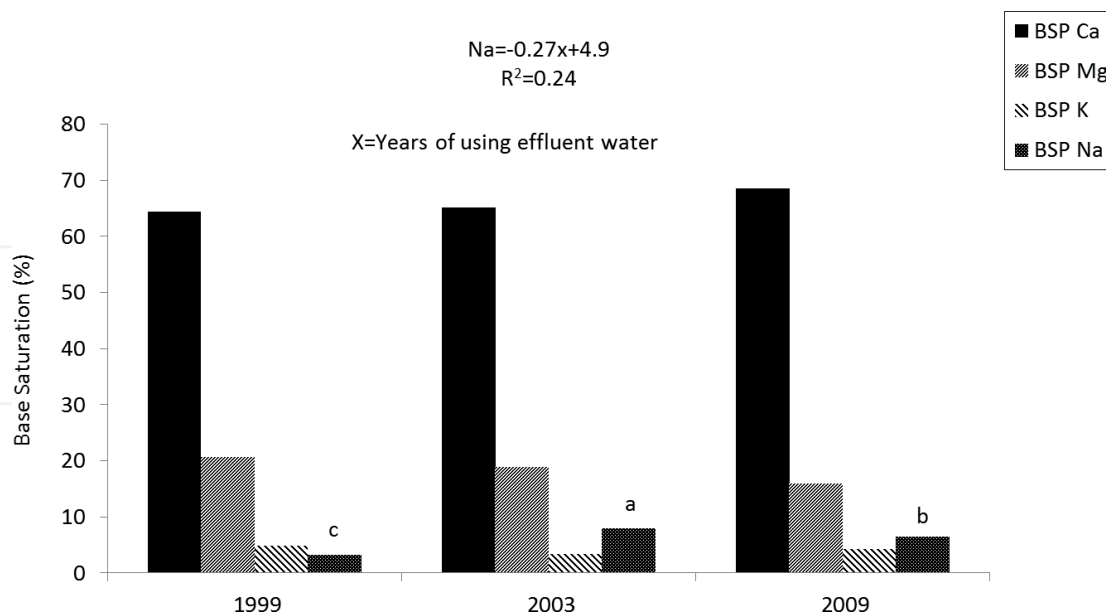
Figure 11. Effect of using effluent irrigation on soil base saturation Ca, Mg, K, and Na. Different letters indicate significant differences within the parameter using LSD ($P < 0.05$).

In this study, a slight increase was recorded in the Ca base saturation percentage ($R^2 = 0.35$). In contrast, a reduction in Mg base saturation percentage was recorded ($R^2 = 0.66$) (**Figure 10**). Calcium and Mg affect each other's availability in the soil, and high Ca may tie up magnesium. However, the Ca/Mg ratios matched the balanced ratio at every sampling time (2.1–5.9) [25]. In general, the base saturation percentages for Ca, Mg, and K in this putting green are considered to be in the ideal or balanced ranges that many soil laboratories use to interpret soil test results. According to the basic cation saturation ratio theory, ideal plant growth will be achieved only when the soil's exchangeable Ca, Mg, and K concentrations are in range of 60–70% Ca, 10–20% Mg, and 4–6% K [26].

A significant increase over time was observed for extractable Fe ($R^2 = 0.81$). The percentage increase was 354% after 9 years of using effluent water, with an average rate of 25 mg kg^{-1} per year (**Figure 12**). These results were in agreement with a short-term (45 days) study done in Iran in 2011 [27]. The authors found that irrigation with wastewater significantly increased extractable Fe by 13% compared to the site that was irrigated with freshwater [27]. Although the effluent water for this course had low levels of Fe (0.3 mg L^{-1}), the soil extractable Fe concentration significantly increased after using effluent water. After nine years of using effluent water, extractable Fe was 288 mg kg^{-1}. Soil pH plays an essential role in micronutrient availability to plants. The availability of micronutrients such as Fe, Mn, and Zn in soil solution begins to decrease when soil pH is above 6.5. As soil pH increases, the availability of Fe decreases. As result, Fe deficiency is common in high pH soil. Iron is essential for chlorophyll synthesis and photosynthesis [28]. Effluent water could supply the soil with Fe with a proper soil pH range. In this site, Fe concentrations after nine years of using effluent water were in the ideal range (100–300 mg kg^{-1}).

Likewise, extractable copper (Cu), manganese (Mn), and zinc (Zn) increased significantly over time ($R^2 = 0.86$, 0.87, and 0.89, respectively). The increased percentages after using effluent water were 290, 1220, and 1608%, by an average rate around 1.0, 3.2, and 2.1 mg kg^{-1} yr^{-1}, respectively,
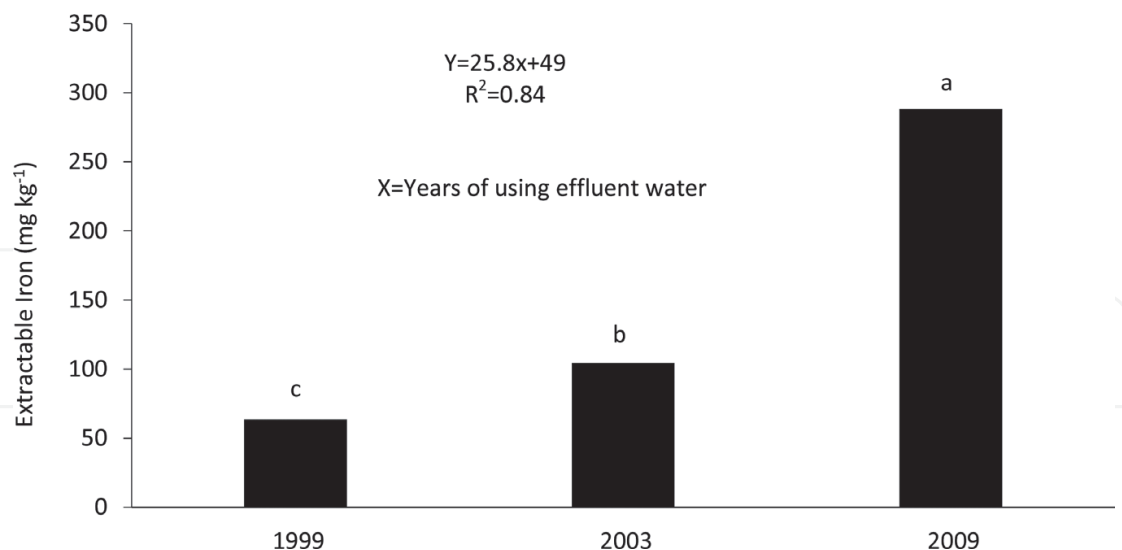
Figure 12. Effect of using effluent irrigation on soil extractable iron. Different letters indicate significant differences using LSD ($P < 0.05$).

for Cu, Mn, and Zn, respectively (**Figure 13**). This finding is in disagreement with the previous study for fairways on the same golf course which suggested that no pattern of change was recorded for extractable Cu, Mn, and Zn after using 9 years of effluent water [9]. These micronutrient availabilities are similar to the availability of Fe and depend on pH as well. Sandy soil usually has low concentrations of micronutrients such as Fe, Mn, Cu, and Zn [29]. Copper is an enzyme activator and disease fighter, and the Cu minimum value needed in the soil is 1.5 mg kg^{-1}, and a value higher than 4 mg kg^{-1} is excessive [30]. Copper and Zn affect each other availabilities to plants, and ideally soil Cu concentration should be half of Zn. Our results showed that after
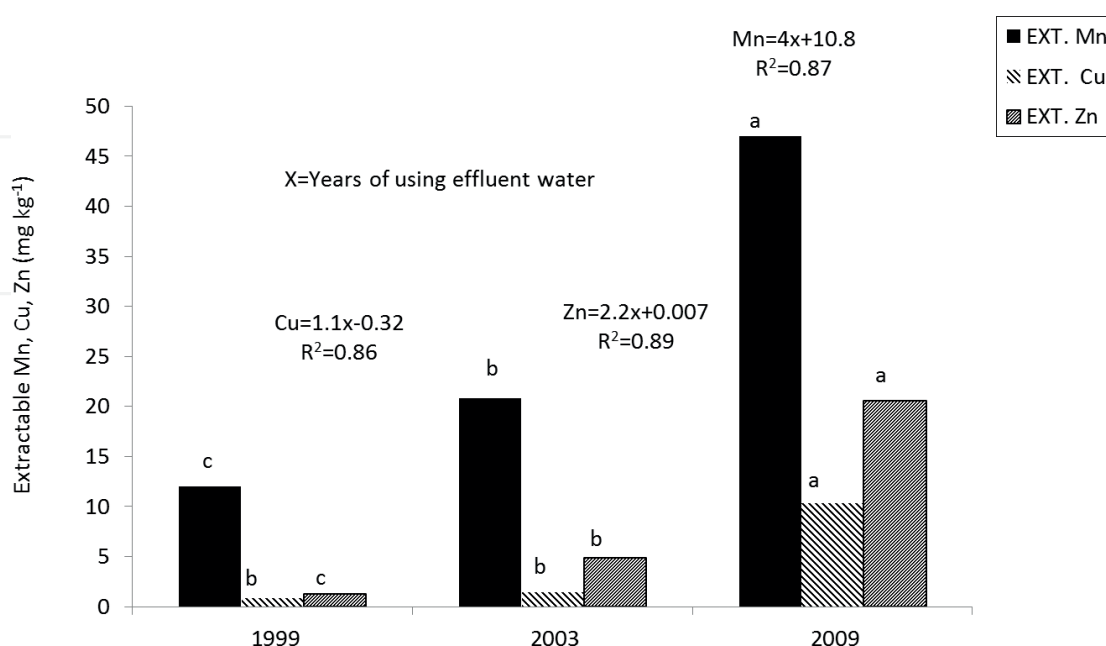

Figure 13. Effect of using effluent irrigation on soil extractable manganese, copper, and zinc. Different letters indicate significant differences within the parameter using LSD ($P < 0.05$).

9 years of effluent water, Cu and Zn concentrations were very high in this putting green soil; however, toxicity is not a concern here for both elements due to the nonacidic soil pH.

Moreover, extractable aluminum (Al) increased over time after using effluent water (R^2 = 0.5) (**Figure 14**), and the percent increase was 63% up to 142 mg kg^{-1}. These increases could be due to the effluent water use and could also be due to the soil aging and management practices. Toxic levels of Al are heavily dependent on the pH. In general, Al toxicity increases as soil acidity increases to a pH level of 4.8. In our study site, Al stayed bonded and not available to the plant.

A significant increase appeared in soil extractable boron (B) after the use of effluent water (R^2 = 0.68) (**Figure 15**), and the percent increase over time was 260% with an average rate of 0.06 mg kg^{-1} year^{-1}. These results are most likely due to effluent water use and are in agreement with the previous study for the same golf course fairway soil. The extractable B gradually increased (R^2 = 0.56) after using effluent water in fairway soils [9]. The criteria for B concentration in soils are as follows: shoot growth of sensitive plants could decline as soil B exceeds 0.5–1.0 mg kg^{-1}. Moderately sensitive plants would start to decline when soil B exceeds 1.0–2.0 mg kg^{-1}. Kentucky bluegrass can tolerate soil B concentration of 2.0–4.0 mg kg^{-1}, while tolerant grasses can tolerate soil B of 6–10 mg kg^{-1}. The effluent water used in this study contained about 0.2 mg L^{-1} boron (**Table 1**). Soil samples collected had a range from 0.2 to 0.7 mg kg^{-1} of B. This average level of soil B concentration was higher in 2009 compared to what was measured in 1999 (0.2 mg kg^{-1}), yet this range of B concentration was well below the toxic threshold for creeping bentgrass greens.

The same study was done previously on Heritage Golf Course fairways [9]. In comparison between the greens and the fairways in these two studies, we found that both green and fairway soil chemistry changed over time after nine years of using effluent water. In many categories, results were similar for the greens and the fairways. In both studies, soluble S was increased significantly due to the S burner mentioned before. Increases in Na concentration, B concentration, soil ESP, and Na available for release were similar between the two studies. Although SOM increased in both studies, CEC increased in the green soil but not in the
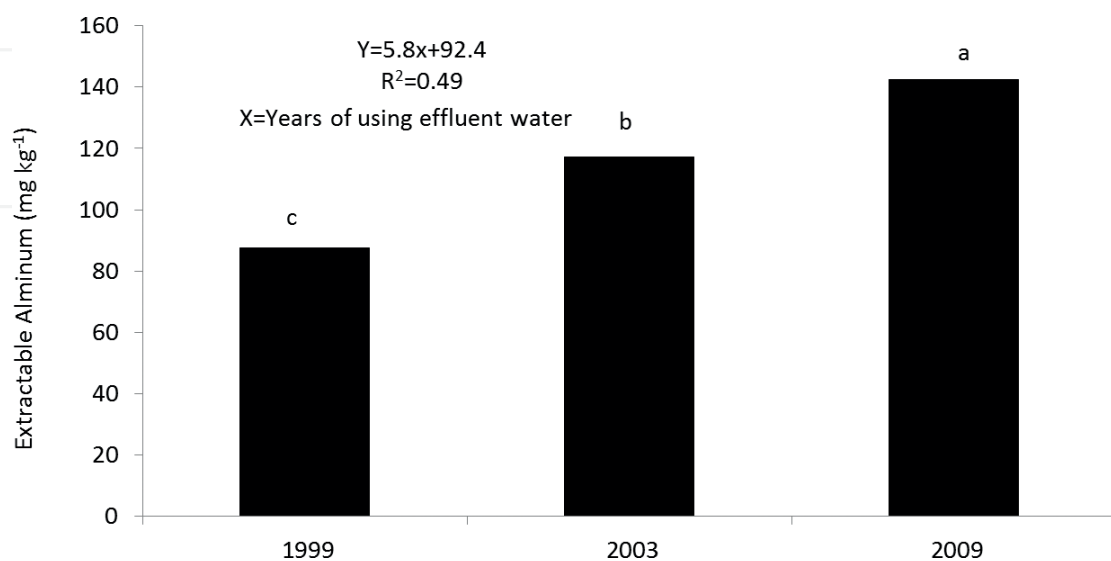

Figure 14. Effect of using effluent irrigation on soil extractable aluminum. Different letters indicate significant differences using LSD (P < 0.05).

Y=0.06x+0.25
R^2=0.63
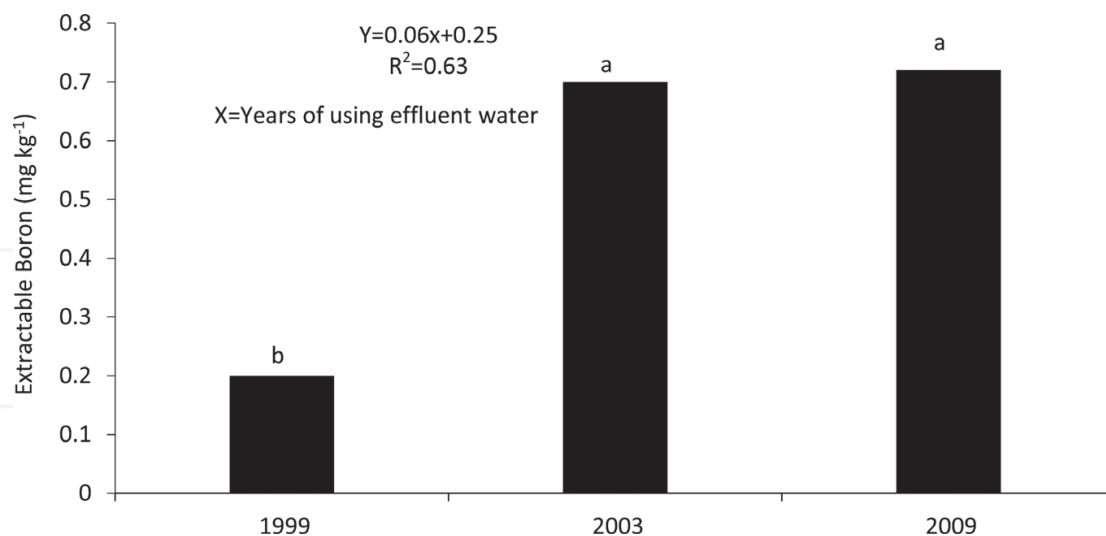
X=Years of using effluent water

Figure 15. Effect of using effluent irrigation on soil extractable boron. Different letters indicate significant differences using LSD ($P < 0.05$).

fairway. In contrast, some soil parameters responded differently in the two studies. For example, significant increases in trace elements such as Cu, Zn, Mn, and Al were only observed in the green studies but not in fairways. Similarly, Fe concentration significantly increased in the greens but not in the fairways. These differences between the two studies could be due to the different soil type and structure in the greens and the fairways. Further studies are needed to determine if the change of soil parameters would continue over time.

4. Conclusion

Soil test data for the Heritage Golf Course, which uses effluent water for irrigation, showed that the soil's chemical characteristics changed over time. Soil organic matter increased from 0.12 to 1.5%. Soil CEC was significantly increased by as much as double over nine years. Exchangeable Ca, Mg, K, and Na also increased by 198, 116, 148, and 452%, respectively, over nine years of effluent water irrigation. More than fourfold increase in Na could affect the soil structure and lead to a lack of aeration for roots. However, the application of gypsum can be used to minimize this effect. In addition, a significant increase over time was shown for extractable Fe, Mn, Cu, Zn, and Al.

In general, most of the chemical parameters have significantly changed over nine years of effluent water irrigation; however, not all changes are necessarily due to the use of effluent water. Some changes in soil chemistry could be the result of golf course management practices, such the use of an S-burning unit, which increased soluble S in the irrigation water. In addition, these greens are relatively young (built in 1998), they need time to become mature, and their soil becomes stable over time. However, increases in other elements such as sodium, boron, and phosphate could be due to the use of effluent water. The greater increases in SOM and estimated N release, and increases in trace elements such as Cu, Zn, and Mn could also be the result of using effluent water for irrigation.

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