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Original Paper

Comparison of Soil Nitrate and Phosphorus Concentrations Prior to and Five to Eleven Years after Recycled Water Irrigation

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Abstract

Increasing demand on water supplies in western US and more stringent wastewater discharge standards have made recycled water a common water source for irrigating urban green spaces. Studies are needed to evaluate nitrate-N leaching potential and phosphorus (P) movement along soil profile when recycled wastewater is used for irrigation. We collected and analyzed soil samples at the commencement and 5 and 11 years after recycled water irrigation on 2 golf courses, 5 metropolitan parks, and 1 school ground. Samples were taken at 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths on golf courses and at 0-20 and 20-40 cm depths at other locations. Soil samples were tested for soil pH, soil nitrate, and AB-DTPA extracted P level. No increase in soil nitrate-N was observed over 5 and 11 years with recycled water irrigation, suggesting leaching of nitrogen to the groundwater was not a great concern. Soil P concentration at the surface soil depth was the highest 11 years after recycled water irrigation. Moreover, soil P increasing below the surface layer was observed on sites with sandy soil, suggesting long-term recycled water irrigation could impose some risk for P leaching on sandy soil.

Keywords

nitrogen, phosphorus, turfgrass, recycled water, irrigation

1. Introduction

Climate change and increasing demands of water have caused water supplies to dwindle in arid and semi-arid climates. To conserve finite water sources, western states of the USA have long implemented reuse programs for municipal wastewater (California Department of Water Resources, 2013). The strategy behind that is to reclaim the increased volume of wastewater and to reduce freshwater demand (US EPA, 2012). Urban landscapes and golf courses are the leading users of recycled wastewater. Throughout the western US, large volumes of municipal recycled water are being used to irrigate community parks, golf courses, schoolyards, and other urban green spaces (Devitt et. al., 2004; GCSAA, 2009; Qian & Mecham, 2005; US EPA, 2012). Water reuse for irrigation in urban green spaces and landscapes is a powerful means of water conservation and water reclamation. Due to their dense plant canopy and active root systems, turfgrass landscapes are increasingly viewed as environmentally desirable disposal sites for recycled water. While the conservation benefits of wastewater reuse in landscape and turfgrass irrigation are clear, concerns associated with wastewater reuse may include potential contamination of ground water caused by leaching of excess nutrients.

Recycled water contains significant concentrations of organic and inorganic nutrients, especially nitrogen and phosphate, macro-nutrients essential for plant growth (Hashem & Xi, 2021). Turfgrasses could utilize a significant amount of water and nutrients in the recycled water. Recycled water irrigation can contribute significantly to a reduction in fertilization need (Isweiri et al., 2022). However, there are also concerns that the contaminants and excess nutrients in the recycled water can make their way into the ground or surface water supplies when recycled water is used for landscape irrigation. Specific concerns are that nitrate and phosphorus will move through the soil profile and cause ground water contamination. Phosphorus may also run off into surface waters, promoting algal blooms and eutrophication. Hayes *et al.* (1990) found that 16 months of recycled water irrigation for turf increased soil nitrate and P concentrations at 0-13 cm by 53% and 210%, respectively. However, Evanylo *et al.* (2010) reported that turfgrass assimilated high amounts of N and P with minimal potential losses to ground water. The success of irrigating urban landscapes with recycled water depends on the ability of the soil and landscape plant systems to integrate the nutrients presented in recycled water.

Information is limited about the long-term soil nitrate and phosphorus changes at different depths of the soil profile. The unique and innovative aspect of this study was long-term and deeper soil samplings that provided opportunities to examine nitrate and phosphorus movement in the soil profile. In this study, the long-term (11 years) effects of recycled water irrigation on the nitrate and phosphorus concentrations in the soil were studied. The objectives of this study were: 1) to assess changes in soil nitrate and phosphorus after 5 and 11 yr of recycled water irrigation on eight landscape facilities by collecting and analyzing soils at the start of using recycled water for irrigation, and after 5 and 11 yr of recycled water irrigation, 2) evaluate soil NO_3-N and P concentrations changes along the soil profiles at 0-100 cm depth on two golf courses and at 0 - 40 cm depth on 5 metropolitan parks.

2. Method

2.1 Site Description

Facilities included in this study were two golf courses, five metropolitan parks, and one school ground. Study sites information have described in a previous publication (Lin & Qian, 2019; Qian & Lin, 2019). All research sites were transitioned to recycled water irrigation in 2004 and have received the same recycled water source for irrigation.

Prior to 2004, two parks and one golf course were irrigated by raw ditch water, and the other landscape sites were irrigated with potable water. Compared with the freshwater and potable water used prior to 2004, recycled water contained higher levels of NO_3–N, P, Na, total dissolved solids, and bicarbonate, which may pose agronomic and environmental concerns (Qian & Harivandi, 2007). The average water quality values of recycled water, potable water, and ditch water are presented Qian and Lin (2019). Established Kentucky bluegrass was grown on all park and school ground sites and perennial ryegrass and Kentucky bluegrass mixture were grown on golf course fairways. All sites received approximately 60 to 75 cm of recycled water and were fertilized at 75 kg ha^{-1} N annually. No synthetic P fertilizer was applied.

2.2 Soil Sampling and Analysis

Soil Sampling Procedures were described in Qian and Lin (2019). Briefly. in July to September 2004, at the commencement of recycled water irrigation, baseline soil samples were collected. All sampling sites were managed as urban turfgrass during the past 25+ yr. In July to September 2009 and 2015, 5 and 11 years after the initiation of recycled water for irrigation, we collected and tested soils again less than 30 cm from these original sites.

At each location, 3-6 sites were randomly selected for sampling. At each sample site, three cores were collected using a hand-held boring tool. At parks and school ground, samples were taken at 0-20 and 20-40 cm depths; at golf course fairways, samples were taken to 100 cm at 20 increments.

Soil samples were tested at the Soil, Water, and Plant Testing Laboratory at Colorado State University. Each soil sample was tested for soil texture, soil NO_3-N, P, pH, soil organic matter, and other element concentrations.

Ammonium-bicarbonate-DTPA (AB-DTPA) solution was added to soil samples to analyze liable P. The Ammonium Bicarbonate—DTPA is a multi—element soil test for alkaline soils developed by Soltanpour (1991) and others (Rodriguez et al., 1994). Phosphorus concentration was measured by colorimeter after adding ammonium-bicarbonate-DTPA extract and ascorbic acid into the soil samples. Nitrate- nitrogen was determined by flow-injection Cd reduction analysis.

The Walkley Black method was used to test for organic matter content. Soil pH were analyzed using a saturated paste extract and measured using a pH meter (Model 2700, Oakton Benchtop pH Meter).

2.3 Statistical Analysis

All data from eight facilities were pooled and were subjected to ANOVA test, and significant differences in soil SOM, soil NO_3-N, soil P, and soil pH prior to, five, and eleven years after recycled water irrigation began were determined by using the general linear model (GLM) procedure (SAS Institute, 2017). Least Significant Difference test (LSD) was set at $P \leq 0.05$.

Data from eight landscape facilities at each depth were also analyzed separately. At each facility, three to six sites were treated as replications. Comparisons were made for the three sampling years at each landscape facility at each depth for soil NO_3-N and AB-DTPA extracted liable P concentrations using ANOVA (SAS Institute, 2017). The results are presented in Tables 1-2 for sites sampled to 40 cm in depth and in figures for golf course study sites where soil was sampled to 100 cm deep (Figures 1, 2).

3. Results and Discussion

The soil textures were generally sandy loam and loamy sand for sampling sites at golf course I, school ground, and Park III and IV. Golf course II, Park I, Park II and V had clay, clay loam, or loam soil (Qian & Lin, 2019). Comparison of soil pH, salinity, and other chemical properties prior to and five to eleven years after recycled water irrigation were reported in Qian and Lin (2019). The foci of this study are about changes in soil NO_3-N and P Concentrations.

3.1 Soil Nitrate-Nitrogen

When data from all facilities and all depths were pooled, an increase in NO_3-N concentration was not observed under recycled water irrigation. In fact, NO_3-N was 140% lower in 2015 when compared to 2004 and 2009 (Table 1). When data from individual facilities were analyzed separately, no persistent trend was observed for soil NO_3-N (Table 2); it appeared that soil NO_3-N concentration varied greatly with sampling times and sites for parks and the school ground.

Table 1. Mean Soil Chemical Properties from the Eight Landscape Facilities at the Initial (Baseline) and 5 and 11 Years after Recycled Water Irrigation (Soils Were Sampled to 1 m at Golf Courses and 0.4 m at Parks)

	2004	2009	2015
Soil Parameter	Baseline	5 years after	11 years after
pH	7.11b*	7.43a	7.43a
SOM (%)	2.2	2.1	2.3
Extractable P (mg kg^{-1})	13.3ab	12.2b	15.8a
NO3-N(mg kg^{-1})	6.6a	5.5a	2.5b

[*] The mean followed by a letter “a” is significantly higher than the mean followed by a letter “b” for individual parameters at $P \leq 0.05$.

Table 2. Results of Soil NO3 at Depth 0-20 cm and 20-40 cm for Assessment Over Three Different Years (2004, 2009 and 2015) at Six Landscape Locations in Denver

Year	SG*	Park I	Park II	Park III	Park IV	Park V
			0-20 cm			
2004	1.7b[1]	7.7a	8.8a	13.0a	10.0a	6.9a
2009	13.7a	9.5a	2.4b	4.3b	5.63b	6.5a
2015	3.3b	3.2b	2.2b	3.5b	2.83c	5.1a
			20-40 cm			
2004	1.3b	3.2b	2.3a	4.3a	2.9a	N.A.[2]
2009	11.6a	7.8a	2.1a	1.9b	1.5b	N.A.
2015	1.7b	2.0c	1.7a	1.7b	1.7b	N.A.
			P value			
Depth 1×2	0.55 ^{ns}	0.14 ^{ns}	0.27 ns	0.05	0.06	N.A.

* SG = The school ground; depth 1= 0-20 cm, depth 2 = 20-40 cm.

[1] Within an individual location, each depth with different letters a,b,c are significantly different at $P \leq 0.05$, ns= non-significant. All units in two depths are mg kg^{-1}.

[2] N.A., not available.

On both golf courses, soil NO_3-N concentration decreased with soil depth; ANOVA results indicated mean nitrate concentration at 0-20 cm depth (7.88 mg kg^{-1}) was significantly higher than deeper depths (in the range of 1.98 to 3.68 mg kg^{-1}) ($P < 0.05$), suggesting that the turfgrass root system was effective in nitrate uptake (Figure 1). Nitrate–N dropped below 2 mg kg^{-1} below 60 cm soil profile (beyond the turfgrass rootzone) in 2015. This is well below the EPA standard for potable water quality (10 mg kg^{-1}). The fact that we did not observe an increase soil NO_3-N under recycled water irrigation and NO_3–N dropped significantly below 60 cm soil profile indicates that nitrate contamination of groundwater should not be a great concern when using recycled water for the irrigation of turf systems (Figure 1). Dense, actively growing turfgrass facilitated the removal of excess nitrate and further reclamation of treated wastewater. When compared to agricultural sites, a properly managed turfgrass site would have less problem with nitrate leaching down into groundwater if best management practices are utilized.

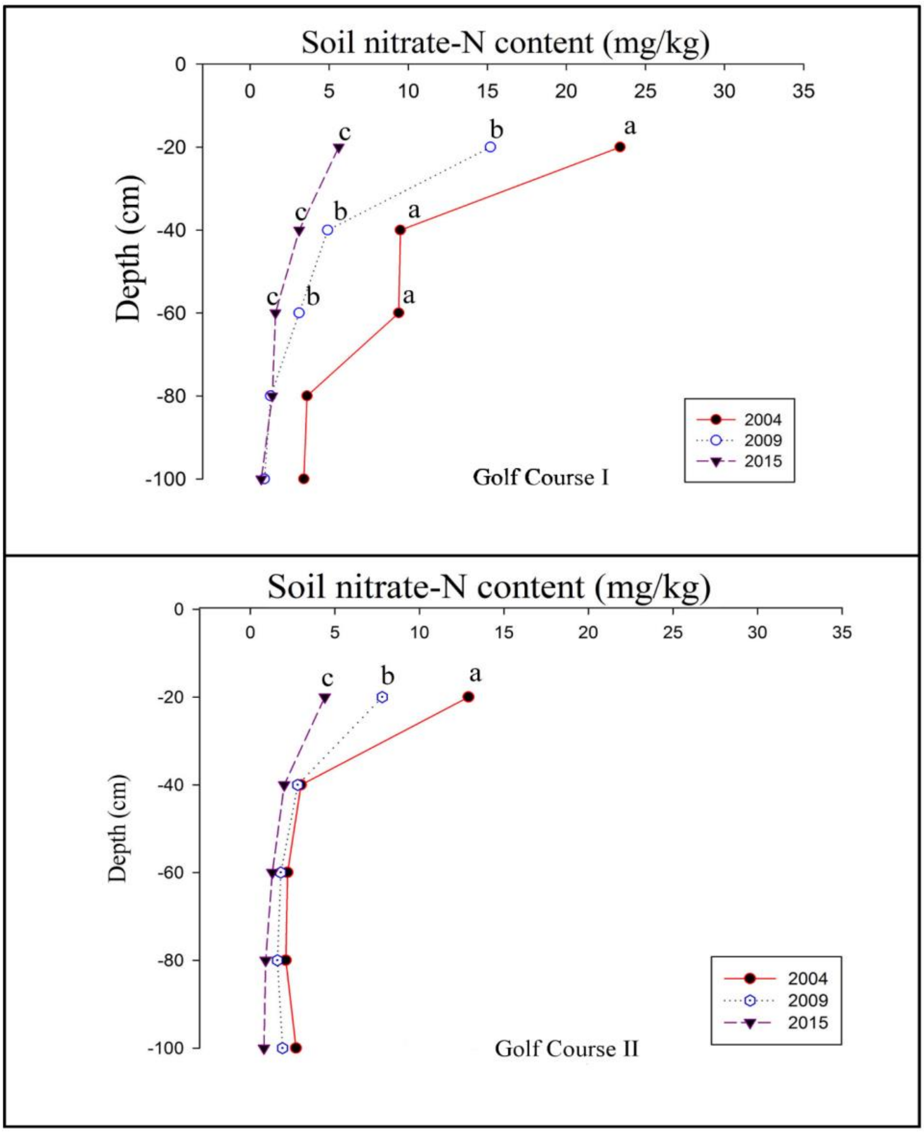

Figure 1. Soil Nitrate-Nitrogen of 2004, 2009 and 2015 at Golf Course I and II

Letters indicate significant difference ($P \leq 0.05$) among years at each depth, and no letters shown indicate not statistically significant.

In a 2-year-study, Ma *et al.* (2018) demonstrated that the average concentrations of NO_3--N in leachate from a turfgrass system with a load of 600 kg N ha^{-1} yr^{-1} from wastewater were 2.96 and 0.80 mg L^{-1},whereas the average concentrations of NO_3 - N from a bare soil leachate were 38.9 and 36.8 mg L^{-1}. The authors stated that turfgrass uptake contribution to 52.5–61.0% nitrogen removal under a nitrogen pollution load of 600 kg N $ha^{-1}yr^{-1}$, indicating that turfgrass play an important role in subsurface wastewater nitrogen removal. Other research has also indicated properly managed turfgrass systems have little problem with nitrogen leaching down into groundwater if best management practices are utilized (Hayes et al., 1990; Higby & Bell, 1999).

Previous research has shown that several factors including soil type (Barton et al., 2005; Geza et al., 2021) and turf species (Thomas et al., 2006) may affect the leaching of nitrate from recycled wastewater. A three-year study conducted on a silty clay soil by Thomas *et al.* (2006) found nitrate in leachate passing below 76 cm when grass was watered with recycled water. Thomas et al. further reported that nitrate concentrations varied over the course of the study from 0.10 to 32.7 mg N L^{-1}, and N concentrations exceeded the drinking water standard of 10 mg L^{-1} on only 6 of 71 sampling dates, primarily during periods of the year when turfgrass growth was slowed and not actively growing. In a 3- month greenhouse experiment, using the HYDRUS model, Geza *et al.* (2021) demonstrated greater nitrate leaching in coarse sand compared to loamy sand. Further they found greater nitrate leaching in buffalograss than bermudagrass and reasoned that more N was taken up by bermudagrass due to a higher nitrogen requirement of bermudagrass. However, Thomas *et al.* (2006) found no difference between the amount of leachate collected between bermudagrass or zoysiagrass. A possible explanation for this is that the nitrogen requirements of both species are similar.

Time of year may also affect nitrate leaching from soils irrigated with recycled wastewater. Thomas *et al.* (2006) observed greater leaching during months when warm season turfgrasses were less actively growing, although no seasonal effect on nitrate leaching was found on recycled water irrigated pasture of ryegrass and white clover in New Zealand (Barton et al., 2005).

3.2 Soil Phosphorus (P)

When all data were pooled for analysis, soil P concentration was higher in 2015 than in 2009 (Table 1).

Table 3. Results of Soil P (AB-DTPA Extracted) at Soil Depth 0-20 cm and 20-40 cm for Assessment over Three Different Years (2004, 2009 and 2015) at Six Landscape Locations in Denver

Year	SG Sandy Loam	Park I Clay loam	Park II Clay loam/ Loam	Park III Sandy Loam	Park IV Sandy Loam	Park V Loam
				0-20 cm		
2004	50.9b	6.5b	18.7a	23.9b	15.2a	22.9a
2009	26.2c	6.2b	21.4a	34.9a	19.7a	14.6b
2015	74.2a	11.9a	17.6a	35.2a	17.6a	14.6b
				20-40 cm		
2004	9.7c	3.4a	12.0a	11.6b	9.9b	N.A.
2009	12.8b	3.5a	15.7a	17.0a	14.8a	N.A.
2015	17.9a	6.3a	15.6a	20.7a	15.3a	N.A.
					P value	
Depth	0.02	0.23^{ns}	0.007	0.03	0.001	N.A

1×2

* SG = The school ground; depth1= 0-20cm, depth 2 = 20-40 cm. Within an individual location, each depth with different letters a, b, c are significantly different at $P \leq 0.05$, ns = non-significant. All units in two depths are mg kg^{-1}.

When data from individual locations were analyzed separately, the school ground, Park I, and Park III had higher soil P concentration 11 years after recycled water irrigation at the surface depths (Table 3). At 20-40 cm below soil surface, 11 years recycled water irrigation increased soil P concentration by 55 – 84% at the school ground (where the soil texture was sandy loam and the baseline P level was elevated at the surface 0-20 cm) and Park III and IV, where the soil texture was sandy loam (Qian and Lin 2019) (Table 3). The elevated baseline P presented at the surface depth and/or sandy soil likely contributed to the increase in P concentration at 20-40 cm depths 11 years after recycled water irrigation at those facilities (Table 3). In contrast, Park II and V with loam/clay loam soils showed no increase in soil P over 11 years with recycled water irrigation (Table 3). In this study, we observed increased soil P concentration at 20-40 cm depths 11 years after recycled water irrigation mostly on sandy soil (Table 3). Our study results contrast to Barton *et al.* (2005). By comparing phosphorus concentration at a 70 cm soil profile from four soil types of pasture lands irrigated with recycled wastewater, Barton *et al.* (19) found that irrigation with recycled wastewater increased P leaching only in the Gley soil, a poorly drained soil formed in clayey estuarine alluvium. The author attributed the increased leaching of P in Gley soil to preferential flow that reduced contact between the recycled water and the soil matrix.

For Golf Course I where soil texture was sandy loam and loamy sand, no significant difference in soil P was found at 0-20, 20-40, 40-60, and 80-100 cm depths prior to and after recycled water irrigation. However recycled water irrigation increased soil P at 60-80 cm soil depth, suggesting that P migration into deep soil profile likely occurred in this site with sandy soil (Figure 2). On Golf Course II, 11 years recycled water irrigation increased soil P concentration by 22% at the 0-20 cm soil depth. No difference was found from 20 to 100 cm soil depth. This was because Golf Course II had clay loam and clay soils, which have a high P sorption capacity. For all except one location, phosphorus levels were significantly lower at depths deeper than 0-20 cm ($P < 0.05$) (Figure 2; Table 3); this is because phosphorus is considered immobile (Bray, 1954). However, data from Golf Course I, the school ground, and Park III and IV suggested that movement of phosphorus in recycled water through the soil profile is possible at sites where soils are sandy and/or P level was elevated at the surface depth after 11 years of recycled water irrigation. We observed an increase in P concentration of surface soil (by 45-145%) at 4 out of 8 research facilities. Although soil P level was not related to P concentration in runoff from home lawns in NY with a narrow range of soil P level, Soldat and Petrovic (2008) found P level in soil was related to P concentration in runoff from turfgrass cross a wider range of soil P levels. Therefore, the risk of phosphorus runoff into surface waters may increase with increased surface soil P concentration.

This indicates that long-term recycled water irrigation contributes to increase in the available P in the soil, especially in the surface soil. In this study, the increase in soil P increase was observed despite the fact of increased soil pH in all study sites (Qian & Lin, 2019). Increased soil pH could have reduced measurable soil P concentration since phosphorus could bind to calcium at high pH, leaving less free phosphate ions available in solution. Similarly results of increase in soil P were reported by Mancino and Pepper (1992), Mohammad and Mazaherh (2003), and Skiles and Qian (2013).

Our study advocated that proper nutrient management of wastewater irrigation and periodic monitoring of soil and groundwater parameters are required to ensure successful, safe, and long-term recycled wastewater irrigation. The management of nitrogen and phosphorus to prevent possible groundwater or surface water contamination is one of the key issues for the long-term sustainable use of recycled water-irrigated land (1997).

4. Conclusions

This study of 11 years of recycled water irrigation on landscapes found that compared to baseline data, no significant increase in soil NO_3-N concentration was observed. However, there is an increase in the amount of phosphorus at the surface 0-20 cm and 20-40 cm of the soil 11 years of recycled water irrigation. At deep soil depth, P increased was only observed on sites with sandy soil, suggesting long-term recycled water irrigation does impose some risk for P leaching on coarse texture soil. It is necessary to reduce nitrogen and phosphorous fertilization when recycled water is used for irrigation and account for the fertilizer present in recycled wastewater. Findings reported in this paper and our previous publication (Qian & Lin, 2019) demonstrated that despite the clear benefits of recycled water reuse in urban landscapes, there are concerns relating to soil property changes. These findings will aid in sustainable urban planning and development of environmentally-sound policies for urban green spaces.

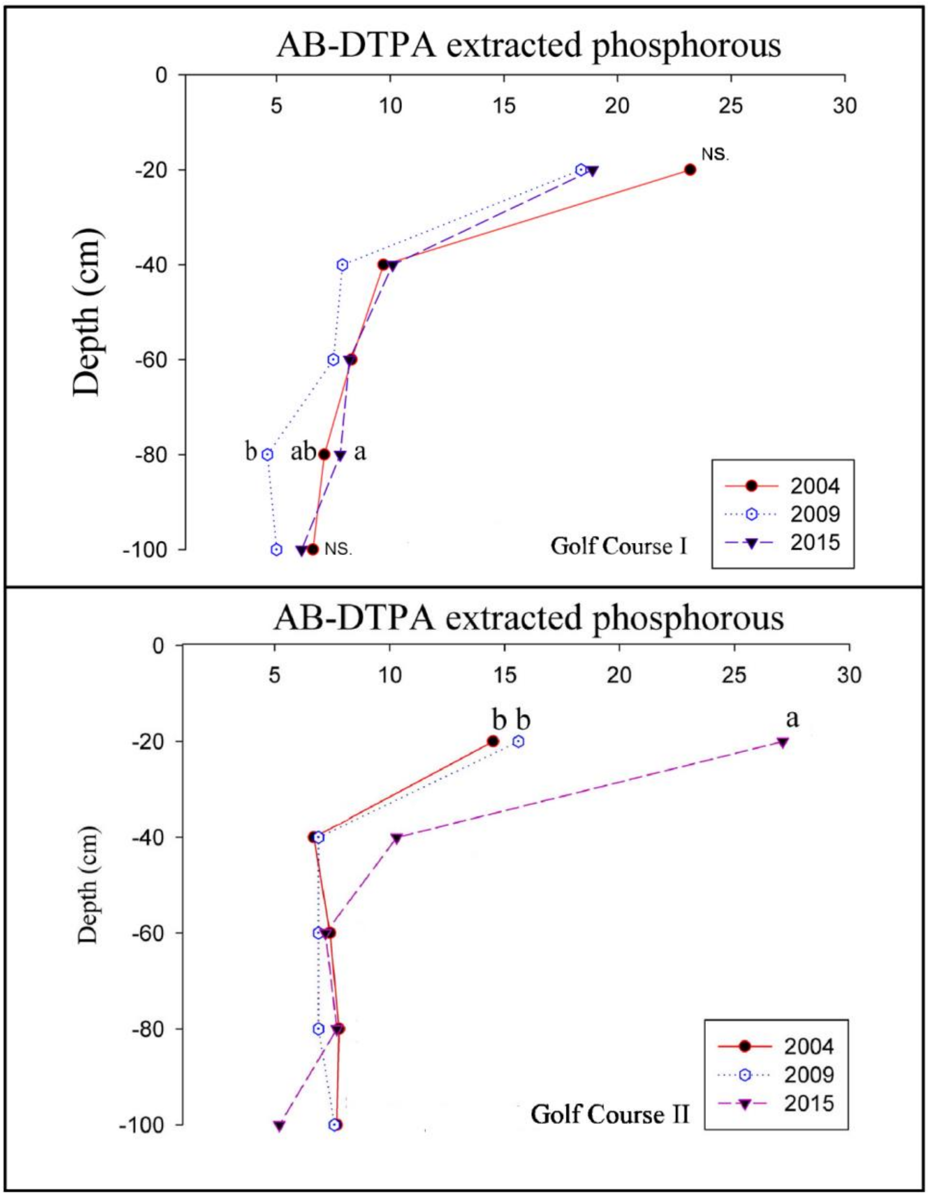

Figure 2. Soil Extractable Phosphorus of 2004, 2009 and 2015 at Golf Course I and II

Letters indicate significant difference ($P \leq 0.05$) among years at each depth, NS or no letters shown indicate no statistically significant difference.

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