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Long Term Effects of Effluent Water Irrigation on Soil Nitrate and Phosphorus Profiles under Turfgrass

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Abstract: This study seeks to determine whether the use of effluent water over time has an effect on the nitrate and phosphorus content of the soil. We took soil samples from six golf courses that have been irrigating with effluent water for various periods of time. On each golf course soil cores were sampled from three different fairways to a depth of one meter and then subdivided into 20 cm increments. Regression analysis was conducted on the averaged values from each golf course to evaluate the relationship between the length of time of effluent usage and soil nitrate or phosphorus content. Results indicate that though there is no significant correlation between the number of years of irrigating with effluent water and the amount of nitrate in the soil, there is a strong correlation between the number of years of effluent irrigation and the amount of phosphorus at the surface 0-20 cm of the soil. The study strongly advocated that proper management of wastewater irrigation and periodic monitoring of soil and groundwater parameters are required to ensure successful, safe, long term wastewater irrigation.

Key words: Effluent water, nitrate, phosphorus, Turfgrass

INTRODUCTION

Water shortages are becoming increasingly common in the arid and semi arid areas of the USA. Increased use of reclaimed wastewater (RWW), i.e., recycled water, is viewed as one of the approaches to maximize the existing water resource and stretch current urban water supplies (US EPA, 2004). Wastewaters often contain significant concentrations of organic and inorganic nutrients for example nitrogen and phosphate. There is potential for these nutrients present in recycled water to be used as a fertilizer source when the water is recycled as an irrigation source. Golf courses and urban landscapes are by far the leading users of recycled wastewater; intensively managed turfgrasses utilize a significant amount of water and nutrients in the wastewater. However, there are concerns that the contaminants and excess nutrients left in the water after treatment can make their way into the ground or surface water supplies. Specific concerns are that nitrates will move through the soil structure and cause ground water contamination and that phosphorus will run off into surface waters, promoting algal blooms and eutrophication.

Research done in southern US has indicated that dense, well-managed turfgrass areas are among the best bio-filtration systems available for removal of excess nutrients (Hayes *et al*., 1990). A properly managed golf course will have little problem with nitrogen leaching down into groundwater, or phosphorus running off to surface waters if best management practices are utilized, including fertilizing in several smaller applications instead of one large one and watering shortly after fertilizer application (Higby and Bell, 1999). The concern is that with the water containing the nutrients, there may be a conflict with how much nutrients vs. how much water the turf needs for maintaining desired color and growth. In applying enough water to maintain desirable turfgrass quality, more nutrients than needed may be applied, thus exceeding the turf's agronomic rate, or rate of nutrient use. Compounding the problem, during the summer months when the nutrient requirements of the cool season turfgrass are lower, more water is being applied to maintain the green turf system.

To date, the contribution of water reuse to water conservation varies by location. Water reuse satisfied 25% of the water demand in Israel, for example, where 66%

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of total treated sewage is reused (Avnimelech, 1993). Water reuse is expected to reach 10 to 13% of water demand in the next few years in Australia and California (Lazarova and Asano, 2005).

Throughout the US, large volumes of municipal recycled water is being used to irrigate golf courses, community parks, cemeteries, athletic fields, schoolyards, roadsides, street medians, industrial and residential landscapes and other urban landscape sites (Golf Course Superintendents Association of America, 2003; US EPA, 2004; Qian, 2004; Qian and Mecham, 2005; Devitt *et al*., 2004, 2005). Mohammad and Mazaherh (2003) focused on change in soil fertility parameters in response to RWW irrigation of forage crops. The average characteristics of wastewater and potable water parameters (mg kg^{-1}) were: PO_4 (49 and 0.03), NH_4 (118 and not determine-ND), NO_3 (29 and 59), Fe (0.14 and ND), Mn (0.07 and ND), Zn (0.03 and ND), Cd (0.04 and ND), Cr (0.01 and ND), Pb (0.02 and ND). In first and second season application of wastewater to crops was 675 and 765 mm, respectively, while application of potable water 540 and 615 mm, respectively. The study revealed that wastewater significantly increased the soil P (9.9 and 9.2 mg kg^{-1}) compared to potable water increased soil P (4.3 and 3.5 mg kg^{-1}) at 0-30 and 30-60 cm soil depth, respectively. Also, wastewater resulted in significant increased in soil K (653 mg kg^{-1}) compared to potable water increased soil K (502 mg kg^{-1}) only at depth of 30-60 cm, while these was no significant change in soil K at 0-30 cm depth. The study concluded that secondary sewage wastewater improved the soil fertility status.

Similarly results of increase in soil fertility were found by Mancino and Papper (1992), secondary sewage effluent containing of phosphorous 27 mg L^{-1}, significant increased the soil P form approximate level of 17 mg kg^{-1} to approximate level of 32 mg kg^{-1}, while with potable water there was reduction soil P form approximate level of 17 mg kg^{-1} to approximate level of 7 mg kg^{-1} in 3.3 years of irrigation to bremudagrass turf.

Hayes *et al*. (1990) studied the effect of secondary sewage effluent on the sandy soil ground under turfgrass cover. And found that after 16 mo of effluent irrigation compared to potable water, effluent was found to increased the soil NO_3-N by 7.8 mg kg^{-1}, P by 31.7 mg kg^{-1}, K by 134 mg kg^{-1} and Na by 6.0 mmol L^{-1}, while there was decrease in the concentration of soil Ca+Mg.

Land application of effluent, as opposed to direct discharge to water ways, is becoming widespread in New Zealand as regulatory authorities move to protect and enhance water quality and meet Maori spiritual and cultural values (Cameron *et al*., 1997; Anonymous, 1999; Wellington Regional Council, 1999a). This method was used to treat effluent from townships, meat works, dairy factories and dairy farms (Schipper and Lloyd-Jones, 1999; Selvarajah, 1996; Cameron *et al*., 1997; Tomer *et al*., 1997; Sparling *et al*., 2001). A major concern in New Zealand at present is the potential impact of farm dairy effluent (FDE) on the environment (Environment Waikato, 1998; Wellington Regional Council, 1999b). Hawke and Summers (2003) reported that the concentrations of total carbon and total Kjeldahl nitrogen were generally low at all depths, the application of effluent caused a significant increase in their concentrations in the upper 10 cm of the profile. Similarly, the concentration of exchangeable cations increased in the upper 10 cm of the profile. The soil showed very low phosphorus retention; however effluent application increased both the total and Olsen phosphorus to 40 cm depth. Most of the changes in soil properties led us to believe that current application rates and pasture production could be maintained and that FDE application improved the soil's long-term fertility or soil quality, especially in the upper 10 cm of the profile. However, there was no evidence to suggest that current application rates are sustainable in terms of other environmental effects (e.g., nitrate leaching). Despite the increasing pressure on farmers to move to land-based application of FDE to decrease impact of effluent on waterways and the considerable research on the impacts of FDE application, the long-term effects on soil properties are not fully known (Degens *et al*., 2000). Rusan *et al*. (2007) concluded that long term wastewater irrigation increased salts, organic matter and plant nutrients in the soil. Also, wastewater irrigation had no significant effect on soil heavy metals (Pb and Cd) regardless of duration of wastewater irrigation.

The main objective of land-based effluent application is to utilize the chemical, physical and biological properties of the soil/plant system to assimilate the waste components without adversely affecting soil quality or releasing potential contaminants to water bodies (including the groundwater) or the atmosphere; hence, the area of land and the soil physical, chemical and biological conditions are important in order to achieve this objective (Cameron *et al*., 1997; Sparling *et al*., 2001). The management of nitrogen and phosphorus to prevent possible groundwater or surface water contamination is a key issue for the long-term sustainable use of effluent-irrigated land (Falkiner and Polglase, 1997). To avoid adverse effects on the environment and human health, rules have been set by some regional councils to restrict the rate of Farm Dairy Effluent (FDE) application; however, such rules fail to take into account the heterogeneous nature of soil (Silva *et al*., 1999).

There are some problems associated with the long-term use of effluent water for irrigation such as change in the soil's physical and chemical properties. The majority of the studies on a turf system's ability to uptake nutrients have been done on young plots (<10 years). We are interested in examining the long-term effects of effluent water irrigation on the nitrate and phosphorus concentrations in the soil. The objectives of this study were: 1): to determine soil NO_3-N and P concentrations at various depths from different golf courses that vary in the time of effluent water usage in the Denver, CO area and 2): to determine the significance of the number of years of effluent water irrigation on nitrate and phosphorus amounts in the soil.

MATERIALS AND METHODS

Sampling and site description: Golf courses for the study were selected on the basis of the number of years of effluent water irrigation. Six golf courses ranging from one to 33 years of effluent water use were sampled. Three fairways were sampled at each course and a total of three soil cores were taken at each fairway. Fairways were sampled using a handheld boring tool, each core was taken to a depth of one-meter and each core separated into 20 cm increments, for a total of five samples per core. The samples from each fairway were combined for a total of 15 samples taken per golf course.

At each golf course three fairways were selected based on their physical characteristics. The soil samples were taken from one fairway with good drainage and the other two with fair to poor drainage at each course. By averaging the data between the three fairways, a reasonable overview of the soil profiles of each course was presented.

The Golf Course No. 1 has been using effluent water irrigation for one year. Fairway soil texture is clay. The turfgrass is fertilized at a rate of 73.5 kg N ha^{-1} $year^{-1}$. The total water applied is approximately 647.7 mm of water per year. The Golf Course No. 2 has been using effluent water irrigation for 3 years. Fairways soil texture is clay loam. The turfgrass is fertilized at a rate of 73.5 kg N ha^{-1} $year^{-1}$. Fairways are irrigated with 254-508 mm of water per year. The Golf Course No. 3 has been using effluent water irrigation for thirteen years. Fairway soil texture is clay. The turfgrass is fertilized at a rate of 196 kg N ha^{-1} $year^{-1}$. The total irrigation water applied is approximately 508-762 mm of water per year. The Golf Course No. 4 has been using effluent water irrigation for thirteen years. Fairway soil texture is clay. The turfgrass is fertilized at a rate of 98 kg N ha^{-1} $year^{-1}$. The irrigation water applied is approximately 610 mm of water per year. The Golf Course No. 5 has been using effluent water irrigation for seventeen years. Fairway soil texture is sandy clay loam. The turfgrass is fertilized at a rate of 73.5 kg N ha^{-1} $year^{-1}$. The total irrigation water applied is around 508-762 mm of water per year. The Golf Course No. 6 has been using effluent water irrigation for thirty-three years. Fairway soil texture is clay. The turfgrass is fertilized at a rate of 98 kg N ha^{-1} $year^{-1}$. The total irrigation water applied ranged between 508-762 mm of water per year (Table 1).

Table 1: Golf courses selected for the study

Golf course	Age (years)	Effluent use (years)	Soil texture
1	27	1	Clay
2	5	3	Clay loam
3	13	13	Clay
4	29	14	Clay
5	47	17	Sandy clay loam
6	33	33	Clay

Determination of soil nitrate and phosphorus content: Extractable soil phosphorus data was collected using the AB-DTPA Soltanpour and Schwab method. Phosphorus content is determined spectrophotometrically at 882 nm at an acidity of 0.18 M H_2SO_4 (Rodriguez *et al*., 1994) by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony (Murphy and Riley, 1962). Soil nitrate was determined by using a two molar KCl extract and running it through a flow injector (Spark, 1996).

Statistical analysis: Statistical analysis was performed using PC-SAS version 8.0 to determine differences among sites, years and depths of soil nitrate and phosphorus. Regression analysis was conducted to evaluate the relationship between the length of time of effluent water usage and soil nitrate or phosphorus content.

RESULTS AND DISCUSSION

In general, NO_3 contents decreased significantly with soil depth, suggesting that the turfgrass root system was very effective for nitrate uptake (Fig. 1). Exceptions were observed at the golf course No. 6 tenth fairway and the golf course No. 3 eleventh fairway, where higher nitrate content was found at the 20-40 cm depth. At both locations, soils are poorly drained and anaerobic conditions were identified approximately 40-50 cm below soil surface.

The average value of the three fairways from each course was used in order to compare golf courses by the number of years of effluent use (Table 2). Although, there were significant differences between the various courses at each depth, but there was no clear indication that the number of years of effluent water irrigation affected the nitrate level in the soil ($r = 0.01$, $p = 0.7$). Since, there was no statistical correlation between the number of years of effluent use and the nitrate levels in the soil, it was clear

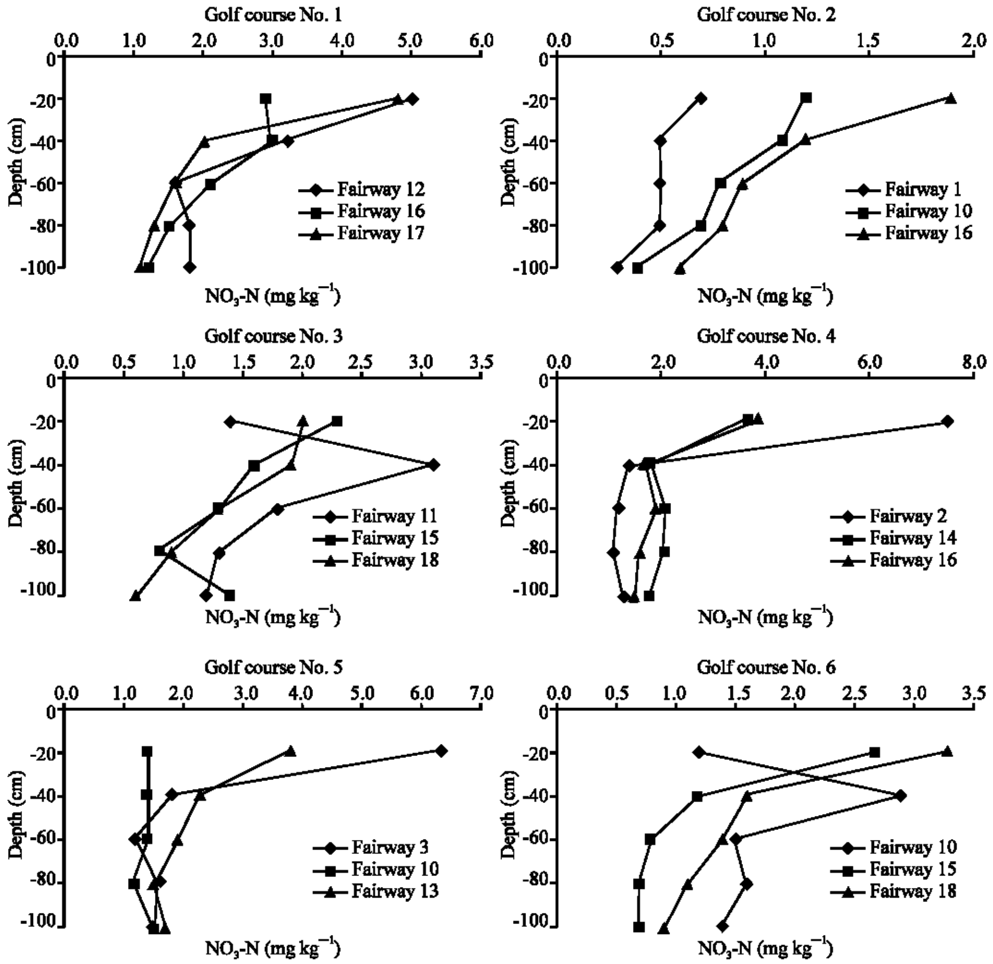

Fig. 1: Soil nitrate concentrations from six sites at 20 cm depth increments to one meter deep

Table 2: Mean concentration of soil NO_3-N from 6 sites

	Sites					
	1	2	3	4	5	6
Depth (cm)	(mg NO_3-N kg^{-1})					
0-20	4.23	1.3	1.90	5.03	3.83	2.40
20-40	2.73	0.9	2.20	1.63	1.83	1.90
40-60	1.77	0.7	1.47	1.73	1.50	1.20
60-80	1.53	0.7	1.00	1.60	1.43	1.10
80-100	1.37	0.4	1.07	1.55	1.57	1.03

Sites are arranged by years of effluent use, youngest to oldest

Table 3: Mean contents of soil P from six sites

	Sites					
	1	2	3	4	5	6
Depth (cm)	(mg P kg^{-1})					
0-20	9.90	4.6	11.53	16.73	15.50	27.03
20-40	7.40	3.4	5.53	4.83	8.03	5.87
40-60	3.01	1.7	4.50	2.00	6.47	3.43
60-80	3.01	1.9	4.57	4.73	3.30	2.33
80-100	2.50	1.4	3.30	4.80	2.80	2.33

Sites are arranged by years of effluent use, youngest to oldest

that the nitrate levels beyond the turfgrass root zone are low (<2 mg kg^{-1}) and were below the EPA standard for potable water quality (10 mg kg^{-1}). This indicates that nitrate contamination of groundwater should not be a concern when using effluent water for the irrigation of turf systems.

Statistical analysis was performed to determine differences among sites, years and depths of soil phosphorus. Data from the three sampled fairways were averaged together to show the length of effluent use on extractable soil P content (Table 3). Phosphorus levels were consistently higher at the 0-20 cm depth than the deeper depths and there is a clear trend showing that the number of years of effluent use affected the amount of phosphorus at the soil surface depths ($r = 0.69$, $p = 0.002$).

The golf course No. 1 did not appear to follow the general trend as there was more phosphorus in the soil than one might expect having used effluent irrigation for such a short time. However, although this golf course has only been using effluent water irrigation for one year, it is an older golf course than the golf course No. 2, which

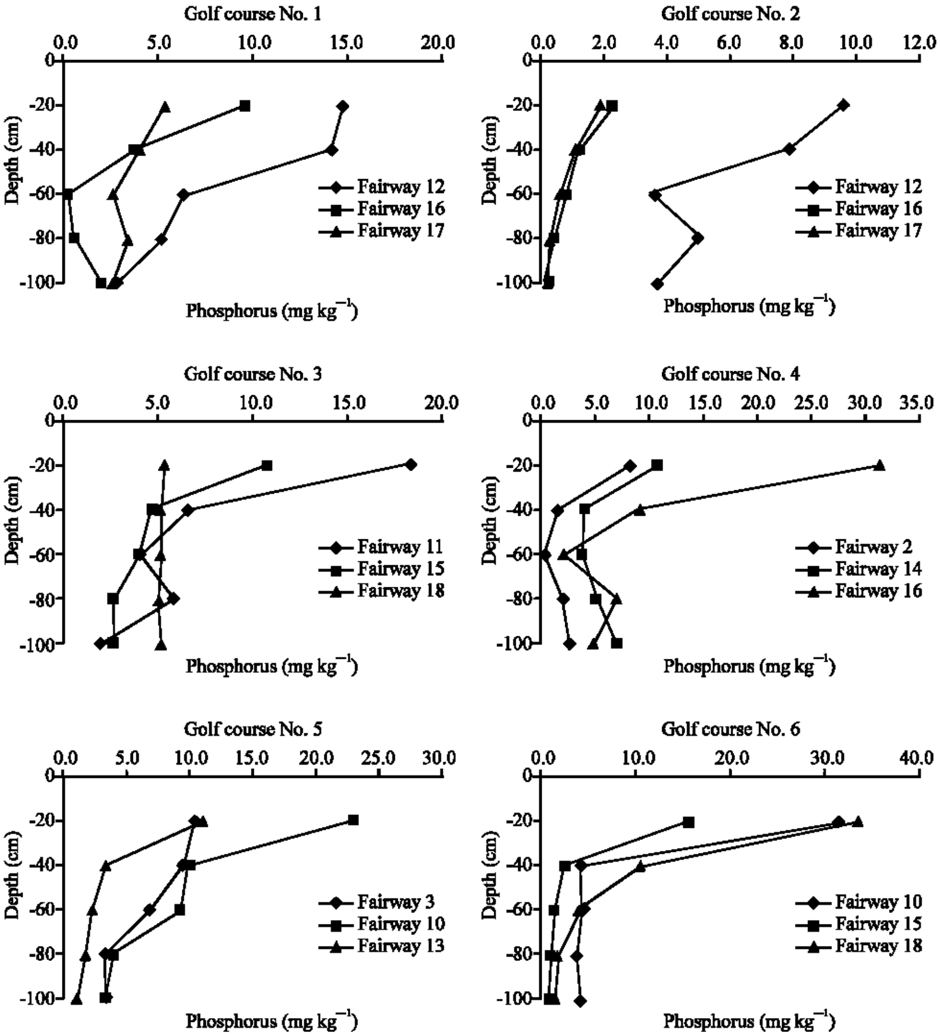

Fig. 2: Soil phosphorus concentrations from six sites at 20 cm depth increments to 1 m deep

could explain this anomaly. In addition, the golf course No. 5 had higher phosphorus concentrations at lower depths than the courses that have used effluent irrigation for a greater number of years. While phosphorus is often considered immobile, the coarse (sandy) soil texture of the golf course No. 5 allowed increased percolation and therefore increased movement of phosphorus through the soil structure (Fig. 2).

The concentration of phosphorus in the upper levels of soil in these courses, particularly those that have been using effluent water for many years, exceeded the very high limit according to the AB-DTBA test that was used to measure phosphorus concentrations (James, 2000). Still, the water features of the golf courses did not display the discoloration or odor associated with the algal blooms caused by excess phosphorus runoff, indicating that the turf is effective at preventing phosphorus runoff. Any change in land use that would require removing the turf will also require some kind of remediation to prevent excessive amounts of phosphorus from entering the watershed. Similar results were reported by Hawke and Summers (2003) who stated that the effluent application increased both total and Olsen phosphorus to 40 cm soil depth.

CONCLUSIONS

There was no correlation between the number of years of effluent irrigation and the amount of nitrate in the soil. A strong correlation was observed between the number of years of effluent irrigation and the amount of phosphorus in the soil. The phosphorus levels in the soil resulting from effluent water use were very high and tend to remain in the upper levels of the soil structure. The study strongly advocated that proper management of wastewater irrigation and periodic monitoring of soil and groundwater parameters are required to ensure successful, safe, long term wastewater irrigation.

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