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Preliminary field study of soil TKN in a wastewater land application system

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ABSTRACT

An accurate nitrogen mass balance is necessary when designing a municipal wastewater land application system in order to reduce the potential for nitrogen contamination of groundwater. Limited information on soil total Kjehldahl nitrogen (TKN) is available to estimate the TKN variance in the soil that can be used for calculating the nitrogen mass balance. This study investigated the soil TKN temporal variance at two different depth ranges within three different soil types irrigated with municipal wastewater effluent in a short-term at a long-term running site under field conditions. Three plots were chosen with each plot growing different plants and with different soil types in Lubbock, Texas, USA. Kruskal–Wallis one way analysis of variance on ranks and Mann–Whitney rank sum test were employed to compare the differences of medians of many groups of data and of two groups of data at $p < 0.05$, respectively. The results show that there was no significant difference among the medians of monthly soil TKN in the depth of 46–61 cm for all three test plots. The risk for nitrogen leaching should be highly considered when the crop grown is alfalfa and during the winter season. Wheat and hay grazer rotation and Bermuda grass are better options to maintain a relatively stable soil TKN. The study calls on further and more detailed field investigations and to quantify the soil TKN at a municipal wastewater land application site in order for more accurate modeling, simulation and prediction of nitrogen leaching.

1. Introduction

Currently, municipal wastewater land application is widely used as an approach to reuse, treat and dispose wastewater in the world (Davison et al., 2006). Its benefits contain reducing pressure on freshwater resources due to agricultural and urban turf irrigation in arid and semi-arid areas as well as saving fertilizer by taking advantage of the nutrients in the wastewater (Toze, 2004; Lazarova and Bahri, 2005; Duan and Fedler, 2007). However, the land application of wastewater possibly brings negative effects including nitrogen contamination to groundwater (Barton et al., 2005; Duan and Fedler, 2010; Tzanakakis et al., 2011) and soil degradations (Duan et al., 2010a).

To control nitrogen leaching, an accurate nitrogen mass balance is required. One challenging issue designers face is how to accurately quantify the soil nitrogen (Duan et al., 2010b). Soil nitrogen mainly consists of total Kjehldahl nitrogen (TKN) and nitrate nitrogen. In soils, nitrate nitrogen is more mobile and not readily retained in the plant root zone caused by electric charge's repelling force between negatively charged nitrate ions and negatively charged soil particles. Therefore, soil TKN is often used to evaluate soil nitrogen storage capacity and to indicate the soil fertility status (Bendfeldt et al., 2001). Nitrogen cycling is complicated (Schipper and McGill, 2008) in wastewater land application systems controlled by multiple factors primarily including applied nitrogen, applied wastewater amount, soil moisture (He et al., 2013), soil temperature, and plant and bacteria uptakes. Unfortunately, limited information is available on soil TKN specifically in wastewater land application systems for a designer and manager for reference.

The objective of this paper was to investigate the soil TKN temporal variance at different depth ranges within three different soil types growing different plants over a one-year period of time at a long-term running land application site irrigated with secondary wastewater effluent, all under field conditions.

2. Methodology

2.1. Field site

This study was conducted at the City of Lubbock Land Application Site (LLAS) in the State of Texas, USA. The Lubbock

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region has a semi-arid climate. Since 1986, the primary irrigation method of secondary treated municipal wastewater effluent is center pivot irrigation systems covering thirty-one treatment plots covering a total area of 1027 hectares. The average applied secondary wastewater is 48,264 cubic meters per day. Crops at the LLAS are primarily alfalfa (*Medicago sativa*), winter wheat (*Triticum* sp.), corn (*Zea mays*), wheat grass (*Agropyron* sp.), Bermuda grass (*Cynodon dactylon*), hay grazer (*Cynodon* sp.), Italian rye grass (*Lolium multiflorum*), and other native grasses.

2.2. Wastewater source

The applied secondary wastewater effluent is from the Southeast Water Reclamation Plant of the City of Lubbock, Texas, USA. The applied wastewater strictly complies with national secondary wastewater effluent standards. The treatment capacity is 119, 240 cubic meters per day. Historically, the average concentration of total nitrogen (TN), TKN, ammonia-nitrogen, and nitrate-nitrogen in the treated effluent are 20 mg/L, 5.9 mg/L, 4.8 mg/L, and 13.2 mg/L, respectively. Wastewater was applied to satisfy the water demand of plants and the leaching requirement for minimizing soil salt accumulation (Duan et al., 2011).

2.3. Water and soil sampling

The research period was for one year from July to June. Plots 6, 9, and 13 were chosen at the LLAS planted with alfalfa, wheat or hay grazer rotation, and Bermuda grass during the research period, respectively. Plots 6, 9, and 13 have had wastewater applied to the land for 10, 14, and 69 years prior to the study, respectively. The soil types are Amarillo Fine Sandy Loam in Plot 6, primarily Acuff Loam and Amarillo Fine Sandy Loam in Plot 9, and a combination of Acuff Loam, Estacado Clay Loam, Friona Loam, and Mansker Clay Loam in Plot 13.

Three irrigation water samples were collected monthly at each of these three plots and immediately analyzed in the lab for TN, nitrate-nitrogen, ammonia-nitrogen and TKN in the lab of the Department of Civil and Environmental Engineering at Texas Tech University. In addition, three random soil samples were collected at the end of each month at each of these three plots from two soil depths, 0 to 15 cm (Depth 1) and 46 cm to 61 cm (Depth 2), and immediately analyzed for soil TKN in the same lab.

2.4. Data analysis

A monthly water balance was calculated using the method introduced by Duan and Fedler (2009). The applied water amount used in the water balance was obtained from the irrigation records at the LLAS. The precipitation data as well as air temperature was collected from NOAA Climatological Data for Lubbock, Texas, and the evapotranspiration was calculated by Penman-Montieth Method (Borrelli et al., 1998). The applied nitrogen mass for each month was the product of the average monthly nitrogen concentration and the quantity of applied water on each plot.

All statistical tests were conducted by using the software package SigmaStat for Windows version 3.10 (SystatSoftware, 2004). One-way analysis of variance (ANOVA) and *t*-test was used to compare the differences of averages of many groups of data and of two groups of data at $p < 0.05$ level, respectively. In cases where the tests of normality and/or equal variance fail, Kruskal–Wallis one way analysis of variance on ranks and Mann–Whitney rank sum test were employed to compare the differences of medians of many groups of data and of two groups of data at $p < 0.05$, respectively.

3. Results and discussion

3.1. Monthly average temperature and monthly water balance

During the research period, the monthly average temperature ranged from 27 °C to 5 °C (Table 1). The highest and lowest monthly average temperature occurs in August and December, respectively. Evapotranspiration (ET) at Plots 6 and 13 had relatively lower values (Table 1) from November to February than in the other months because planted crops were at slow growing stage or even stopped growth. ET at Plot 9 was higher from March to July than in the other months due to wheat or hay grazer rotation specific growth cycle. The total precipitation (PPT) during the 12-month period was 511 mm with the monthly average of 43 mm. The maximum PPT, 215 mm, occurred in June while the lowest PPT, 0 or 1 mm, occurred in the months of November, January, and February (Table 1). The monthly average irrigation was 102 mm, 105 mm, and 75 mm at Plot 6, 9, and 13, respectively. Primary leaching occurred in March, April, and June on Plot 6, from September to March on Plot 9, and in October, December, and June on Plot 13.

3.2. Applied nitrogen mass and soil TKN

Applied nitrogen mass (Table 2) was determined by applied wastewater amount (Table 1) and nitrogen concentration (Table 2). Applied nitrogen is one of the factors that affect the soil TKN. Soil TKN on Plot 6 with alfalfa planted showed a similar pattern (Table 3) in both depth ranges. Soil TKN in the lower layer (Depth 2) had slightly higher values than in the upper layer. Soil TKN

Table 1
Monthly average temperature and water balance at plots.

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Average temperature, °C	27	26	22	16	9	5	4	6	10	16	21	25
	Plot 6 (Alfalfa)											
Evapotranspiration, mm	212	196	150	122	84	67	66	78	128	160	188	204
Precipitation, mm	20	16	83	15	0	27	0	1	71	42	20	215
Applied water, mm	99	121	138	8	101	123	79	100	128	137	77	111
Water leaching, mm	0	0	0	0	0	0	0	0	54	19	0	31
	Plot 9 (Wheat/Hay grazer)											
Evapotranspiration, mm	182	37	18	77	66	71	71	83	113	150	171	216
Precipitation, mm	20	16	83	15	0	27	0	1	71	42	20	215
Applied water, mm	50	106	110	204	140	107	82	108	91	66	102	93
Water leaching, mm	0	0	149	143	73	63	11	26	49	0	0	2
	Plot 13 (Bermuda grass)											
Evapotranspiration, mm	189	175	134	108	70	56	54	65	113	141	168	183
Precipitation, mm	20	16	83	15	0	27	0	1	71	42	20	215
Applied water, mm	37	57	85	184	74	62	48	75	35	73	68	106
Water leaching, mm	0	0	0	24	5	33	0	5	0	0	0	37