Irrigation with Recycled Wastewater: The NDMA Story

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BACKGROUND

The scarcity of water supply in many arid regions, combined with the need for disposal of large volumes of wastewater, has led to an increased use of recycled water for landscape irrigation. Although this practice has been employed for decades in many parts of the world, public health officials recently have begun to express concerns about the potential for wastewater-derived trace contaminants to contaminate potable water supplies. The trace contaminants in recycled wastewater include steroid hormones, pharmaceuticals, personal care products, and chlorination byproducts such as *N*-nitrosodimethylamine or NDMA. Known for its high cancer potency, NDMA is detected frequently in municipal wastewater effluent at concentrations up to 1000 parts per trillion (ppt), including at a number of wastewater treatment plants in California. California Department of Health Services (CDHS) has set a reporting level of only 10 ppt for NDMA. As a result of such stringent guidelines, reuse of wastewater is being scrutinized for potential to introduce NDMA into groundwater, particularly through practices such as use of recycled wastewater for groundwater recharge and landscape irrigation.

Earlier studies show that NDMA has negligible affinity for soils but moderate to long persistence in soil. These characteristics suggest that NDMA may readily move through soil and contaminate groundwater if NDMA-containing wastewater is applied at the soil surface. To evaluate the leaching risk of NDMA during the use of recycled water for irrigating turfgrass soils, researchers at UC Riverside and UC Berkeley conducted a field study in the summer of 2004 using the lysimetered turfgrass plots located at the UCR Agriculture Experimental Station. Recycled water was trucked in from a local wastewater treatment plant and used to irrigate mature turfgrass plots, and leachate was monitored for about 4 months for appearance of NDMA. Findings from this study have been published in two papers in *Journal of Environmental Quality* (Gan et al., 2006; Arienzo et al., 2006). Copies of these publications are available upon request from Jay Gan at jgan@ucr.edu. This study and its main outcomes are briefly reviewed here.

STUDY SETUP AND PROCEDURES

Test Plots

The field study was carried out in turfgrass plots that were constructed in 1992 and transplanted in 1994 with Tifway II bermudagrass (*Cynodon dactylon* X *C. transvaalensis*). Each plot was 3.7 × 3.7 m in dimension and was equipped with a separate sprinkler system with four pop-up sprinklers situated at the corners. At the time of construction, the top 90 cm was filled with soil, either a sandy loam or a loamy sand, while the bottom layer (8 cm) was paved with gravel. At the center of each plot, a cluster of five 55-gallon steel drums were similarly filled with the soil and gravel. Leachate from each drum was directed through a galvanized steel conduit pipe to an outlet at the edge of the field (see pictures). At the time of this study, soil samples were taken and analyzed for organic matter content and texture. Both soils contained little organic matter below the thatch layer. Both soils were highly sandy, and are highly conducive for water movement.

Source of Wastewater

Nitrified, filtered wastewater effluent, collected after chlorine disinfection was transported from a City of Riverside wastewater treatment plant using water trucks and stored in a 6000-gallon opaque polyethylene tank at the study site. A total of five tanks of treated wastewater were used for irrigation over a period of 113 days. During the study, samples were taken once a week from the tank and analyzed for NDMA. The overall concentration of NDMA in the received wastewater was high (Figure 1), and no additional NDMA was spiked into the water before it was used for irrigation.

Field study test plots were retrofitted and only recycled water was used for irrigation

Treatments and Leachate Collection

Eight bermudagrass plots, four for each soil type, were used for the irrigation study. The field study was conducted from June 15 to October 8 in 2004. No precipitation occurred during the period of the study, and the test plots received water solely from irrigation of recycled water. The average daily air maximum, air minimum, and mean soil temperatures were 31.5, 15.8, and 22.8 °C, respectively. The average maximum, minimum, and mean relative humidity values were 71, 29, and 52%, respectively. The warm and dry conditions, which are typical of southwestern U.S.

regions during summer, were expected to result in high evapotranspiration rates for the turfgrass plots and need for high irrigation rates.

Four treatments, each in two random plots, were included in this study: two soil types (a sandy loam soil and a loamy sand soil), and two irrigation schedules. The two irrigation schedules were used to evaluate the potential effect of sunlight on NDMA leaching, as NDMA is known to be unstable in sunlight. Irrigation occurred at night (from 10:30 PM) or in the daytime (from 7:30 AM). The irrigation rate was frequently adjusted based on California Irrigation Management Information System (CIMIS) reference evapotranspiration (ETo) measured at the site. The irrigation rate was maintained at 110-130% of ETo during the first 11 weeks and was increased to 160% ETo thereafter to further increase the leachate flux. These irrigation rates were higher than normal and were used to create a worst-case scenario.

Recycled water was transported to the study site and stored in a 6000-gallon tank.

Leachate was collected from each plot for 4 months.

Leachate from each plot was collected in an opaque polyethylene container. Three times a week, the leachate samples were transferred into 1-L brown glass bottles and immediately transported to the laboratory. Samples were analyzed on the same day of sample collection. For quality control, split samples were sent to the Water Quality Laboratories, Long Beach Water District, California, for confirmatory analysis of NDMA.

NDMA Analysis

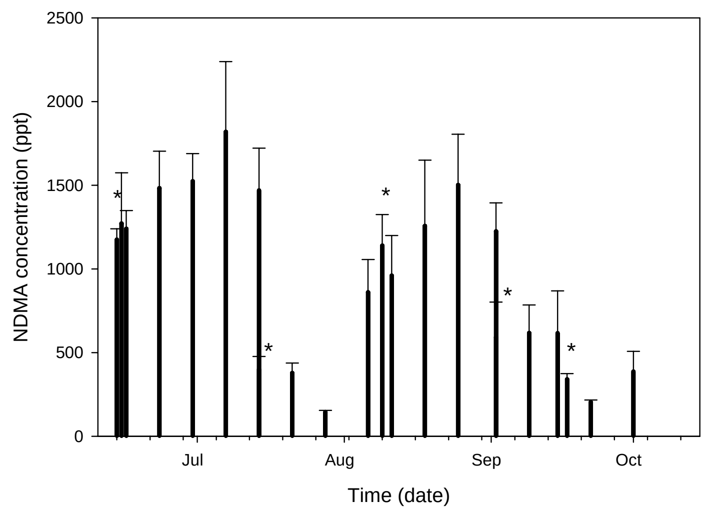
The method used for analyzing NDMA was based on solvent extraction and chromatographic analysis using a stable isotope labeled NDMA as surrogate for calibration. Leachate samples were generally clean and had little background noises. The method detection limit for this procedure was about 2 ppt. Confirmatory analysis of NDMA was performed using similar analytical methods.

STUDY FINDINGS AND INTERPRETATION

NDMA in Wastewater Effluent

The concentration of NDMA in the wastewater effluent was relatively high, with a mean concentration of 930 ppt (Figure 1). The level of NDMA varied drastically from batch to batch, with the lowest concentration in the second and fifth tanks (average concentration of 310 ppt), and the highest level in the first (1420 ppt) and third tanks (1220 ppt). Although the concentrations of NDMA detected here were higher than expected for a wastewater treatment plant that employs nitrification, they were not outside the range of concentrations expected in wastewater effluent that is used for landscape irrigation.

Figure 1. Concentrations of NDMA in wastewater effluents used for irrigation (Bars are mean of three replicates, lines are standard errors, and * indicates time when the tank was filled with a new batch of wastewater effluent).

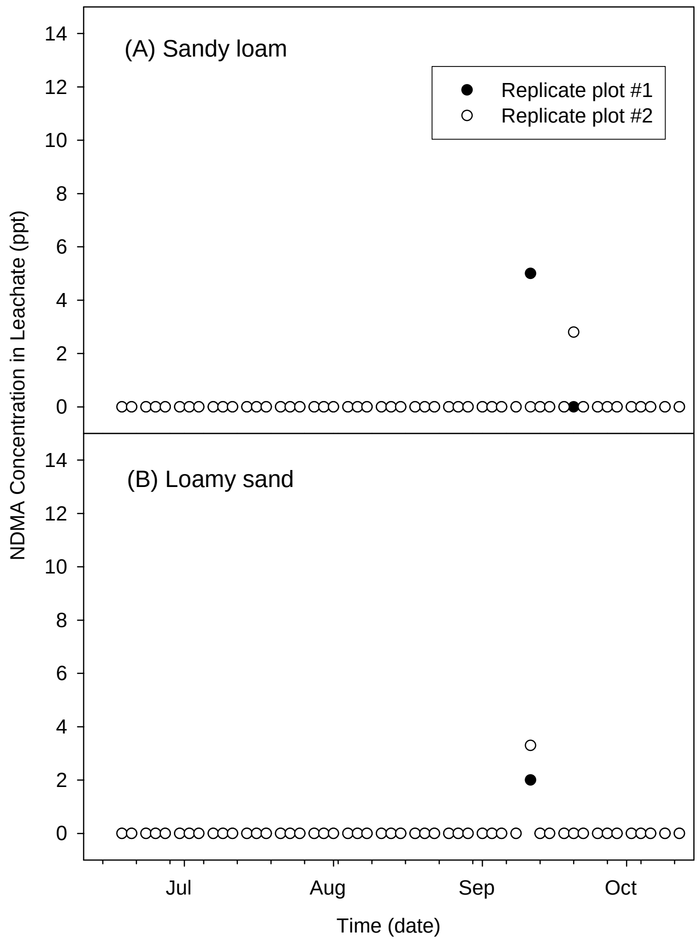


Leaching of NDMA during Wastewater Irrigation

From June 16 through October 12, 2004, leachate from each test plot was sampled and analyzed for a total of 50 times, at a frequency of 3 times per week. In most samples, NDMA was not detected (Figures 2 and 3). At a method detection limit of 2 ppt, of the 200 samples taken from the daytime irrigated plots, only 4 samples, or 2%, gave positive NDMA detection (Figure 2). When detected, NDMA concentrations were low, with the highest concentration at 5 ppt. Of the 200 samples taken from the nighttime irrigated plots, only 6 samples, or 3.0%, had positive detection of NDMA (Figure 3). Similarly, even when detected, the NDMA level, at less than 5 ppt, was very low. Analysis of split samples by external laboratories confirmed that no NDMA was present in the leachate.

No difference was observed between the two irrigation schedules, or between the two soil types. Given that the NDMA

Figure 2. Concentrations of NDMA in leachate water collected from the turfgrass plots irrigated during daytime.



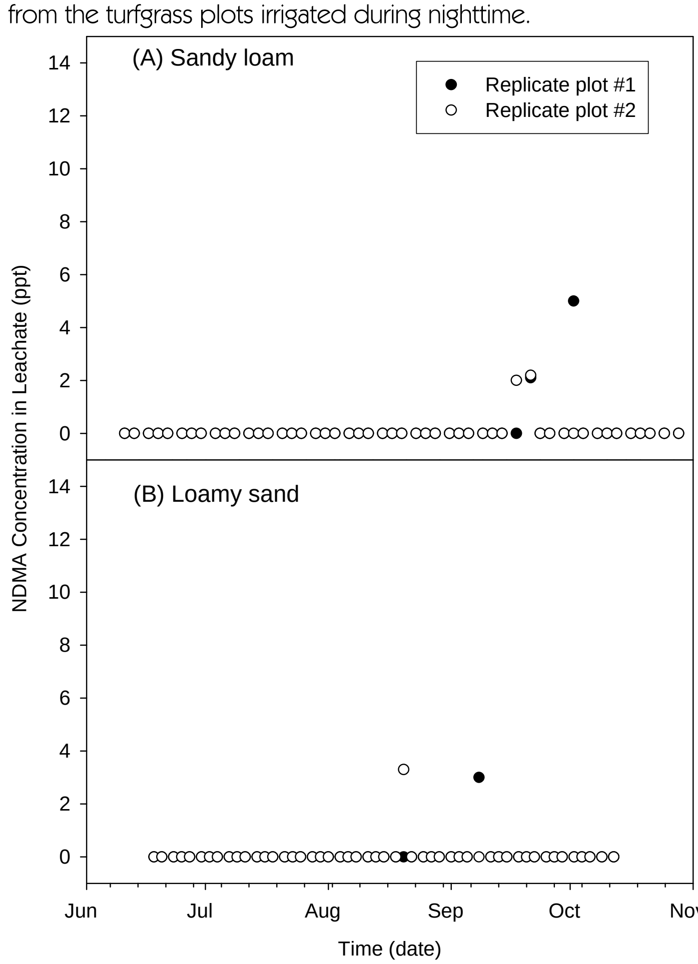
concentration in the input water was always about two orders of magnitude higher than the limit of detection and that excessive irrigation rates were used, it may be concluded that NDMA has little potential for leaching to groundwater when recycled water is used to irrigate turfgrass systems such as golf courses, parks, or lawns under conditions similar to those employed in this study. The lack of NDMA appearance in the leachate also implies that one or more attenuation mechanisms effectively removed NDMA from the soil profile, preventing it from reaching the leachate in the worst-case scenario used in this study.

NDMA Loss Pathways in Turfgrass Systems

NDMA is miscible with water and is negligibly adsorbed to soil, which suggests that NDMA should have a high leaching potential. We measured adsorption coefficient of NDMA in the turfgrass soils, and found that NDMA was essentially not adsorbed in turfgrass soils. We also measured degradation of NDMA in the test soils and found that the half-life of NDMA was over 5 days in the turfgrass soils. Given the sandy texture and the limited distance from the surface to the leachate exit point, it may be concluded that degradation did not contribute appreciably to the rapid NDMA removal. We further measured uptake of NDMA by turfgrass under field conditions, and found that the removal due to plant uptake was no more than 3%.

The above observations suggest that volatilization was the only possible loss pathway for NDMA that effectively prevented its downward movement. The rapid NDMA volatilization loss was likely a result of both rapid NDMA volatilization at the soil-air interface, and active upward transport of NDMA due to efficient gaseous phase diffusion and negative water potential gradients expected under dry, warm conditions in the soil. Volatilization of NDMA from water was measured under ambient conditions. Volatilization loss of NDMA from water at 20 °C was rapid even under static conditions, with a first-order half-life of about 25 hours. Rapid volatilization loss of NDMA was further observed to occur from a layer of moist soil under similar laboratory conditions, with half-life of only 10 hours. Much more rapid volatilization may be expected to occur in the field where volatilization at the soil-air interface is facilitated by much greater wind speed and higher temperatures. Furthermore, under field conditions, in addition to gas phase transport, the water-miscible NDMA may also move along with soil water. The dense and fibrous roots of turfgrass may promote extremely active upward movement of soil water, and the upward moving water may have transported NDMA to the soil surface, where it volatilizes into the air.

Figure 3. Concentrations of NDMA in leachate water collected from the turfgrass plots irrigated during nighttime.



SUMMARY

In conclusion, although perceived as a high leaching contaminant, NDMA introduced through surface irrigation of recycled wastewater was found to not leach through a 1-m profile of turfgrass soil under field conditions. The limited NDMA leaching was likely due to rapid NDMA volatilization that was a result of its volatility and active upward water movement in the turfgrass system. As the field irrigation study was carried out under scenarios that were conducive to rapid leaching of NDMA, it may be concluded that most of the NDMA applied to soil will not leach to groundwater if recycled water is used to irrigate golf courses, parks, or other landscaped areas. The mitigation capacity of turfgrass should be further investigated for other trace contaminants, such as pharmaceuticals and hormones.◆

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News from the UCR Turfgrass Program

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For the complete article, please see the May 2006 "News" available on the UCR Turf website (http://ucrturf.ucr.edu) under "Publications".

Summary: Although perceived as a high leaching contaminant, ***N*-nitrosodimethylamine or NDMA**, introduced through surface irrigation of recycled wastewater was found to not leach through a 3.4-ft profile of turfgrass soil under field conditions. The limited NDMA leaching was likely due to rapid NDMA volatilization that was a result of its volatility and active upward water movement in the turfgrass system. As the field irrigation study was carried out under scenarios that were conducive to rapid leaching of NDMA, it may be concluded that most of the NDMA applied to soil will not leach to groundwater if recycled water is used to irrigate golf courses, parks, or other landscaped areas. The mitigation capacity of turfgrass should be further investigated for other trace contaminants, such as pharmaceuticals and hormones.

Background: The scarcity of water supply in many arid regions, combined with the need for disposal of large volumes of wastewater, has led to an increased use of recycled water for landscape irrigation. Although this practice has been employed for decades in many parts of the world, public health officials recently have begun to express concerns about the potential for wastewater-derived trace contaminants to contaminate potable water supplies. The trace contaminants in recycled wastewater include steroid hormones, pharmaceuticals, personal care products, and chlorination byproducts such as NDMA. Known for its high cancer potency, NDMA is detected frequently in municipal wastewater effluent at concentrations up to 1000 parts per trillion (ppt), including at a number of wastewater treatment plants in California. California Department of Health Services has set a reporting level of only 10 ppt for NDMA. As a result of such stringent guidelines, reuse of wastewater is being scrutinized for potential to introduce NDMA into groundwater, particularly through practices such as use of recycled wastewater for groundwater recharge and landscape irrigation.

Objectives: To evaluate leaching of NDMA during the use of recycled water for irrigating turfgrass maintained under actual field conditions.

Materials and Methods: A field study was conducted during the summer of 2004 using the lysimetered turfgrass plot facility located at the UCR Agricultural Experiment Station. Plots in this facility were constructed in such a way that allows for the collection of water (leachate) that drains below the turfgrass plots. Each plot was: 12.0 × 12.0 ft; constructed with either a sandy loam or a loamy sand; individually controlled and irrigated; and covered with a well-established Tifway II bermudagrass which was maintained under conditions similar to a fairway. Wastewater effluent, collected after chlorine disinfection, was transported from a City of Riverside wastewater treatment plant using water trucks and stored in a 6000-gallon opaque polyethylene tank at the study site. A total of five tanks of treated wastewater were used for irrigation over a period of 113 days. During the study, samples were taken once a week from the tank and analyzed for NDMA.

Four treatments, each in two random plots, were included in this study: two soil types and two irrigation schedules. The two irrigation schedules were used to evaluate the potential effect of sunlight on NDMA leaching, as NDMA is known to be unstable in sunlight. Irrigation occurred at night (from 10:30 p.m.) or in the daytime (from 7:30 a.m.). The irrigation rate was frequently adjusted based on CIMIS ET_o measured at the site. The irrigation rate was maintained at 110-130% ET_o during the first 11 weeks and was increased to 160% ET_o thereafter to further increase the leachate flux. These irrigation rates were higher than normal and were used to create a worst-case scenario. From June 16 through October 12, 2004, leachate from each plot was collected in an opaque polyethylene container, transferred into 1-liter brown glass bottles, and then immediately transported to the laboratory for analysis of NDMA concentration. There were a total of 50 leachate sample collections that involved three collections per week.

Findings: The concentration of NDMA *in the wastewater effluent that was stored in the tank* was relatively high, with a mean concentration of 930 ppt. The concentration of NDMA *in the leachate* was not detected in most samples (the method detection limit was 2 ppt). Of the 200 samples taken from the daytime irrigated plots, only 4 samples, or 2%, gave positive NDMA detection. When detected, NDMA concentrations were low, with the highest concentration at 5 ppt. of the 200 samples taken from the nighttime irrigated plots, only 6 samples, or 3.0%, gave positive NDMA detection. Similarly, even when detected, NDMA concentrations were low, with the highest concentration at less than 5 ppt. Analysis of split samples by external laboratories confirmed the accuracy of our NDMA analysis. No difference was observed between the two irrigation schedules, or between the two soil types. It may be concluded that NDMA has little potential for leaching to groundwater when recycled water is used to irrigate turfgrass systems such as golf courses, parks, or lawns under conditions similar to those employed in this study. The lack of NDMA appearance in the leachate also implies that one or more mechanisms effectively removed NDMA from the soil profile, preventing it from reaching the leachate in the worst-case scenario used in this study.

Under laboratory conditions, we measured the adsorption coefficient of NDMA in the turfgrass soils, and found that it was essentially not adsorbed. We also measured chemical breakdown of NDMA in the turfgrass soils and found that the half-life of NDMA was over 5 days. Given the sandy texture and the limited distance from the surface to the leachate exit point, it may be concluded that chemical breakdown did not contribute appreciably to the rapid NDMA removal. We further measured uptake of NDMA by turfgrass under field conditions, and found that the removal due to plant uptake was no more than 3%.

The above observations suggest that volatilization was the only possible loss pathway for NDMA that effectively prevented its downward movement. The rapid NDMA volatilization loss was likely a result of both rapid NDMA volatilization at the soil-air interface, and active upward transport of NDMA due to efficient gaseous phase diffusion and negative water potential gradients expected under dry, warm conditions in the soil. Rapid volatilization of NDMA was measured in the laboratory from water and from a layer of moist soil. Much more rapid volatilization may be expected to occur in the field where volatilization at the soil-air interface is facilitated by much greater wind speed and higher temperatures.