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Biodegradable dissolved organic carbon in urban and remnant soils in south-central Texas, USA

D.M. Cioce [a], J.A. Aitkenhead-Peterson [b,*]

[a] Dept. of Geosciences, Texas A&M University, College Station, TX 77843, USA
[b] Dept. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843, USA

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ABSTRACT

Urban streams have been found to have high exports of dissolved organic carbon (DOC) relative to native land use. While wastewater effluent is considered to be a contributor of carbon to streams, it does not wholly account for high concentrations of DOC above which would be expected from the watershed under native vegetation. This study examined biodegradable DOC (BDOC) in urban and remnant soils in order to understand the influence of urbanization on microbial carbon cycling. Average soil BDOC ranged from 24.4 ± 32.7% in a city parks under mixed, warm-season turfgrass to 52.9 ± 38.4% in remnant forests under senesced mixed forest leaf litter. Highest average soil %BDOC was observed in the soils of multi-family homes (61.4 ± 7.7%), which tended to have more weeds and species diversity and were not exposed to sodic irrigation water. Water extractable soil sodium explained 53% of the variability in %BDOC. Urban soils in the study area are generally irrigated using municipal tap water, which is high in sodium. This may lead to a buildup of sodium in the soil, and the noted reduction in %BDOC resulting in a greater availability of DOC for runoff to surface waters.

1. Introduction

Global population is increasing exponentially and with it the expansion of urban and suburban ecosystems. Between 1982 and 2007, there was a 79% increase (21 million acres) in the extent of land development (O'Driscol et al., 2010) in the southern USA. Yet to date, no research has been reported on the effects of urbanization and suburbanization on the biodegradation of dissolved organic matter (DOM) in urban soils. Given the global increase in urbanization, it was important to examine how urban soils might differ from remnant soils in terms of C cycling. More recent work in the study area showed that increased release of DOC from soil exchange sites and higher DOC reactive soil pools could be explained by time since initial soil disturbance (when the house was built), soil pH, and soil cations (Aitkenhead-Peterson and Cioce, 2013). Soil cations, specifically sodium, increased in urban soils as a result of high sodium in irrigation water (Aitkenhead-Peterson and Cioce, 2013).

The importance of examining biodegradable dissolved organic carbon (DOC) in urban and remnant soils lies in identifying why urban streams tend to have such high exports of DOC relative to native land use (Sickman et al., 2007; Aitkenhead-Peterson et al., 2009; Petrone, 2010). While point source wastewater effluent is recognized as a source of DOC input to urban streams (Sickman et al., 2007), it does not account for the additional DOC exported over and above that which could be expected from the watershed under native vegetation. Based on the effect of irrigation water with high sodium on soil microbial community composition changes in a laboratory experiment (Holgate et al., 2011), we designed the DOC biodegradability study to test the hypothesis that urban soils exposed to high sodium irrigation water would have decreased %BDOC relative to remnant soils due to a repressive effect of soil sodium on soil microbial function. The expectations were that if BDOC was decreased then more DOC would be available for runoff to surface waters. Our alternative hypothesis was that soils below vegetation with a higher N content such as grasses would have increased %BDOC relative to remnant soils below vegetation with a lower N content such as forests.

Biodegradability of dissolved organic matter (DOM) is defined "as the utilization of compounds by microorganisms as measured through the disappearance of DOM or O_2, or by the evolution of CO_2" (Marschner and Kalbitz, 2003). Biodegradability of DOM is controlled by many factors in three categories: intrinsic quality, soil properties, and external factors (Marschner and Kalbitz, 2003).

* Corresponding author.
E-mail addresses: danielle.cioce@gmail.com (D.M. Cioce), jpeterson@ag.tamu.edu (J.A. Aitkenhead-Peterson).

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The main objective of this study was to assess the extent of BDOC in urban and remnant soils, in order to understand the influence of urbanization on soil microbial C cycling and the effect it might have on availability of DOC for runoff.

2. Materials and methods

2.1. Site description

The Bryan/College Station metropolitan area in Brazos County, Texas, had a population of 228,660 in 2010, compared to a population of 184,884 in 2000, an increase of approximately 19% (U.S. Census, 2010; Aitkenhead-Peterson et al., 2011). Soil samples were taken from an area of approximately 300 km^2 which covered the extent of urban (185 km^2) and suburban (115 km^2) land uses in the region. The climate is classified as humid sub-tropical with an average temperature of 20 °C and an average yearly precipitation of 1000 mm, which falls mostly as short, high intensity storms in the spring and fall (Aitkenhead-Peterson et al., 2011). Soils in the region include several soil series, but are dominated by alfisols underlain with marine clays and sandstone (Aitkenhead-Peterson et al., 2011). Urban sites were dominated by warm season mixed turf grasses (*Cynodon dactylon*, *Eremochloa ophiuroides* (Munro) Hack, or *Zoysia japonica*) coupled with various weeds or St. Augustine Grass (*Stenotaphrum secundatum*). Senescent leaves from trees and shrubs (including *Lagerstroemia* or *Quercus* sp.) were also present in some of the urban landscapes. Remnant sites comprised soil beneath forest, forest wetlands, shrub and scrub and pasture that were fragmented in varying degrees by urban development. Urban sites comprised soil beneath turfgrass of commercial, single-family and multi-family homes and city parks. Nineteen sites were selected and comprised eight remnant sites and eleven urban sites.

Municipal tap water is typically used for irrigating landscapes in these urban areas and in the study region has naturally high concentrations of sodium, reported at 206 ± 25 mg Na^+ L^{-1} with a sodium adsorption ratio (SAR) of 34 ± 5 (Pannkuk et al., 2011). Irrigation water is considered sodic when its SAR is >13.

2.2. Soil collection and extraction

Three soil cores (2 cm diameter, 15 cm length) were taken from an area of 1 m^2 at each of the 19 sites and bulked (Table 1). We did not remove the upper organic portion of the soil cores, which tended to be <2 cm and instead used the whole 15 cm for the biodegradation experiment. Soil was air-dried and then sieved (2 mm) to remove stones and roots. Three laboratory replicates were used for each of the 19 sites sampled. 9.0 g of each soil was combined with 90 mL DDW (1:10 soil:water ratio) and shaken at 50 rpm for 4 h. The soil and water mixture was centrifuged at 10,000 *g*-force for 15 min. Supernatant was removed and pH and EC were recorded prior to syringe filtration through a Whatman GF/F filter (nominal pore size 0.7 μm). Approximately 75 mL of extract solution was available from each sample replicate after centrifuging. An aliquot from each extract solution was removed to quantify DOC concentration so that solutions for the biodegradability experiment could be diluted to achieve approximately 20 mg L^{-1} DOC if needed and to assess the water extractable soil chemistry. Typically DOC in soil solution for biodegradability studies should be between 10 and 30 mg/L (McDowell et al., 2006).

2.3. DOC biodegradation

Biodegradation of DOC was based on the 7 day incubation method of McDowell et al. (2006) at 25 °C. 70 mL of the soil extract was inoculated with 10 mL sewage effluent. DOC in effluent ranged from 5.84 to 11.71 mg L^{-1} which added between 0.06 and 0.12 mg DOC to the incubation flasks. This additional DOC represented between 2.9 and 15.2% of the total DOC in the incubation vessel at t = 0. To adjust for the effluent addition which we assumed was non-biodegradable, we removed the mass of added effluent from each sample replicate from the mass of DOC in the incubation flask at t = 7 prior to calculating %BDOC of the soil extracts. Effluent was collected from the Carters Creek wastewater treatment plant in College Station, Texas, after all treatment stages, but before UV disinfection to ensure a viable microbial population. Because of the number of samples and laboratory replicates (19 sites × 3 laboratory reps) and the small size of our incubator, effluent was collected on the mornings prior to 4 separate biodegradability incubations, hence the difference in effluent DOC concentrations. McDowell et al. (2006) reported that the source and community structure of microbes used in batch experiments to degrade DOM did not matter, but that nutrient availability was important to the extent of degradation. A nutrient mixture (2 mL), with concentrations of 1.82 mM nitrogen, 2.43 mM phosphorus, 0.070 mM sulfur, and 2.42 mM potassium, was added to create ideal conditions for DOC biodegradation by microbes (McDowell et al., 2006). Three small pieces (1 cm^2) of ashed filter paper were added to each incubation flask to stabilize microbes (Qualls

Table 1
Average ± standard deviation (3 laboratory replicates) of %BDOC in soils and water extractable soil DOC and cations in urban and remnant soils at 19 different sites.

Land use/land cover classification	Description	Type	Vegetation	Soil pH	Soil %BDOC	DOC	Na^+	K^+	Mg^{2+}	Ca^{2+}
						mg kg^{-1} soil				
Forest	Forest	Remnant	SMFL	8.0 ± 0.5	80.0 ± 0.9	358 ± 6	109 ± 49	89 ± 22	6 ± 3	45 ± 18
Forest	Forest	Remnant	SMFL	6.7 ± 0.1	25.7 ± 14.2	69 ± 12	140 ± 7	99 ± 115	10 ± 0	37 ± 2
Pasture	Pasture	Remnant	FG	6.2 ± 0.1	38.7 ± 4.4	408 ± 147	50 ± 52	65 ± 22	7 ± 1	43 ± 15
Pasture	Pasture	Remnant	FG	9.3 ± 0.2	19.2 ± 4.2	153 ± 10	148 ± 5	25 ± 1	4 ± 0	20 ± 1
Shrub scrub	Shrub	Remnant	FG + SSL	6.5 ± 0	46.7 ± 5.1	129 ± 48	20 ± 3	60 ± 24	2 ± 1	17 ± 0
Shrub scrub	Shrub	Remnant	FG + SSL	6.5 ± 0	35.3 ± 3.8	174 ± 20	61 ± 6	37 ± 17	3 ± 0	30 ± 0
Wet forest	Wetland	Remnant	SMFL	6.8 ± 0.5	24.3 ± 5.0	307 ± 54	109 ± 71	227 ± 205	7 ± 3	51 ± 24
Wet forest	Wetland	Remnant	HP + SMFL	7.4 ± 0.2	23.5 ± 2.6	195 ± 68	124 ± 15	50 ± 11	11 ± 1	96 ± 16
Urban high	Commercial	Urban	MT + W	10.0 ± 0.2	26.7 ± 5.4	724 ± 56	518 ± 35	140 ± 10	19 ± 1	151 ± 10
Urban high	Commercial	Urban	SAT	9.5 ± 0.2	5.4 ± 3.0	388 ± 58	593 ± 29	26 ± 4	15 ± 0	136 ± 0
Urban high	Commercial	Urban	MT	8.4 ± 0.4	29.9 ± 16.7	365 ± 64	253 ± 6	76 ± 21	4 ± 1	33 ± 11
Urban low	Single-family	Urban	MT + SOL	8.0 ± 0.1	23.7 ± 27.0	276 ± 123	110 ± 34	46 ± 15	8 ± 2	64 ± 12
Urban low	Single-family	Urban	MT + SOL	7.6 ± 0	70.0 ± 1.0	269 ± 22	312 ± 248	42 ± 2	5 ± 1	47 ± 1
Urban low	Single-family	Urban	SAT + SOL	7.5 ± 0.2	15.4 ± 2.4	272 ± 2	128 ± 27	54 ± 4	6 ± 1	46 ± 5
Urban med	Multi-family	Urban	MT	7.5 ± 0.3	65.9 ± 1.1	187 ± 25	110 ± 7	59 ± 11	32 ± 10	173 ± 60
Urban med	Multi-family	Urban	MT	8.3 ± 0	52.5 ± 2.8	153 ± 5	159 ± 12	191 ± 15	10 ± 1	84 ± 6
Urban med	Multi-family	Urban	MT + SOL	7.6 ± 0.3	65.9 ± 1.2	345 ± 3	192 ± 29	93 ± 7	5 ± 1	41 ± 10
Urban open	Park	Urban	MT	10.2 ± 0.2	2.3 ± 4.0	909 ± 51	1142 ± 180	71 ± 29	39 ± 0	285 ± 25
Urban open	Park	Urban	MT	9.2 ± 0	48.5 ± 2.7	400 ± 2	390 ± 63	45 ± 4	18 ± 2	165 ± 34

Vegetation codes: MT = fresh mixed warm-season turfgrass, fresh FG = fescue grasses, W = weeds, SOL = senesced ornamental shrub/tree leaf litter, SAT = St. Augustine turfgrass, SSL = senesced shrub leaf litter, SMFL = senesced mixed forest leaf litter.