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Quality of Water from Tile Drains in Fields Treated with Poultry Litter in McLean County, Kentucky

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Contents

Figures

Tables

Tables (Continued)

Quality of Water from Tile Drains in Fields Treated with Poultry Litter in McLean County, Kentucky

E. Glynn Beck[1], Lisa Y. Blue[2], and David A. Atwood[2]

Abstract

Poultry litter (a mixture of feed, manure, and bedding material) is commonly used as a soil amendment to row-crop fields in western Kentucky. Because of feed additives, litter typically has elevated concentrations of contaminants, including metals and anions. These metals and anions can accumulate in the soil and therefore could be transported to surface water through drainage tiles. In order to assess water quality in tile drains, a pilot study was conducted in 2008 in McLean County, Kentucky, in which 10 tile drains and six drainage ditches were sampled for total metals and anions. Seven of the tile-drained fields were amended with poultry litter and three tile-drained fields were not amended. Drainage ditches received discharge from the tile drains. Acidified and unacidified samples were collected for laboratory analysis, and the acidified samples were analyzed for total major and trace metals (aluminum, arsenic, calcium, cadmium, copper, iron, mercury, magnesium, manganese, nickel, lead, and zinc). To determine the association of major and trace metals to suspended material in the water, the unacidified samples were filtered using 0.45- and 0.20-µm filters, and each filtered sample was analyzed for major and trace metals.

Mean concentrations for total calcium and magnesium were similar for the amended and unamended field samples. Total aluminum, iron, and manganese concentrations were higher in the amended-field samples than in the unamended-field samples. Total arsenic, cadmium, and mercury concentrations were below the method detection limits for all samples. Total copper and nickel concentrations were higher in the amended-field samples than in the unamended-field samples.

Calcium, magnesium, and manganese concentrations did not decrease after samples were filtered. Aluminum and iron concentrations decreased, indicating that these metals are associated with suspended sediment in the tile discharge water. Copper and nickel concentrations did not decrease after the samples were filtered.

Chloride, sulfate, and nitrate concentrations were higher in amended-field samples than in unamended-field samples. The mean nitrate concentration for the tile-drain samples from amended fields was above the U.S. Environmental Protection Agency maximum contaminant level of 10 ppm. All phosphate concentrations were below the MDL.

Additional sampling is needed to more thoroughly document concentrations and evaluate the impact of potential contaminants associated with poultry litter on the quality of tile-drain water in Kentucky.

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Introduction

Poultry is Kentucky's highest grossing agricultural commodity (Kentucky Poultry Federation, 2013), with more than 300 million chickens produced annually (U.S. Department of Agriculture, 2011). A large percentage of the birds produced in Kentucky are grown in 400 poultry houses distributed throughout McLean County (Blue and others, 2009). The poultry are fed various additives to promote accelerated growth and treat parasites (Sims, 1995). Many of these additives contain trace metals such as arsenic, copper, and zinc (Sims, 1995). The majority of the trace metals are excreted by the chickens and accumulate in high concentrations in the poultry litter (Anderson and Chamblee, 2001; Jackson and others, 2003). Litter is the floor material in broiler houses that consists of a mixture of feed, manure, and bedding material, such as sawdust, wood shavings, or rice hulls (D'Angelo and others, 2012). Common practice is to dispose of litter by spreading it on nearby pasture and row-crop fields. Litter has a high concentration of nitrogen, phosphorus, and potassium, which improves soil fertility (Coufal and others, 2006). Over time, however, the accumulation of poultry litter can result in elevated concentrations of trace metals and other metals (Daigh and others, 2009; Ashjaei and others, 2011; D'Angelo and others, 2012). Many of the row-crop fields amended with poultry litter, especially in Kentucky, are tile-drained, which removes excess water from the fields to nearby drainage ditches. In 2008, water samples were collected by the Kentucky Geological Survey from 10 tile drains in McLean County (Fig. 1), and were sampled and analyzed for total major and trace metals (aluminum, arsenic, calcium, cadmium, copper, iron, mercury, magnesium, manganese, nickel, lead, and zinc) and anions (F^-, Cl^-, Br^-, NO_2^--N, NO_3^--N, SO_4^{2-}, and PO_4^{3-}). Additional samples were collected and filtered in the laboratory with 0.45- and 0.20-μm filters to determine the association of metals to suspended material in the water. Seven of the sampled tile-drained fields were amended with poultry litter (sites A through G) and three tile-drained fields were not amended with litter (sites H through J) (Fig. A1). Four of the drainage ditches received tile water from amended fields (sites A, C, F, and G) and two received tile water from unamended fields (sites H and I) (Fig. A1).

This report presents water-quality data obtained from the tile drains and drainage ditches sampled in the study area, and some general conclusions about the potential impacts of applying poultry litter to stream water quality. Funding for this project was provided in part by the National Science Foundation's Kentucky Experimental Program to Stimulate Competitive Research.

Appendix 1 shows the locations of tile-drain and drainage-ditch sampling points. Appendix 2

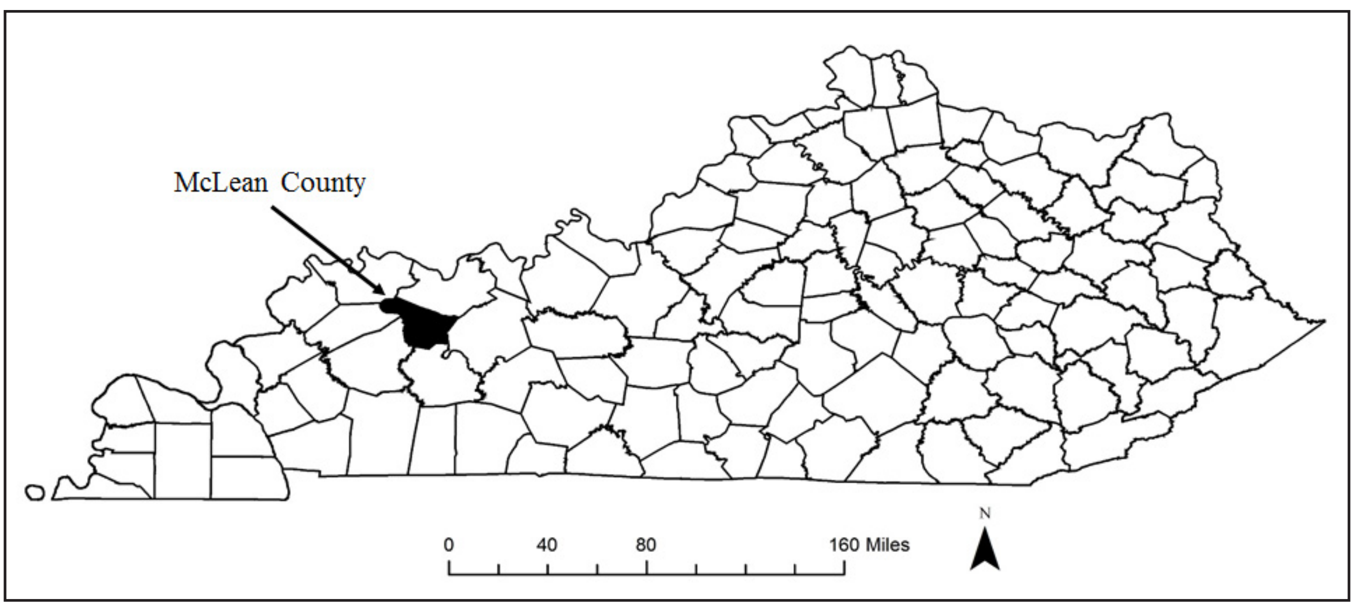

Figure 1. Location of McLean County in Kentucky.

contains water-quality and statistical summaries for all of the tile-drain and drainage-ditch samples.

Sample Sites

Site A

Sample site A is approximately 5.8 mi southwest of Calhoun (Fig. A1). The site is in the southwest corner of a 48-acre row-crop field that was amended with poultry litter in the fall of 2007 (Fig. A2, Table B1). Three sample splits were collected from the tile drain at site A and one split was collected from the drainage ditch just northwest of the tile drain at site A (Table B2).

Sites B and C

Sample sites B and C are approximately 3.7 mi east of Calhoun, north of Ky. 136 (Fig. A1). Sites B and C are along the south-central edge of a 66-acre row-crop field that was amended with poultry litter in the fall of 2007 (Table B1). The tile drain at site B drains the western part of the field, and the tile drain at site C drains the eastern part of the field (Fig. A3). Three sample splits were collected from the tile drains at sites at sites B and C and one split was collected from the drainage ditch just south of the tile drain at site C (Table B2).

Sites D, E, and F

Sample sites D, E, and F are approximately 4 mi east of Calhoun, just north of Ky. 136 (Fig. A1). Tile drains at sites D, E, and F drain three separate fields that are approximately 24, 7, and 28 acres in size, respectively (Fig. A4). Each field was previously amended with poultry litter (Table B1). The tile drain at site D drains the field west of the drainage ditch. The tile drain at site E drains the field north of the sampling location. The tile drain at site F drains the field east of the drainage ditch. Three sample splits were collected from each of the tile drains at sites D, E, and F (Table B2), and one split was collected from the drainage ditch just south of the tile drain at site F (Table B2).

Site G

Sample site G is approximately 4 mi east of Calhoun, just north of Ky. 136 (Fig. A1). The site is in the southwest corner of a 16-acre row-crop field that was amended with litter in the fall of 2007 (Fig. A5, Table B1). Three sample splits were collected from the tile drain at site G and one split was collected from the drainage ditch just south of the tile drain (Table B2).

Site H

Sample site H is approximately 3 mi south of Calhoun, just west of Ky. 81 (Fig. A1, Table B1). The site is in the southeast corner of a 246-acre unamended row-crop field (Fig. A6). Three sample splits were collected from the tile drain at site H and one split was collected from the drainage ditch just south of the sampled tile drain (Table B2).

Sites I and J

Sample sites I and J are approximately 3 mi southwest of Calhoun, south of Ky. 138 (Fig. A1, Table B1). Tile drains at sites I and J drain a 188-acre unamended row-crop field (Figs. A7–A8, respectively). Three sample splits were collected from the tile drains at site I (Table B2) and site J (Table B2). One split was collected from the drainage ditch just west of the tile drain at site I (Table B2).

Methods

Water-Sample Collection

Tile-drain and drainage-ditch water samples were collected using a 1-L plastic beaker taped to an aluminum telescopic handle. Prior to sampling, the plastic beaker was rinsed three times with deionized water and three times with either tile or drainage-ditch water. At least three splits were collected from each tile drain. A separate 250-ml sample was collected for anion and total major- and trace-metal analysis (Table B2) The 250-ml total-metal sample was acidified with nitric acid at the time of collection. An unacidified 1-L sample was collected from each tile drain and drainage ditch for filtration in the laboratory and major- and trace-metal analysis (Table B2). Field measurements (pH, temperature, and dissolved oxygen) and discharge were not recorded at any of the sites.

Analytical Methods

Sample splits were prepared in the field and transported to the laboratory in bottles certified clean by the manufacturer. If preservation was required by analysis protocol, the samples were preserved at the time of collection and kept at a temperature of 4°C until delivered to the University of Kentucky Environmental Research and Training

Laboratory (Table B2); all water analyses were performed there.

Major metals (aluminum, calcium, iron, magnesium, and manganese) and trace metals (copper, mercury, nickel, and zinc) were analyzed using inductively coupled plasma optical emission spectrometry, following methods 3030E and 3120B (American Public Health Association and others, 1998). Concentrations of these metals were recorded in parts per million. Trace metals (arsenic, cadmium, and lead) were analyzed using graphite furnace atomic absorption spectrometry following methods 3030E and 3113B (American Public Health Association and others, 1998). Concentrations of these metals were recorded in parts per billion. After being analyzed for total major and trace metals, the 1-L unacidified tile-drain and drainage-ditch samples were filtered in the laboratory using 0.45- and 0.20-µm filters. Each 0.45- and 0.20-µm filtered sample was analyzed for major and trace metals. The minimum detection level for each major and trace metal is listed in Table B3.

Following EPA method 300.0, anions (F^-, Cl^-, Br^-, NO_2^--N, NO_3^--N, SO_4^{2-}, and PO_4^{-3}) were analyzed using ion chromatography. The MDL for each anion is listed in Table B3.

Results

Total Major and Trace Metals

Tile-drain samples acidified with nitric acid in the field were analyzed to determine total major- and trace-metal concentrations (Table B4). Mean calcium and magnesium concentrations were similar for amended and unamended tile waters (Table B5). This similarity can most likely be attributed to lime being applied as a soil amendment. Aluminum, iron, and manganese concentrations were higher in tile-water samples from amended fields than from unamended fields (Table B2). These results may indicate that aluminum, iron, and manganese are accumulating in the amended soils over time and are being transported through the soil column, most likely via macropores, to the underlying tile drain. All of the amended fields are in Karnak soil (Table B1), which has a high montmorillonite clay content (Wells and others, 1993). The montmorillonite could also be a source of the elevated aluminum concentrations in the tile-drain water. Some of the samples from the tile drains from the amended fields had aluminum and manganese concentrations greater than the EPA secondary maximum contaminant levels of 0.2 and 0.05 ppm, respectively (Table B4). All iron concentrations were below the SMCL of 0.3 ppm (Table B4).

Total arsenic, cadmium, and mercury concentrations were below the MDL in all samples (Table B6). Mean concentrations of total copper and nickel in the amended tile samples were 0.535 and 0.033 ppm, respectively (Table B7). Copper concentrations were well below the SMCL of 1.0 ppm. Total copper and nickel concentrations in the three unamended tile samples were below the MDL for each metal (Table B6). These data indicate that elevated copper and nickel concentrations in tile-drain water may be derived from an accumulation of these metals in the amended soil. No samples from amended tile drains contained lead concentrations greater than the MDL (Table B6). One unamended tile-drain sample (from site J) contained lead at a concentration greater than the MDL, but was well below the EPA action level of 15 ppb (Table B6). Only one sample (from site A) contained zinc concentrations greater than the MDL, but that concentration was well below the SMCL of 5 ppm (Table B6).

Dissolved Major and Trace Metals

Tile-Drain Samples. In order to minimize the dissolution of suspended material, the 1-L tile-drain and drainage-ditch splits were not acidified in the field with nitric acid. The goal was to determine if total major- and trace-metal concentrations were linked to the presence of suspended solids. The samples were first analyzed without filtering to determine the unacidified total major- and trace-metal concentrations, then filtered using 0.45- and 0.20-µm filters and analyzed again. Unacidified major-metal concentrations for tile drains in amended and unamended fields are presented in Table B8. Mean concentrations of all of the total (unfiltered) major metals in the unacidified samples (Table B9) are very similar to the acidified total major-metal concentrations (Table B5). Calcium, magnesium, and manganese mean concentrations changed very little, if at all, after the samples were filtered with a 0.45- and 0.20-µm filter (Table B9). Aluminum and iron mean concentrations decreased after the

0.45-µm filtering (Table B9), but mean concentrations increased slightly after the 0.20-µm filtering (Table B9). After the 0.20-µm filtering, mean concentrations were still lower than the unfiltered concentrations, however (Table B9). The decreases in concentration after filtering indicate that a large percentage of aluminum and iron are associated with suspended solids, most likely suspended clay particles.

Like the unacidified total (unfiltered) major metals, unacidified total (unfiltered) trace-metal concentrations (Table B10) were similar to the acidified total-metal concentrations (Table B5). Arsenic, cadmium, mercury, and lead concentrations were below their respective MDL's (Table B10). After filtering, copper, nickel, and zinc mean concentrations showed no significant change (Table B11).

Drainage-Ditch Samples. Unacidified drainage-ditch samples were also collected and analyzed for major and trace metals, following the same protocol used for the unacidified tile-drain samples. Unacidified major-metal concentrations for the drainage-ditch samples are presented in Table B12. Aluminum, iron, magnesium, and manganese mean concentrations were higher in the amended drainage-ditch samples (Table B13) than in the amended tile-drain samples (Table B9), whereas mean calcium concentrations were lower (Table B13). Calcium, magnesium, and manganese mean concentrations in the amended ditches did not change after both filtering rounds (Table B13). Aluminum and iron mean concentrations decreased substantially, however (Table B13), most likely because of the removal of suspended clay particles. Only two samples were collected from unamended ditches; therefore, statistical data are not presented for these samples.

With the exception of one sample, arsenic and zinc concentrations were below the MDL at site I (unfiltered) and site C (0.20 µm), respectively (Table B14). All cadmium and mercury concentrations were below the MDL (Table B14). Mean copper and nickel concentrations in the unfiltered samples (Table B15) were similar to those in the unfiltered tile-drain samples (Table B11). Mean copper and nickel concentrations in the amended ditch samples also showed very little change after filtering (Table B15). Only two samples were collected from unamended ditches; therefore, statistical data are not presented for these samples.

Anions. Anion concentrations for samples collected from all tile drains are presented in Table B16. As expected, mean concentrations of chloride, sulfate, and nitrate in the amended tile-drain samples were significantly higher than those in the unamended tile-drain samples (Table B17). The mean concentration of nitrate for the amended tile-drain samples was greater than the MCL of 10 mg/L (Table B17). All fluoride concentrations were below the SMCL of 4.0 mg/L. All phosphate, nitrite, and bromide concentrations were below the MDL (Table B16).

Conclusions

Ten tile drains and six drainage ditches in McLean County, Kentucky, were sampled for major and trace metals (arsenic, aluminum, calcium, cadmium, copper, iron, mercury, magnesium, manganese, nickel, lead, and zinc) and anions (F^-, Cl^-, Br^-, NO_2^--N, NO_3^--N, SO_4^{2-}, and PO_4^{3-}). Seven of the tile-drained fields were amended with poultry litter and three were not amended. The mean concentrations of total calcium and magnesium for the amended and unamended fields were very similar. Total aluminum, iron, and manganese concentrations were higher in tile-water samples collected from amended fields than from unamended fields. Total arsenic, cadmium, and mercury concentrations were below MDL's in water samples collected from tile drains in fields amended with poultry litter and unamended fields. Total copper and nickel concentrations were greater in the amended-field tile drains than in the unamended-field tile drains.

After filtering, total calcium, magnesium, and manganese concentrations in the amended field samples did not change, which indicates that these metals are not associated with suspended material. Aluminum and iron concentrations decreased significantly after filtering, however, which indicates that these metals are associated with suspended material, most likely clays. Even though copper and nickel were present in the amended-field samples, concentrations did not significantly decrease after filtering.

Chloride, sulfate, and nitrate concentrations were significantly higher in the amended-field samples compared to the unamended-field samples. The mean nitrate concentration for the amended-field samples was greater than the MCL of 10 mg/L. Phosphate concentrations for all tile samples were below the MDL.

Additional tile-drain water-quality data are needed to better evaluate the occurrence and range of metal and anion concentrations derived from poultry-litter-amended and unamended fields in Kentucky.

Acknowledgments

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Appendix 1: Sampling Sites

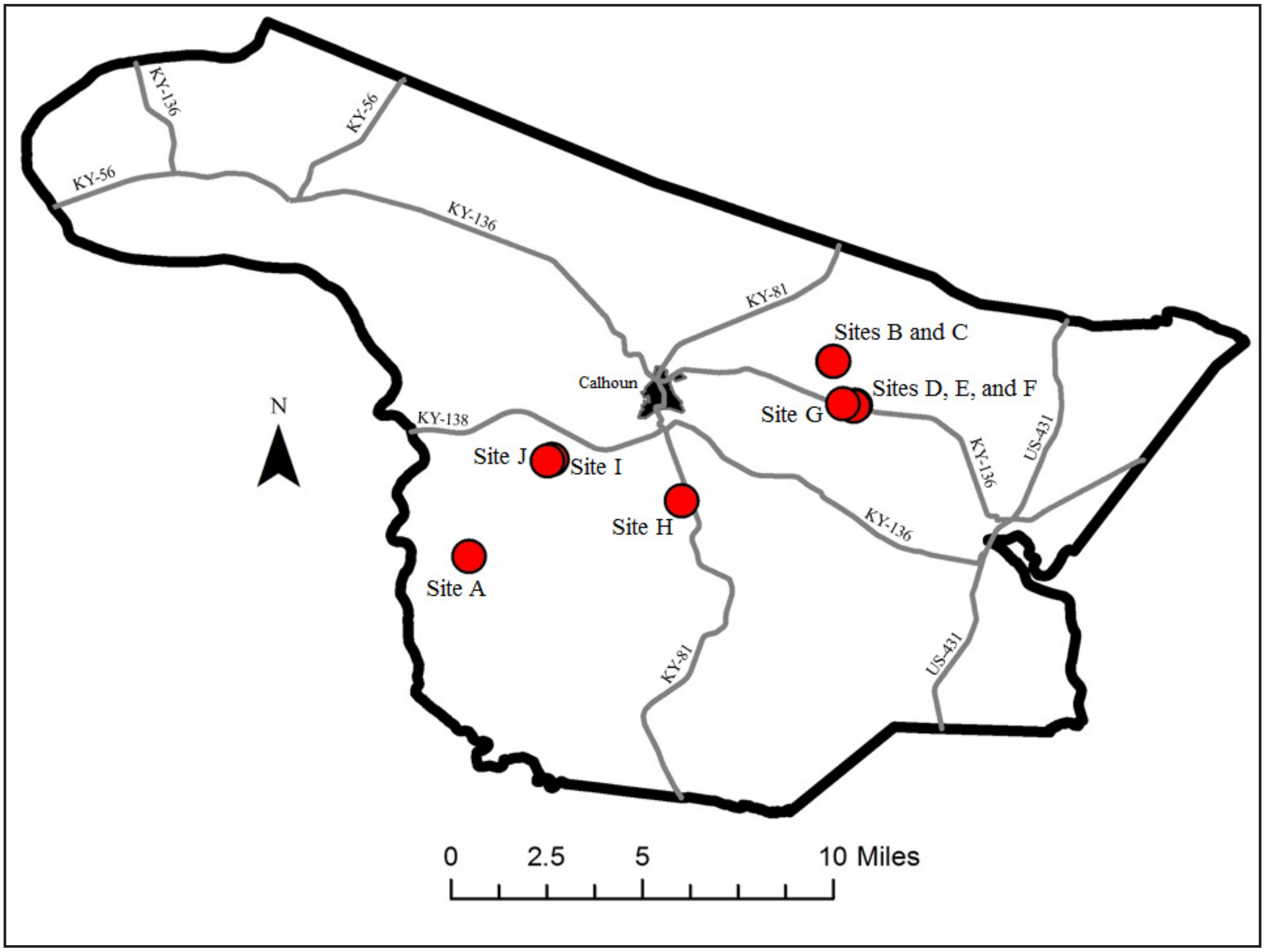

Figure A1. Locations of sites A through J in McLean County, Kentucky.

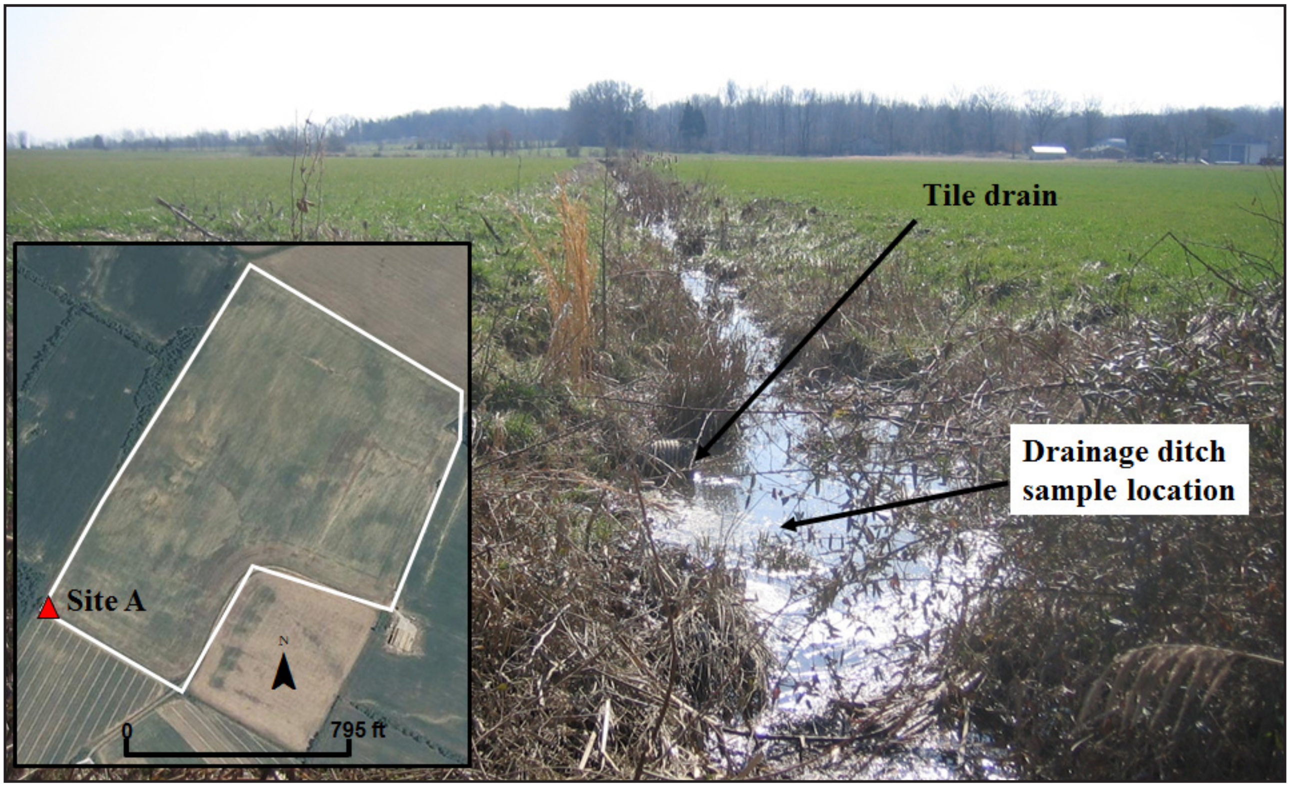

Figure A2. Site A tile-drain and drainage-ditch sample sites. Picture was taken standing on a farm road looking southwest. Inset map shows the location of site A relative to the litter-amended field, outlined in white.

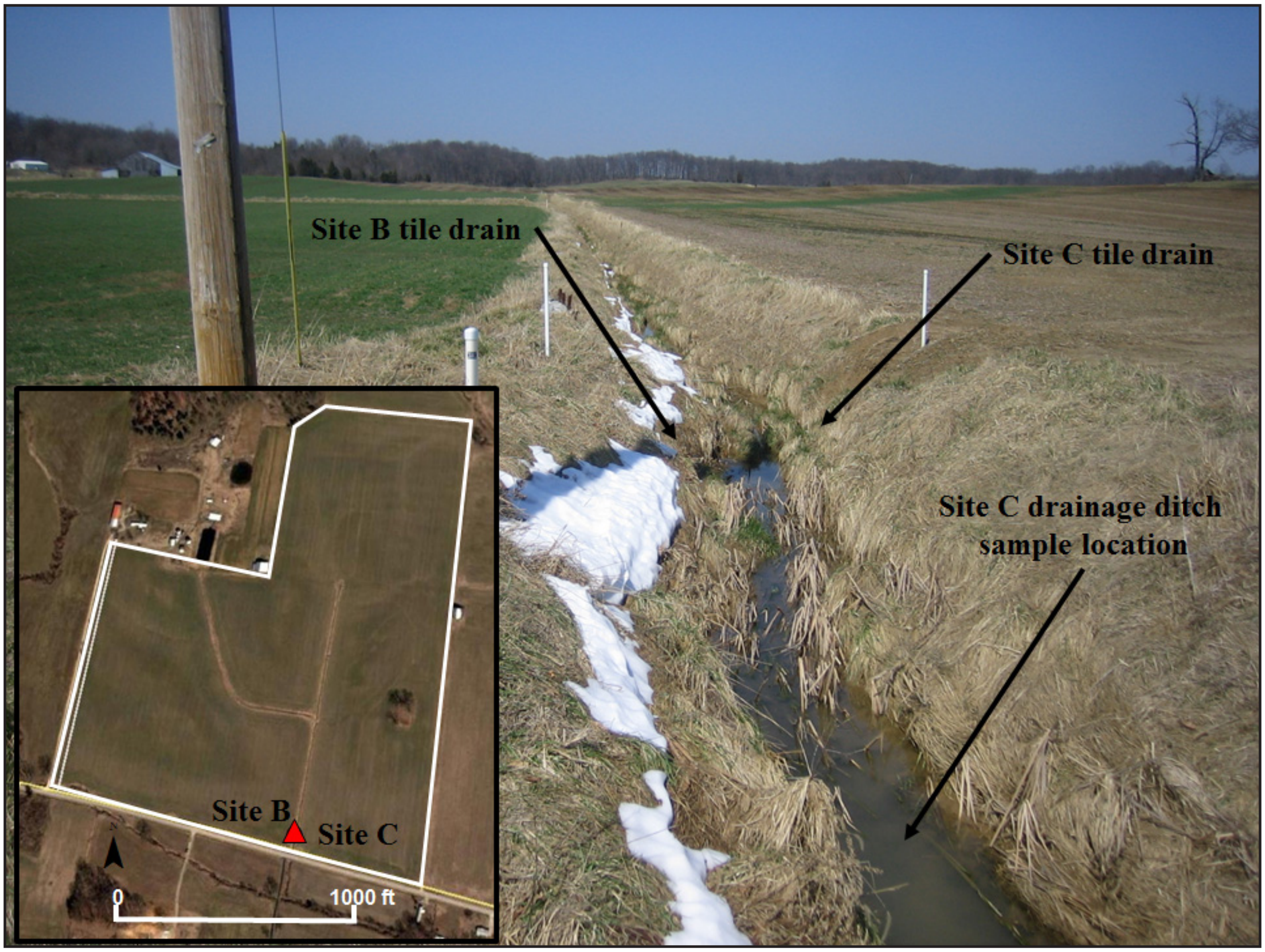

Figure A3. Sites B and C tile-drain and drainage-ditch sample sites. Picture was taken standing on Old Buel Road looking north. Inset map shows the location of sites B and C relative to the litter-amended fields, outlined in white.

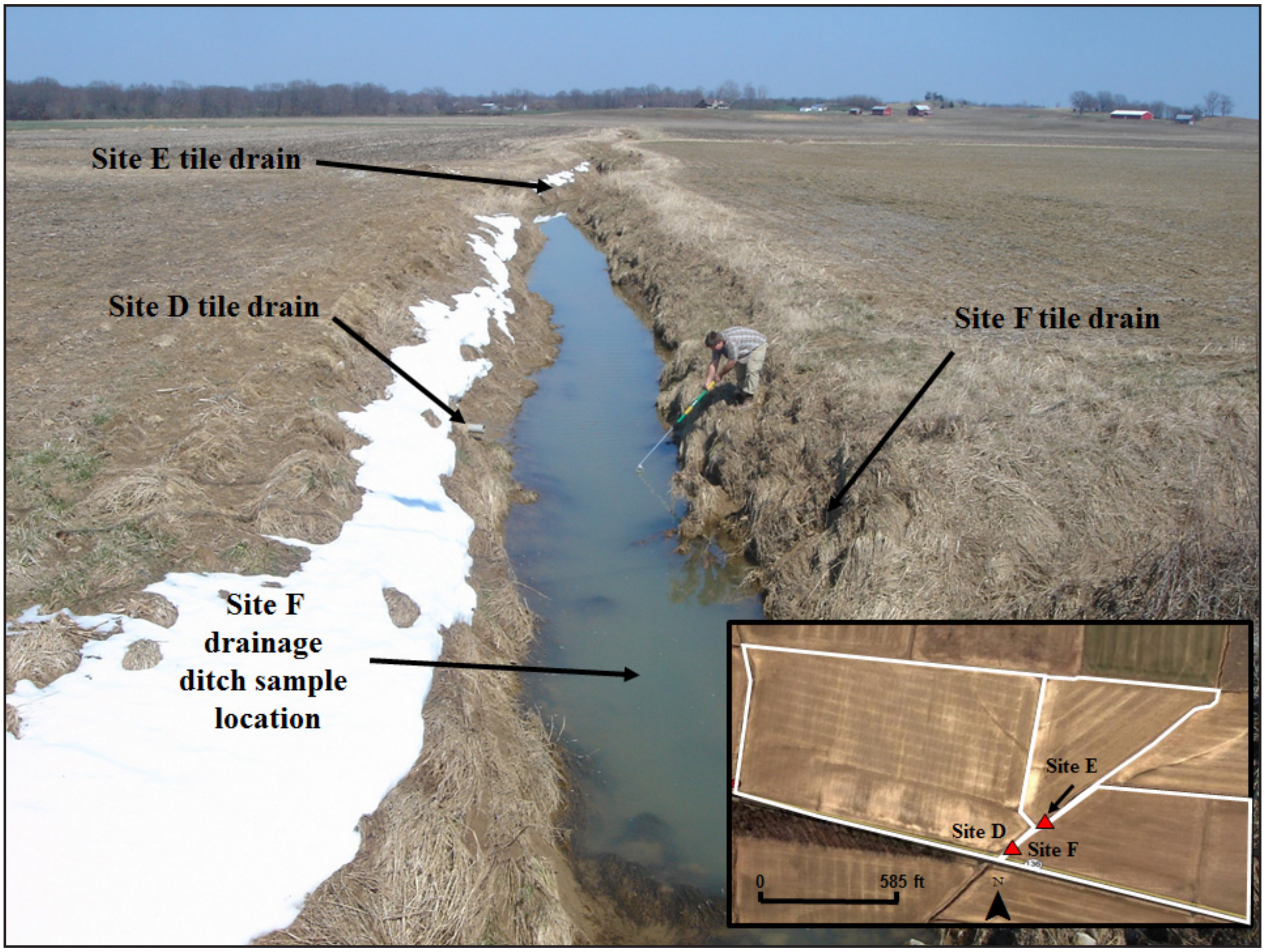

Figure A4. Sites D, E, and F tile-drain and drainage-ditch sample sites. Picture was taken standing on Ky. 136 looking northeast. Inset map shows the location of sites D, E, and F relative to their respective litter-amended fields, outlined in white.

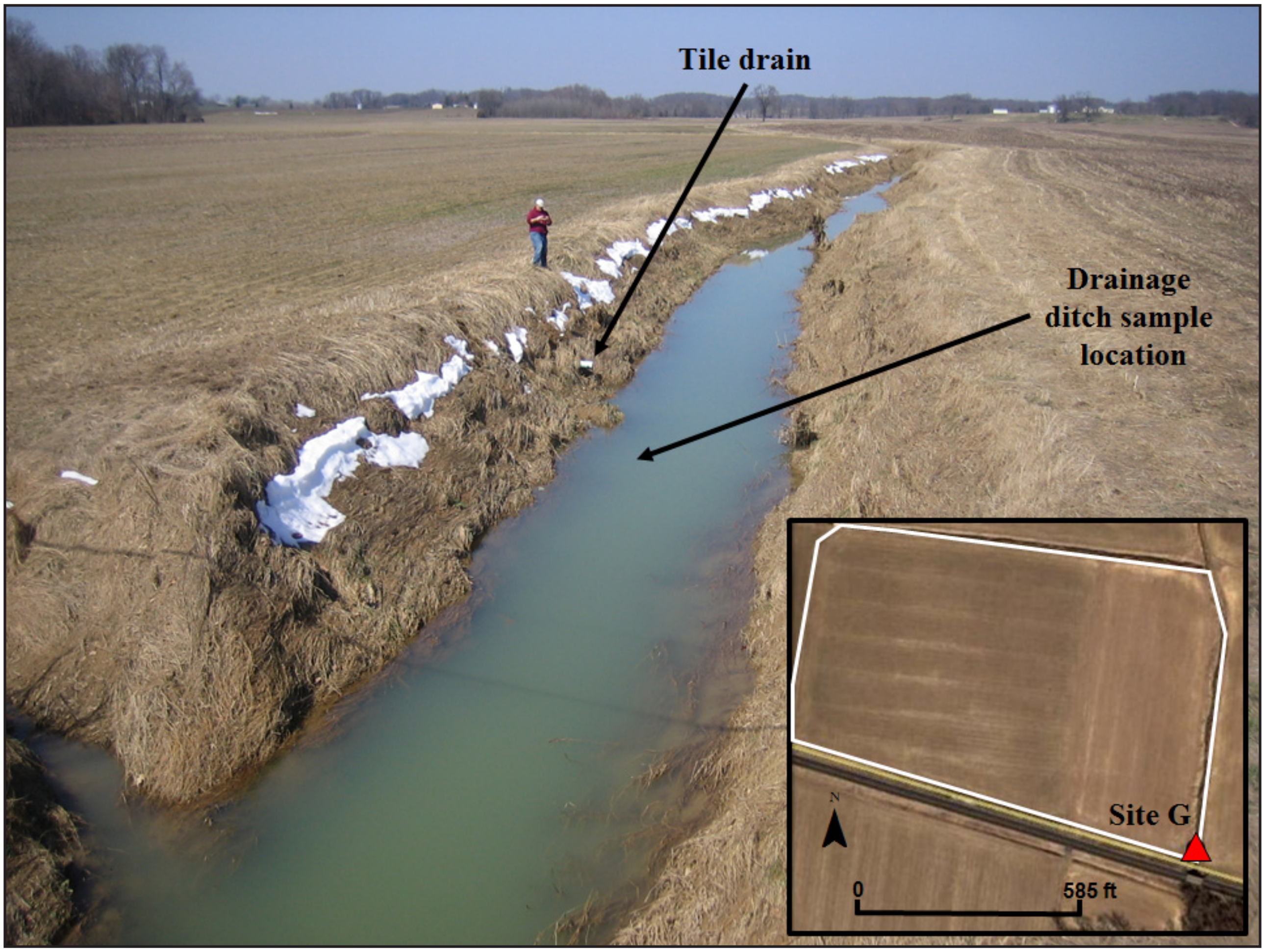

Figure A5. Site G tile-drain and drainage-ditch sample sites. Picture was taken standing on Ky. 136 looking north. Inset map shows the location of site G relative to the litter-amended field, outlined in white.

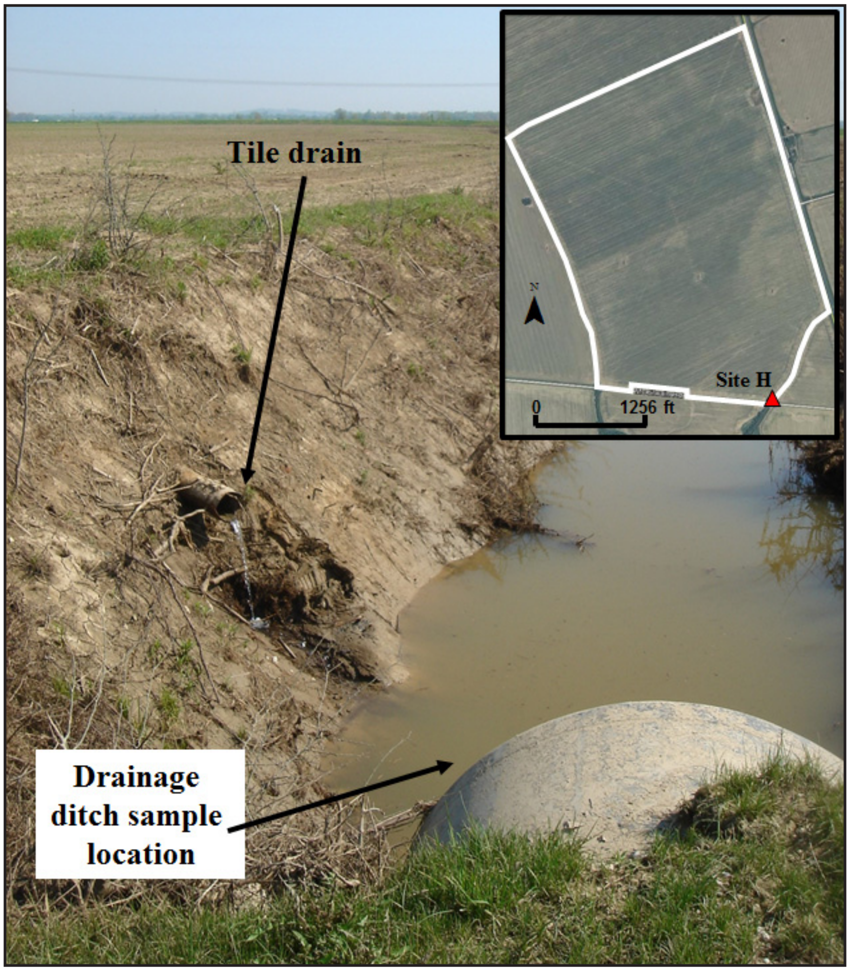

Figure A6. Site H tile-drain and drainage-ditch sample sites. Picture was taken standing on McElwain Road looking northeast. Inset map shows the location of site H relative to the unamended field, outlined in white.

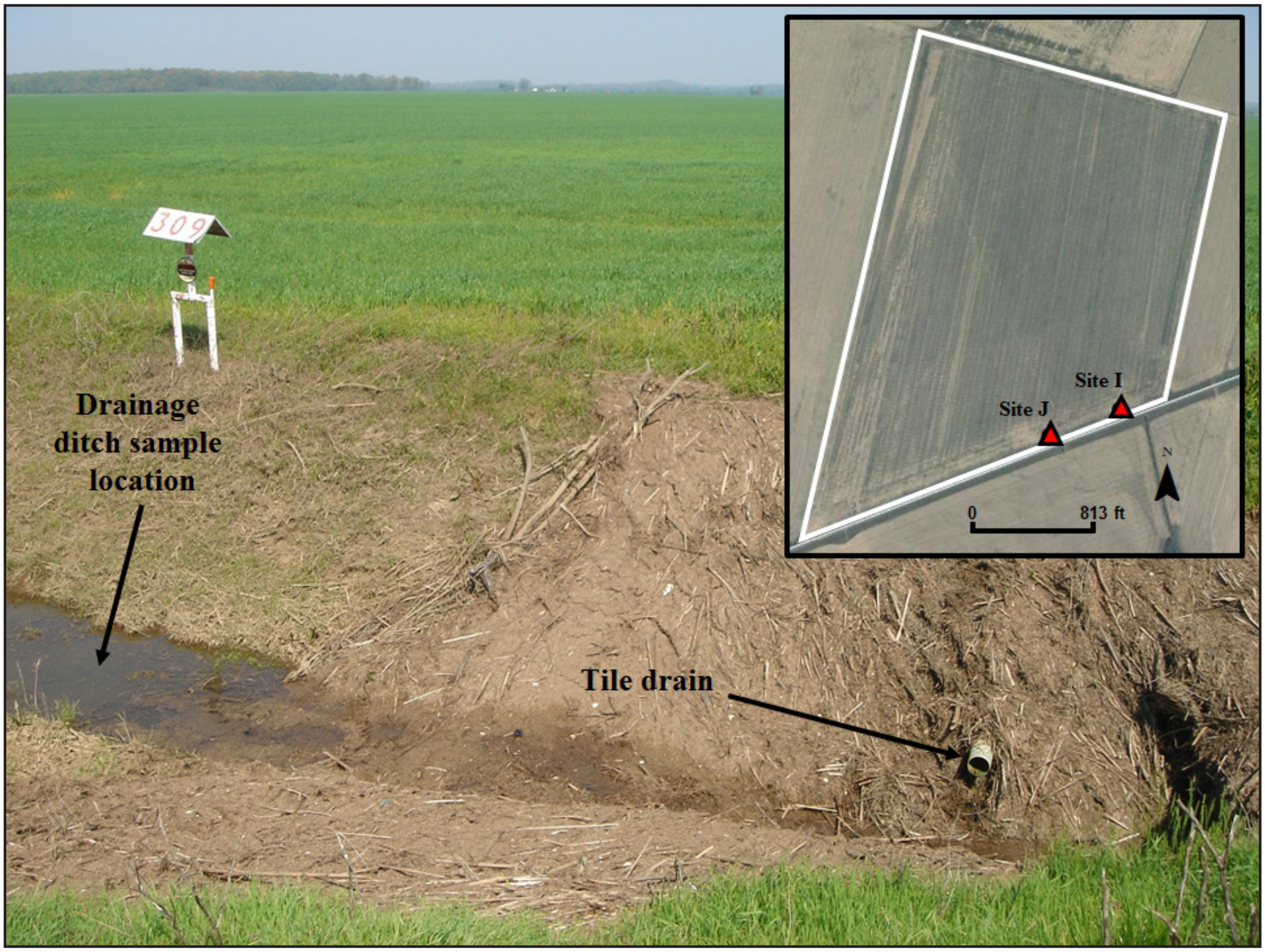

Figure A7. Site I tile-drain and drainage-ditch sample sites. Picture was taken standing on Pack Church Road looking north. Inset map shows the location of site I relative to the unamended field, outlined in white.

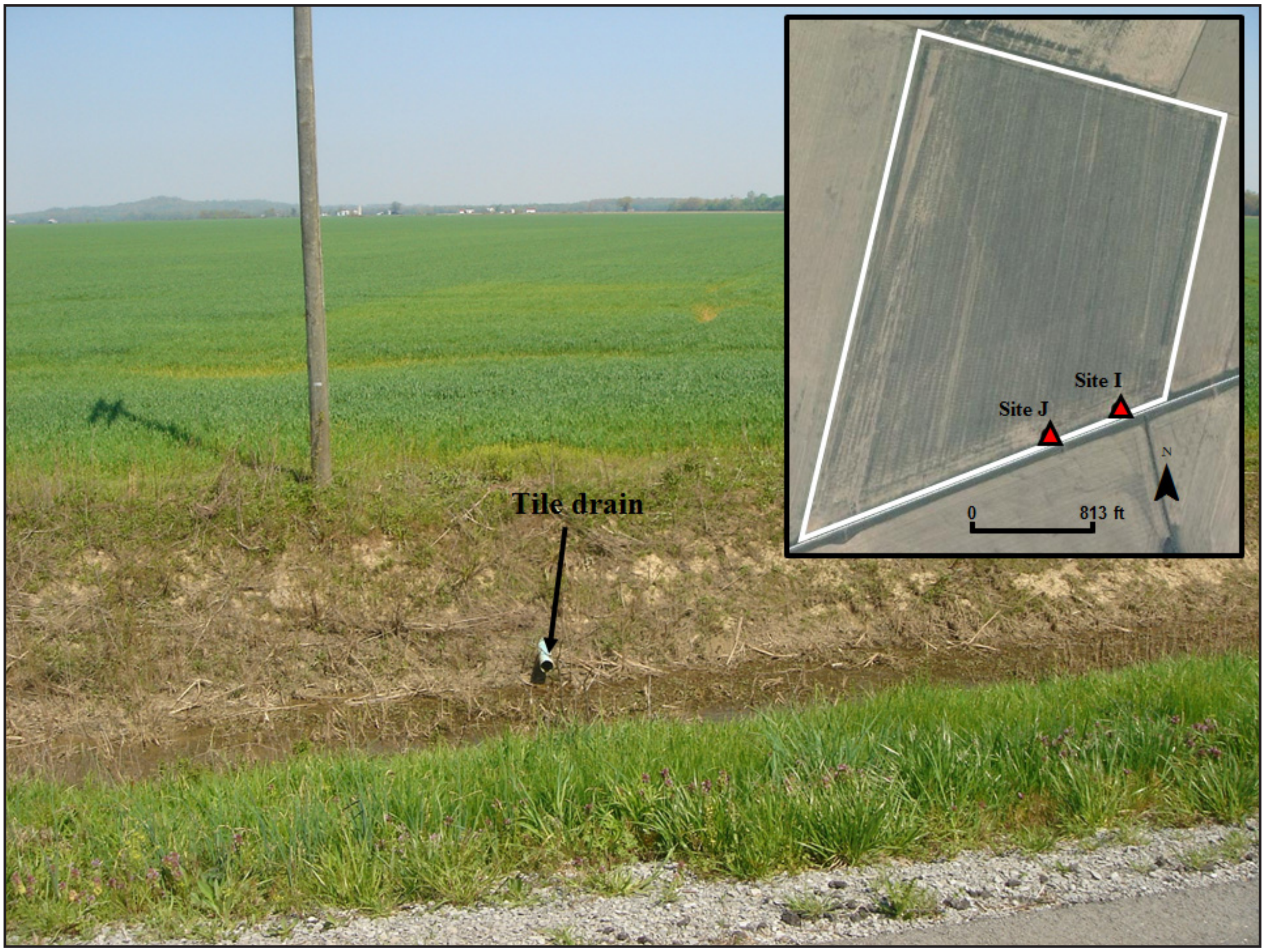

Figure A8. Site J tile-drain sample site. Picture was taken standing on Pack Church Road looking north. Inset map shows the location of site J relative to the unamended field, outlined in white.

Appendix 2: Water-Quality and Statistical Summary Data

Table B1. Sample date, litter application rate, soil type, and location information for sites A through J.

Site	*Date Sampled*	*Application Rate (tons/acre)*	*Application Date*	*Soil Type (Cox, 1980)*	*Latitude (NAD 83)*	*Longitude (NAD 83)*
A	3/12/2008	4	fall 2007	Belknap and Grenada	37.478738	–87.332221
B	3/12/2008	4	fall 2007	Belknap	37.553520	–87.194217
C	3/12/2008	4	fall 2007	Belknap	37.553500	–87.194110
D	3/12/2008	4	fall 2006	Belknap	37.536280	–87.186420
E	3/12/2008	4	fall 2006	Belknap	37.536640	–87.185940
F	3/12/2008	4	fall 2007	Belknap	37.536280	–87.186420
G	3/12/2008	4	fall 2007	Belknap	37.537227	–87.190517
H	4/23/2008	none		Karnak	37.500113	–87.251727
I	4/23/2008	none		Karnak	37.515920	–87.300890
J	4/23/2008	none		Karnak	37.515420	–87.302580

Table B2. Sample splits collected from sites A through J.

Site	*Split*	*Source*	*Analytes*	*Sample Volume*	*Preservation*
A	1	tile	anions	250 ml	4°C
A	2	tile	total metals	250 ml	nitric acid, 4°C
A	3	tile	total metals	1 L	4°C
A	5	drainage ditch	total metals	1 L	4°C
B	1	tile	anions	250 ml	4°C
B	2	tile	total metals	250 ml	nitric acid, 4°C
B	3	tile	total metals	1 L	4°C
C	1	tile	anions	250 ml	4°C
C	2	tile	total metals	250 ml	nitric acid, 4°C
C	3	tile	total metals	1 L	4°C
C	4	drainage ditch	total metals	1 L	4°C
D	1	tile	anions	250 ml	4°C
D	2	tile	total metals	250 ml	nitric acid, 4°C
D	3	tile	total metals	1 L	4°C
E	1	tile	anions	250 ml	4°C
E	2	tile	total metals	250 ml	nitric acid, 4°C
E	3	tile	total metals	1 L	4°C
F	1	tile	anions	250 ml	4°C
F	2	tile	total metals	250 ml	nitric acid, 4°C
F	3	tile	total metals	1 L	4°C
F	4	drainage ditch	total metals	1 L	4°C
G	1	tile	anions	250 ml	4°C
G	2	tile	total metals	250 ml	nitric acid, 4°C
G	3	tile	total metals	1 L	4°C
G	4	drainage ditch	total metals	1 L	4°C
H	1	tile	anions	250 ml	4°C
H	2	tile	total metals	250 ml	nitric acid, 4°C
H	3	tile	total metals	1 L	4°C
H	5	drainage ditch	total metals	1 L	4°C
I	1	tile	anions	250 ml	4°C
I	2	tile	total metals	250 ml	nitric acid, 4°C
I	3	tile	total metals	1 L	4°C
I	4	drainage ditch	total metals	1 L	4°C
J	1	tile	anions	250 ml	4°C
J	2	tile	total metals	250 ml	nitric acid, 4°C
J	3	tile	total metals	1 L	4°C

Table B3. Analytical method detection limits for major and trace metals and anions.		
Analyte	*Method Detection Limit*	*Unit*
aluminum	0.010	ppm
calcium	1.00	ppm
iron	0.010	ppm
magnesium	1.00	ppm
manganese	0.010	ppm
arsenic	5.00	ppb
cadmium	0.500	ppb
copper	0.100	ppm
mercury	0.100	ppm
nickel	0.010	ppm
lead	5.00	ppb
zinc	0.010	ppm
fluoride	0.125	ppm
chloride	0.125	ppm
bromide	0.125	ppm
nitrite	0.125	ppm
nitrate	0.125	ppm
sulfate	0.125	ppm
phosphate	1.000 and 10.000*	ppm

*Unable to determine phosphate less than 10.000 ppm for samples collected at sites H, I, and J because of poor ion chromatography column performance.

Table B4. Total major-metal concentrations (ppm) for samples collected from tile drains at sites A through J. Standard deviations in parentheses.

Site	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
amended					
A	0.666 (0.005)	61.89 (0.49)	0.186 (0.006)	33.07 (0.21)	0.839 (0.011)
B	0.117 (0.002)	19.58 (0.08)	0.034 (0.000)	10.76 (0.01)	0.140 (0.001)
C	0.177 (0.002)	22.05 (0.12)	0.133 (0.003)	13.52 (0.10)	0.096 (0.001)
D	0.277 (0.001)	88.37 (0.18)	0.143 (0.008)	44.97 (0.15)	0.067 (0.000)
E	0.113 (0.000)	61.98 (0.28)	0.074 (0.001)	27.82 (0.08)	0.044 (0.001)
F	0.151 (0.003)	70.94 (0.67)	0.077 (0.001)	34.65 (0.26)	0.039 (0.000)
G	0.165 (0.000)	70.87 (0.27)	0.087 (0.000)	42.05 (0.03)	0.035 (0.000)
unamended					
H	0.121 (0.004)	68.29 (1.11)	0.088 (0.001)	25.20 (0.31)	< MDL
I	< MDL	71.99 (0.54)	0.050 (0.001)	24.31 (0.16)	< MDL
J	< MDL	78.74 (1.00)	0.041 (0.001)	27.07 (0.39)	< MDL

Table B5. Statistical summary for total major-metal concentrations (ppm) in samples collected from amended (n = 7) and unamended (n = 3) field tile drains.

Field Type	*Statistic*	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
amended	minimum	0.113	19.58	0.034	10.76	0.035
	mean	0.238	56.53	0.105	29.55	0.180
	maximum	0.666	88.37	0.186	44.97	0.839
unamended	minimum	< MDL	68.29	0.041	24.31	
	mean		73.01	0.060	25.53	< MDL
	maximum	0.121	78.74	0.088	27.07	< MDL

Table B6. Total trace-metal concentrations for samples collected from tile drains at sites A through J. Standard deviations in parentheses.

Site	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
amended							
A	< MDL	< MDL	0.726 (0.013)	< MDL	0.063 (0.03)	< MDL	0.035 (0.002)
B	< MDL	< MDL	0.737 (0.007)	< MDL	0.029 (0.002)	< MDL	< MDL
C	< MDL	< MDL	0.620 (0.003)	< MDL	0.030 (0.000)	< MDL	< MDL
D	< MDL	< MDL	0.527 (0.003)	< MDL	0.029 (0.001)	< MDL	< MDL
E	< MDL	< MDL	0.462 (0.000)	< MDL	0.025 (0.001)	< MDL	< MDL
F	< MDL	< MDL	0.358 (0.009)	< MDL	0.026 (0.006)	< MDL	< MDL
G	< MDL	< MDL	0.316 (0.002)	< MDL	0.026 (0.001)	< MDL	< MDL
unamended							
H	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
I	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
J	< MDL	< MDL	< MDL	< MDL	< MDL	5.12 (0.12)	< MDL

Table B7. Statistical summary for total trace metals sampled from amended (n = 7) and unamended (n = 3) field tile drains.

Field Type	*Statistic*	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
amended	minimum			0.316		0.025		< MDL
	mean	< MDL	< MDL	0.535	< MDL	0.033	< MDL	
	maximum	< MDL	< MDL	0.737	< MDL	0.063	< MDL	0.035
unamended	minimum						< MDL	
	mean	< MDL	< MDL	< MDL	< MDL	< MDL		< MDL
	maximum	< MDL	< MDL	< MDL	< MDL	< MDL	5.12	< MDL

Table B8. Major-metal concentrations (ppm) for the unacidified samples collected from sites A through J. Standard deviations in parentheses.

Site	*Filter (µm)*	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
			amended			
A	unfiltered	0.646 (0.004)	61.37 (0.60)	0.245 (0.004)	33.09 (0.32)	0.864 (0.011)
	0.45	0.187 (0.001)	61.81 (0.39)	0.013 (0.000)	33.47 (0.07)	0.865 (0.022)
	0.20	0.161 (0.001)	61.11 (0.77)	< MDL	33.20 (0.17)	0.852 (0.018)
B	unfiltered	0.115 (0.002)	19.80 (0.44)	0.036 (0.001)	10.90 (0.23)	0.142 (0.002)
	0.45	0.067 (0.000)	20.15 (0.15)	< MDL	11.02 (0.08)	0.138 (0.001)
	0.20	0.063 (0.002)	19.88 (0.11)	< MDL	10.94 (0.02)	0.140 (0.002)
C	unfiltered	0.638 (0.002)	22.33 (0.15)	0.589 (0.002)	13.76 (0.09	0.093 (0.000)
	0.45	0.022 (0.002)	21.90 (0.17)	< MDL	13.50 (0.04)	0.069 (0.000)
	0.20	0.161 (0.002)	22.41 (0.13)	0.125 (0.001)	13.76 (0.06)	0.074 (0.000)
D	unfiltered	0.227 (0.003)	88.41 (1.04)	0.167 (0.003)	45.40 (0.25)	0.064 (0.000)
	0.45	0.022 (0.001)	89.41 (0.18)	< MDL	45.56 (0.19)	0.061 (0.001)
	0.20	0.214 (0.005)	88.54 (0.41)	0.153 (0.002)	45.28 (0.35)	0.062 (0.000)
E	unfiltered	0.126 (0.002)	62.77 (0.53)	0.072 (0.000)	28.18 (0.15)	0.044 (0.000)
	0.45	0.017 (0.002)	62.83 (0.33)	< MDL	27.67 (0.06)	0.062 (0.000)
	0.20	0.080 (0.001)	63.21 (0.17)	0.041 (0.000)	27.68 (0.08)	0.059 (0.001)
F	unfiltered	0.149 (0.005)	71.84 (1.19)	0.077 (0.002)	34.85 (0.46)	0.037 (0.001)
	0.45	0.014 (0.001)	71.23 (0.20)	< MDL	34.99 (0.16)	0.032 (0.001)
	0.20	0.062 (0.001)	71.96 (0.40)	0.030 (0.000)	35.00 (0.32)	0.034 (0.000)
G	unfiltered	0.213 (0.001)	70.56 (0.66)	0.120 (0.004)	42.00 (0.43)	0.034 (0.000)
	0.45	0.016 (0.001)	71.24 (0.34)	< MDL	42.31 (0.21)	0.034 (0.000)
	0.20	0.163 (0.002)	71.33 (0.29)	0.112 (0.001)	42.54 (0.10)	0.030 (0.000)
			unamended			
H	unfiltered	0.130 (0.007)	68.61 (0.46)	0.084 (0.002)	25.40 (0.12)	< MDL
	0.45	< MDL	66.54 (3.63)	0.010 (0.001)	24.43 (1.15)	< MDL
	0.20	0.104 (0.009)	68.63 (0.81)	0.090 (0.000)	25.54 (0.32)	< MDL
I	unfiltered	< MDL	75.99 (4.86)	0.052 (0.004)	25.87 (1.67)	< MDL
	0.45	< MDL	72.53 (0.86)	0.023 (0.001)	24.48 (0.25)	< MDL
	0.20	< MDL	72.56 (1.02)	0.037 (0.001)	24.47 (0.36)	< MDL
J	unfiltered	< MDL	79.17 (1.18)	0.025 (0.001)	27.17 (0.54)	< MDL
	0.45	< MDL	79.12 (1.02)	0.015 (0.001)	27.01 (0.28)	< MDL
	0.20	< MDL	83.19 (7.92)	0.022 (0.001)	28.81 (3.32)	< MDL

Table B9. Statistical summary of major-metal concentrations (ppm) for unacidified samples collected from amended (n = 7) and unamended (n = 3) field tile drains.

Field Type	*Statistic*	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
unfiltered						
amended	minimum	0.115	19.80	0.036	10.90	0.034
	mean	0.302	56.73	0.187	29.74	0.183
	maximum	0.646	88.41	0.589	45.40	0.864
unamended	minimum	< MDL	68.61	0.025	25.40	
	mean		74.59	0.054	26.15	
	maximum	0.130	79.17	0.084	27.17	< MDL
0.45-µm filter						
amended	minimum	0.014	20.15	< MDL	11.02	0.032
	mean	0.049	56.94		29.79	0.180
	maximum	0.187	89.41	0.013	45.56	0.865
unamended	minimum		66.54	0.010	24.43	
	mean		72.73	0.016	25.31	
	maximum	< MDL	79.12	0.023	27.01	< MDL
0.20-µm filter						
amended	minimum	0.062	19.88	0.030	10.94	0.030
	mean	0.129	56.92	0.092	29.77	0.179
	maximum	0.214	88.54	0.153	45.28	0.852
unamended	minimum	< MDL	68.63	0.022	24.47	
	mean		74.79	0.050	26.27	
	maximum	0.104	83.19	0.090	28.81	< MDL

Table B10. Trace-metal concentrations for unacidified samples collected from sites A through J. Standard deviations in parentheses. NA = not analyzed.

Site	*Filter (µm)*	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
amended								
A	unfiltered	< MDL	< MDL	0.930 (0.007)	< MDL	0.062 (0.005)	< MDL	0.034 (0.004)
	0.45	NA	NA	1.135 (0.005)	< MDL	0.060 (0.003)	NA	0.036 (0.003)
	0.20	NA	NA	0.799 (0.011)	< MDL	0.060 (0.001)	NA	0.034 (0.004)
B	unfiltered	< MDL	< MDL	0.734 (0.013)	< MDL	0.029 (0.000)	< MDL	< MDL
	0.45	NA	NA	0.595 (0.003)	< MDL	0.030 (0.002)	NA	0.011 (0.002)
	0.20	NA	NA	0.681 (0.001)	< MDL	0.031 (0.002)	NA	0.011 (0.001)
C	unfiltered	< MDL	< MDL	0.649 (0.005)	< MDL	0.033 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.488 (0.009)	< MDL	0.028 (0.003)	NA	< MDL
	0.20	NA	NA	0.555 (0.002)	< MDL	0.029 (0.003)	NA	< MDL
D	unfiltered	< MDL	< MDL	0.473 (0.003)	< MDL	0.027 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.455 (0.004)	< MDL	0.027 (0.000)	NA	< MDL
	0.20	NA	NA	0.465 (0.004)	< MDL	0.025 (0.002)	NA	< MDL
E	unfiltered	< MDL	< MDL	0.465 (0.005)	< MDL	0.021 (0.002)	< MDL	< MDL
	0.45	NA	NA	1.019 (0.006)	< MDL	0.032 (0.002)	NA	0.011 (0.002)
	0.20	NA	NA	0.860 (0.003)	< MDL	0.035 (0.000)	NA	< MDL
F	unfiltered	< MDL	< MDL	0.345 (0.017)	< MDL	0.023 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.270 (0.000)	< MDL	0.025 (0.002)	NA	< MDL
	0.20	NA	NA	0.296 (0.002)	< MDL	0.023 (0.001)	NA	< MDL
G	unfiltered	< MDL	< MDL	0.322 (0.001)	< MDL	0.027 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.339 (0.004)	< MDL	0.026 (0.001)	NA	< MDL
	0.20	NA	NA	0.253 (0.001)	< MDL	0.025 (0.001)	NA	< MDL
unamended								
H	unfiltered	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
	0.45	NA	NA	< MDL	< MDL	< MDL	NA	0.018 (0.001)
	0.20	NA	NA	< MDL	< MDL	< MDL	NA	< MDL
I	unfiltered	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
	0.45	NA	NA	< MDL	< MDL	< MDL	NA	< MDL
	0.20	NA	NA	< MDL	< MDL	< MDL	NA	0.011 (0.000)
J	unfiltered	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
	0.45	NA	NA	< MDL	< MDL	< MDL	NA	< MDL
	0.20	NA	NA	< MDL	< MDL	< MDL	NA	< MDL

Table B11. Statistical summary of trace-metal concentrations for unacidified samples collected from amended (n = 7) and unamended (n = 3) field tile drains.

Field Type	*Statistic*	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
				unfiltered				
amended	minimum			0.322		0.021		< MDL
	mean	< MDL	< MDL	0.560	< MDL	0.032	< MDL	
	maximum			0.930		0.062		0.034
unamended	minimum							
	mean	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
	maximum							
				0.45-µm filter				
amended	minimum			0.270		0.025		< MDL
	mean			0.614	< MDL	0.033		0.019
	maximum			1.135		0.060		0.036
unamended	minimum							< MDL
	mean			< MDL	< MDL	< MDL		
	maximum							0.018
				0.20-µm filter				
amended	minimum			0.253		0.023		< MDL
	mean			0.558		0.033		
	maximum			0.860	< MDL	0.060		0.034
unamended	minimum							< MDL
	mean			< MDL	< MDL	< MDL		
	maximum							0.011

Table B12. Major-metal concentrations (ppm) for unacidified samples collected from amended and unamended drainage ditches. Standard deviations in parentheses.

Site	*Filter (μm)*	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
			amended			
A	unfiltered	1.128 (0.019)	25.82 (0.17)	0.746 (0.005)	11.19 (0.05)	0.262 (0.001)
	0.45	0.059 (0.001)	26.20 (0.13)	0.055 (0.001)	11.08 (0.02)	0.293 (0.004)
	0.20	0.022 (0.002)	26.00 (0.12)	0.021 (0.001)	11.12 (0.09)	0.277 (0.001)
C	unfiltered	1.013 (0.014)	22.86 (0.29)	0.796 (0.009)	11.69 (0.09)	0.099 (0.000)
	0.45	0.368 (0.006)	22.64 (0.19)	0.254 (0.005)	11.59 (0.11)	0.086 (0.000)
	0.20	0.288 (0.002)	23.02 (0.16)	0.207 (0.001)	11.72 (0.04)	0.082 (0.000)
F	unfiltered	0.624 (0.011)	36.93 (0.56)	0.478 (0.009)	16.92 (0.18)	0.063 (0.000)
	0.45	0.059 (0.001)	36.47 (0.16)	0.043 (0.001)	16.80 (0.07)	0.055 (0.000)
	0.20	0.511 (0.010)	36.85 (0.13)	0.459 (0.004)	16.92 (0.04)	0.059 (0.001)
G	unfiltered	0.586 (0.008)	26.80 (0.12)	0.545 (0.004)	12.24 (0.02)	0.054 (0.001)
	0.45	0.061 (0.001)	26.54 (0.20)	0.048 (0.000)	12.11 (0.10)	0.050 (0.000)
	0.20	0.395 (0.007)	26.92 (0.09)	0.363 (0.001)	12.29 (0.04)	0.048 (0.000)
			unamended			
H	unfiltered	0.576 (0.007)	67.01 (0.55)	1.394 (0.012)	25.43 (0.23)	0.411 (0.001)
	0.45	< MDL	65.59 (0.70)	0.067 (0.003)	24.89 (0.31)	0.393 (0.009)
	0.20	0.585 (0.007)	67.55 (0.73)	1.504 (0.017)	25.80 (0.16)	0.415 (0.007)
I	unfiltered	0.158	68.36 (0.72)	1.217 (0.006)	26.15 (0.26)	0.100 (0.001)
	0.45	< MDL	68.06 (0.30)	0.664 (0.005)	26.16 (0.14)	0.094 (0.000)
	0.20	0.102 (0.006)	67.95 (0.53)	1.149 (0.008)	26.06 (0.23)	0.095 (0.001)

Table B13. Statistical summary of major-metal concentrations (ppm) for unacidified samples collected from amended-field drainage ditches (n = 7).

Field Type	*Statistic*	*Aluminum*	*Calcium*	*Iron*	*Magnesium*	*Manganese*
			unfiltered			
amended	minimum	0.586	22.86	0.478	11.19	0.054
	mean	0.838	28.10	0.641	13.01	0.120
	maximum	1.128	36.93	0.796	16.92	0.262
			0.45-μm filter			
amended	minimum	0.059	22.64	0.043	11.08	0.050
	mean	0.137	27.96	0.100	12.90	0.121
	maximum	0.368	36.47	0.254	16.80	0.293
			0.20-μm filter			
amended	minimum	0.022	23.02	0.021	11.12	0.048
	mean	0.304	28.20	0.263	13.01	0.117
	maximum	0.511	36.85	0.459	16.92	0.277

Table B14. Total-metal concentrations for unacidified samples collected from amended- and unamended-field drainage ditches. Standard deviations in parentheses. NA = not analyzed.

Site	*Filter (µm)*	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
				amended				
A	unfiltered	< MDL	< MDL	0.203 (0.001)	< MDL	0.022 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.980 (0.012)	< MDL	0.022 (0.003)	NA	< MDL
	0.20	NA	NA	0.642 (0.002)	< MDL	0.019 (0.001)	NA	< MDL
C	unfiltered	< MDL	< MDL	0.540 (0.005)	< MDL	0.030 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.465 (0.004)	< MDL	0.026 (0.003)	NA	< MDL
	0.20	NA	NA	0.432 (0.002)	< MDL	0.024 (0.003)	NA	0.011 (0.001)
F	unfiltered	< MDL	< MDL	0.316 (0.003)	< MDL	0.030 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.256 (0.001)	< MDL	0.023 (0.002)	NA	< MDL
	0.20	NA	NA	0.273 (0.000)	< MDL	0.025 (0.004)	NA	< MDL
G	unfiltered	< MDL	< MDL	0.249 (0.003)	< MDL	0.025 (0.001)	< MDL	< MDL
	0.45	NA	NA	0.299 (0.002)	< MDL	0.024 (0.002)	NA	< MDL
	0.20	NA	NA	0.221 (0.001)	< MDL	0.022 (0.001)	NA	< MDL
				unamended				
H	unfiltered	< MDL	< MDL	< MDL	< MDL	0.012 (0.002)	< MDL	< MDL
	0.45	NA	NA	< MDL	< MDL	< MDL	NA	< MDL
	0.20	NA	NA	< MDL	< MDL	0.012 (0.001)	NA	< MDL
I	unfiltered	5.61 (0.25)	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
	0.45	NA	NA	< MDL	< MDL	< MDL	NA	< MDL
	0.20	NA	NA	< MDL	< MDL	< MDL	NA	< MDL

Table 15. Statistical summary of minor-metal concentrations for unacidified samples collected from amended-field drainage ditches (n = 7).

Field Type	*Statistic*	*Arsenic (ppb)*	*Cadmium (ppb)*	*Copper (ppm)*	*Mercury (ppm)*	*Nickel (ppm)*	*Lead (ppb)*	*Zinc (ppm)*
				unfiltered				
amended	minimum			0.203		0.022		
	mean	< MDL	< MDL	0.327	< MDL	0.027	< MDL	< MDL
	maximum			0.540		0.030		
				0.45-µm filter				
amended	minimum			0.256		0.022		
	mean			0.500	< MDL	0.024		< MDL
	maximum			0.980		0.026		
				0.20-µm filter				
amended	minimum			0.221		0.019		< MDL
	mean			0.392	< MDL	0.023		
	maximum			0.642		0.025		0.011

Table B16. Anion concentrations (ppm) for samples collected from tile drains at sites A through J.

Tile Drain	*Fluoride*	*Chloride*	*Nitrite*	*Sulfate*	*Bromide*	*Nitrate*	*Phosphate*
amended							
A	0.131	51.719	< MDL	282.935*	< MDL	5.778	< MDL
B	< MDL	34.710	< MDL	76.732	< MDL	6.382	< MDL
C	< MDL	30.742	< MDL	42.198	< MDL	17.880	< MDL
D	< MDL	42.374	< MDL	212.465*	< MDL	9.826	< MDL
E	< MDL	38.090	< MDL	52.851	< MDL	9.009	< MDL
F	0.135	46.059	< MDL	79.576	< MDL	12.794	< MDL
G	0.204	58.099	< MDL	113.310	< MDL	12.524	< MDL
unamended							
H	0.179	28.147	< MDL	24.319	< MDL	2.997	< MDL
I	0.182	23.050	< MDL	31.734	< MDL	0.341	< MDL
J	0.187	24.157	< MDL	41.204	< MDL	0.306	< MDL

*Sulfate concentration obtained by 10x sample dilution.

Table B17. Statistical summary of anion concentrations (ppm) for samples collected from amended- (n = 7) and unamended-field (n = 3) tile drains.

Field Type	*Statistic*	*Fluoride*	*Chloride*	*Nitrite*	*Sulfate*	*Bromide*	*Nitrate*	*Phosphate*
amended	minimum	< MDL	30.742		42.198		5.778	
	mean	0.157	43.113	< MDL	122.867	< MDL	10.599	< MDL
	maximum	0.204	58.099		282.935		17.880	
unamended	minimum	0.179	23.050		24.319		0.306	
	mean	0.183	25.118	< MDL	32.419	< MDL	1.215	< MDL
	maximum	0.187	28.147		41.204		2.997	