Nutrient and Hormone Export from Tile Drains and Ditches Draining Midwestern Agricultural Fields Fertilized with Animal Waste

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PROJECT SUMMARY:

Problem Statement: The recent shift towards more concentrated animal feeding operations (CAFOs) has challenged farm mangers regarding the effective handling of the large amount of wastes generated without applying energy intensive technologies (Bradford et al., 2008). Transportation costs limit the distance over which the animal wastes are hauled economically, resulting in land-application typically within a 16-km radius around CAFO locations (Bradford et al., 2008). The negative impacts associated with manure application have traditionally focused on nutrients; however, it is now well understood that manure applications also introduce hormones into the environment (Irwin et al., 2001; Soto et al., 2004; Matthiessen et al., 2006; Kolok et al., 2007; Chen et al., 2010). While the negative impacts of excess nitrogen (N) and phosphorus (P) in the environment have been recognized for over 60 years (Hasler, 1947), the widespread detection of hormones in surface water bodies was not recognized until 2002.

Despite the significance of improving water quality at the local, regional, national, and global scales, there remains a dearth of high-temporal resolution data that are essential to better understand how natural processes and anthropogenic drivers affect water quality. The nation as a whole relies heavily on the food production service of agroecosystems in the Midwestern United States, and Midwestern communities need this service to sustain their socio-economics. Therefore, understanding the processes that influence agro-ecosystem services and downstream water quality is vital to the long-term environmental, economic, and social prosperity of the Midwest.

Research questions and hypotheses:
How do the export dynamics of nutrients and hormones compare? The applied animal waste was essentially the sole source of both E1 and DRP (*i.e.,* same anthropogenic driver), whereas fields were supplemented with an inorganic N fertilizer. Both estrone (E1) and phosphate sorb to soils (*i.e.,*similar natural driver), albeit by different magnitudes and mechanisms, Additionally, of the estrogens, E1 was chosen for comparison to phosphate because it is the metabolite of 17α- and 17β-estradiol under aerobic conditions (Lee and Liu, 2002; Lee et al., 2007; Combalbert and Hernandez-Raquet, 2010), is the most persistent estrogen (Xuan et al., 2008), and was the most frequently detected hormone at the study site.
Hypothesis: Given that for fields receiving animal waste application, phosphorus and hormones share the same source and are influenced by similar natural drivers, the export dynamics of dissolved reactive phosphorus (DRP) and hormones (estrone, in particular) will be similar.

What best management practices are likely to be most effective at reducing nutrient and hormone export from a tile-drained agroecosystem? Although some research has been conducted regarding the potential of nutrient best management practices to reduce hormone loads, most studies have been conducted on experimental plots under simulated rainfall. Few studies have quantified hormone transport dynamics under natural conditions. Understanding how environmental and human controls influence hormone export is essential for defining best management practices that can minimize their input to surface water bodies, thereby reducing their potential to impact sensitive aquatic organisms.

Hypothesis: Given that hormones sorb to soil, hormone chemograph dynamics will trend hydrographs, leading to the majority of hormone loads exported during the highest flow rates and implying that best management practices must reduce loads during large events to significantly decrease hormone export to downstream locations.

Objectives: (i) Calculate the loads of 17α- and 17β-estradiol (E2), estrone (E1), and estriol (E3), nitrate, and dissolved reactive phosphorus (DRP) exported from a subsurface tile drain and a receiving ditch; (ii) Compare the export dynamics of nutrients and hormones in response to animal waste applications; (iii) Assess the potential for nutrient best management practices (*e.g.*, no-till, buffer strips, wetlands, etc.) to reduce hormone export from tile-drained agroecosystems.

Study Site Description: The study was conducted at Purdue's Animal Science Research and Education Center (ASREC), a working farm and EPA-designated concentrated animal feeding operation, consisting of 600 ha of tile drained cropland in North Central Indiana. Animal wastes were stored on-site in lagoons and land-applied through lagoon effluent pivot irrigation, solids broadcasting, and subsurface injection. Tilling practices at ASREC consist of deep chisel tilling post-harvest and prior to manure solids applications. Seven monitoring stations were installed (funding provided by EPA STAR Grant RD833417) to monitor flow and collect samples from four tile drain (D1-D4) and three receiving ditch (S1-S3) locations, as shown in Figure 1. Two of the monitoring stations (D1 and S1) were selected for nutrient and hormone analysis. Samples were collected at a time-paced interval during baseflow and at a flow-paced interval during storm events (Figure 2).

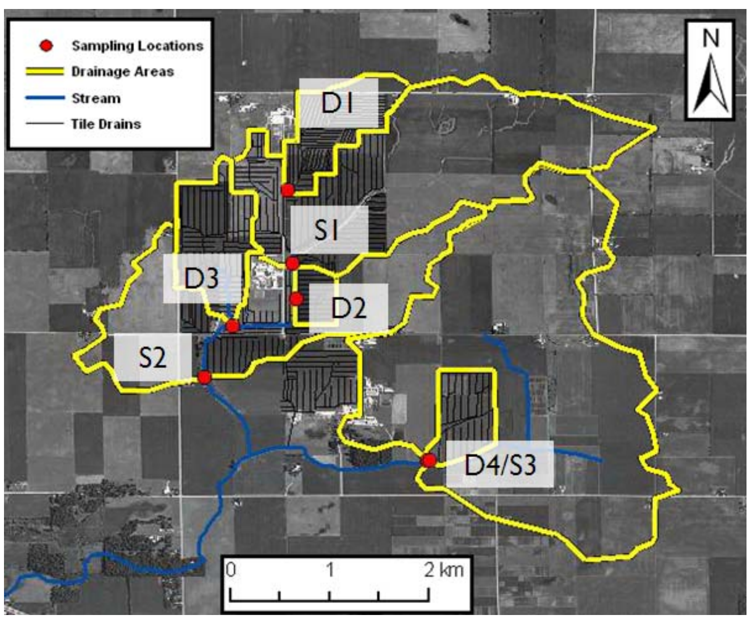

Figure 1. Purdue's Animal Science Research and Education Center. Map of the study site, including monitoring stations (S = stream and D = tile drain), subsurface tile drain locations, and watershed boundaries for each station.

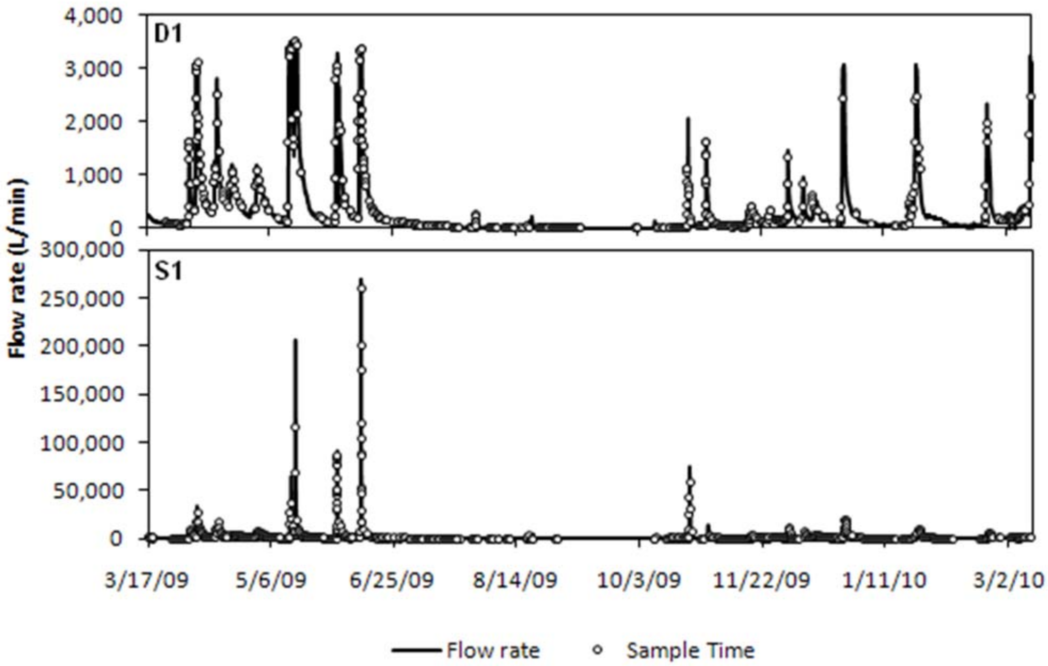

Figure 2. Hydrograph and corresponding sample times at D1 (top) and S1 (bottom). Each dot represents a 1-L grab sample collected by an ISCO automated sampler.

During the one-year study period (March 2009 – March 2010), lagoon effluent primarily from beef and dairy units was applied to approximately 32 ha within D1's drainage area and 128 ha within S1's drainage area using a center irrigation pivot system. 36 kg/ha of nitrogen was added as a starter fertilizer at the time of corn planting in the form of 28% URAN (urea-ammonium-nitrate). Additionally, 28% URAN was knifed into corn fields in June 2009 at a rate of 129 kg-N/ha at fields that also receive lagoon effluent irrigation and at a rate of 202 kg-N/ha at fields outside of the pivot's application range.

Significant Findings:

Frequency of Detection: Estrogens and nutrients were detected in more than 70% of tile drain samples and more than 85% of stream samples. At both stations, the most to least frequently detected estrogens were E1, 17β-E2, 17α-E2, and E3 (Table 1). The highest concentrations of estrogens and nutrients were not observed during the same events, reflecting differences in the rates and magnitudes of the biogeochemical drivers. In the ditch, the highest observed estrogen concentrations (> 100 ng/L) occurred during a storm event in June approximately two weeks after dairy lagoon effluent irrigation. The highest DRP concentrations in the ditch (> 2 mg/L) were observed in December 2009, after fields had been irrigated with dairy effluent from a primary lagoon.

Loads: The loads of each constituent exported by D1 and S1 were calculated and are reported in Table 1. The masses exported were normalized by the area to which animal wastes were applied to facilitate comparison between monitoring stations. The normalized loads were greater for S1 than D1, suggesting that transport processes other than tile drainage (*e.g.,* surface runoff) are responsible for the majority of hormone and nutrient export.

To compare the export dynamics of the various constituents, cumulative export plots were developed (Figure 3). The majority of 17α- and 17β-E2 was exported early compared to the other constituents with nearly 80% of export occurring by mid-June (Figure 3). This early export of 17α- and 17β-E2 is likely driven by the relatively rapid microbial transformation of these compounds, thereby resulting in minimal export despite additional applications during the rest of the year and suggesting that the system (*i.e.,* field) acts as a sink for these compounds. Nitrate export was observed to occur at approximately the same rate as discharge due to the low variability in nitrate concentration (coefficient of variation = 0.3 in the tile drain and stream). E1 and DRP exhibited similar trends in cumulative export; however, the majority of these constituents were exported later in the study period as compared to 17α- and 17β-E2, suggesting that the system acted as a long-term source due to the importance of winter events to the export of these constituents. These observations are consistent with others who have reported E1 to be the most persistent estrogen (Xuan et al., 2008).

Table 1. Nutrient and estrogen data summary: March 2009 – March 20109. Range of concentrations is provided, along with the percent of samples with concentrations above the limit of quantitation (LOQ) and the annual load. The total number of samples analyzed for nutrients were 497 at D1 and 581 at S1. The total number of samples analyzed for hormones were 463 at D1 and 527 at S1.

Constituent	**Tile Drain (D1)** Range % n > LOQ Annual load	**Artificial Ditch (S1)** Range % n > LOQ Annual load
Nitrate+Nitrite-N	2.19 - 25.0 mg/L 100% 29.5 kg/ha*	< LOQ – 18.3 mg/L 99.5% 48.0 kg/ha*
Orthophosphate-P	< LOQ – 3.68 mg/L 91% 0.14 kg/ha*	< LOQ – 2.15 mg/L 85% 0.63 kg/ha*
Estrone	< LOQ – 13.3 ng/L 56% 0.31 mg/ha*	< LOQ – 13.7 ng/L 80% 4.07 mg/ha*
17β-Estradiol	< LOQ – 38.1 ng/L 45% 0.49 mg/ha*	< LOQ – 10.2 ng/L 51% 2.41 mg/ha*
17α-Estradiol	< LOQ – 8.23 ng/L 20% 1.07 mg/ha*	< LOQ – 8.68 ng/L 26% 1.53 mg/ha*
Estriol	< LOQ – 3.14 ng/L 4% 0.18 mg/ha*	< LOQ – 5.89 ng/L 10% 0.98 mg/ha*

*****Loads are normalized to the area on which animal waste is applied rather than the entire drainage area.

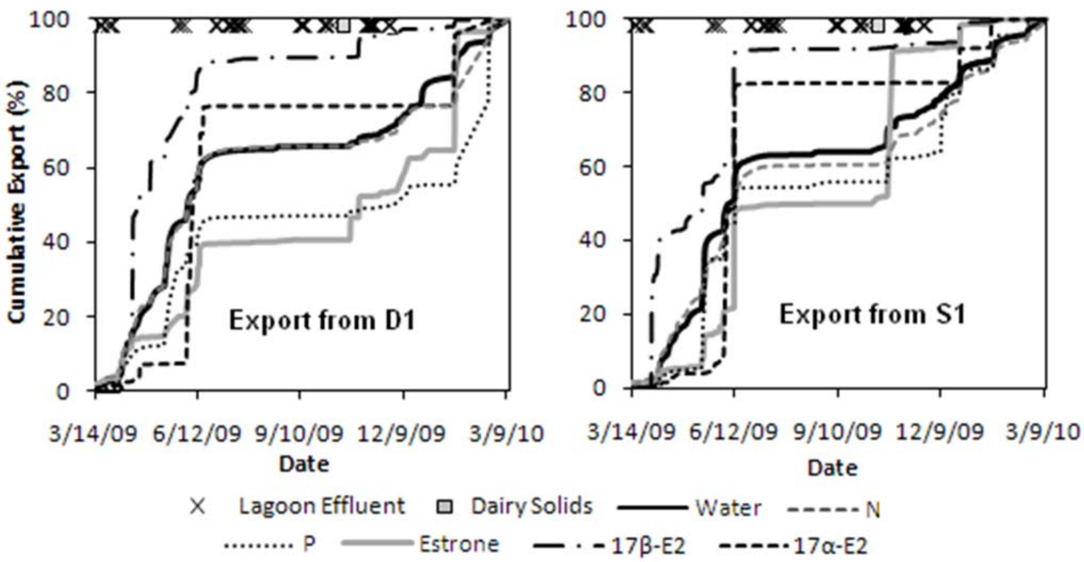

Figure 3. Cumulative measured exports at D1 (left) and S1 (right). Timing of animal waste applications are shown across the top of the figure.

Implications for Best Management Practices: To develop a relationship between constituent loads and water discharge, flow duration curves were generated and plotted with cumulative constituent export. This methodology allows the contribution of high flow events to constituent export to be evaluated. Results for E1 and DRP are shown in Figure 4.

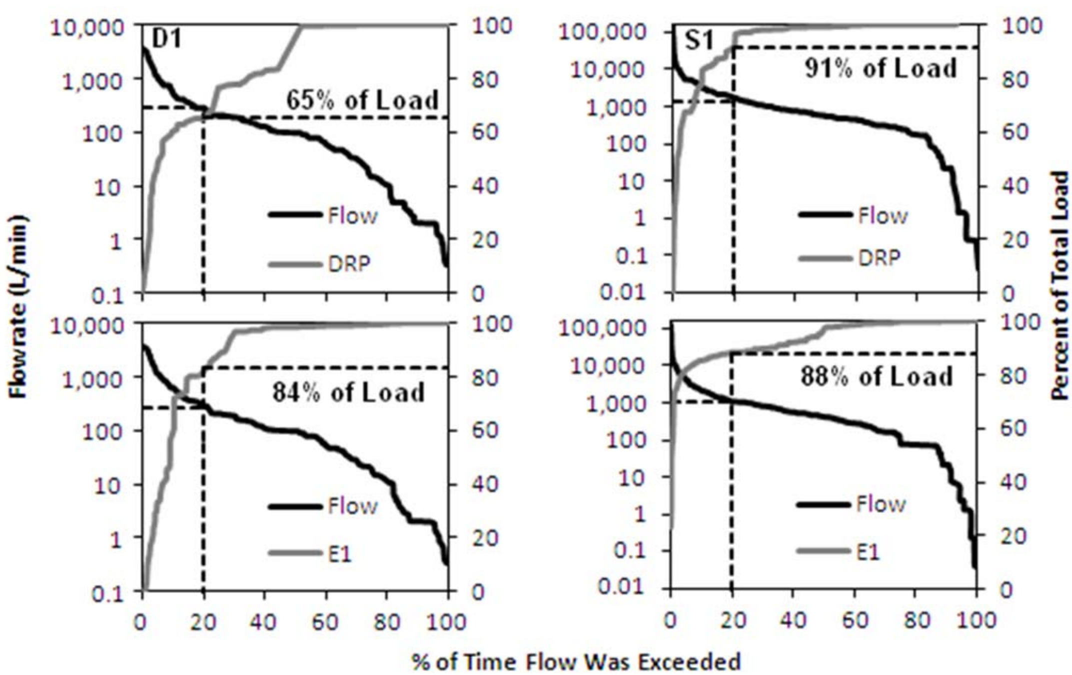

Figure 4. Flow duration curves and cumulative load plots at D1 (right) and S1 (left).

The results show that the majority of export occurs during high flow rates. Loads exported by flow rates in the 80th percentile (*i.e.,* exceeded 20% of the time) accounted for ~90% of the stream loads for DRP and hormones. For the tile drain, the 80th percentile flow rates accounted for >80% of the hormone export; however, due to the high winter export of DRP in the tile, the high flow rates contributed to a smaller percent of the DRP export (65%). Overall, these results suggest that best management practices effective at reducing loads during low-flow events are not likely to significantly reduce downstream export. Rather, best management practices must aim to reduce high-flow loads rather than low-flow loads in order to significantly reduce downstream export.

Accomplishments: This Sea Grant fund provided the resources necessary to incorporate nutrient-related research into the EPA STAR project (Grant RD833417), which focused on hormones. The major findings of this research were: (i) of the various estrogens, E1 exhibited export dynamics most similar to phosphate; (ii) the majority of hormone and nutrient export occurs during flow rates in the 80th percentile; and (iii) best management practices must reduce loads during high-flow events to substantially decrease export to downstream locations.

Impacts: Although the hormone concentrations observed in the ditch were typically below the lowest observable effect level (LOEL), the high frequency of detection suggests that animal waste applications may lead to the chronic exposure of aquatic organisms to hormones below the LOEL with temporary high concentrations well above the LOEL. Additionally, the results of this research indicate that the export dynamics of E1 and phosphate are similar, and therefore it is likely that best management practices that effectively reduce phosphate load also will reduce hormone loads, as estrone was found to be the largest contributor to hormone loads. Based on the results of this research, best management practices aimed at reducing hormones applied to agricultural fields in animal waste are likely to yield the largest reduction in hormone export. Therefore, reducing the hormone to macronutrient ratio in animal wastes may serve as a good indicator of the potential to reduce hormone export. Effective best management practices are likely to include: (i) applying animal wastes to meet crop phosphorus rather than nitrogen demands; (ii) composting manure solids prior to application; and (iii) aerating lagoons prior to effluent irrigation.

STUDENTS SUPPORTED AND DEGREES CONFIRMED:

This grant supported Heather Gall during her final semester as a graduate student. She graduated with her Ph.D. (civil engineering) in May 2011.

LIST OF PUBLICATIONS:

Draft Manuscript Attached: *Hormone and Nutrient Dynamics in a Tile-Drained Agroecosystem: Implications for Best Management Practices*

Gall,H.E. *Hormone Transport in a Tile-Drained Agroecosystem Receiving Animal Waste Applications*. Ph.D. Dissertation, Purdue University, 2011.

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