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Transport and transformation of nutrients and sediment in two agricultural watersheds in Northeast Arkansas

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ABSTRACT

Understanding pollutant transport at different spatial and temporal scales is crucial to agroecosystems management and planning. This study aimed to reduce the knowledge gap between edge-of-field and larger agricultural watersheds. Nutrients and sediment transport and transformation at two small agricultural watersheds, Little River Ditches Basin (LRDB) and Lower St. Francis Basin (LSFB), in Northeast Arkansas, were evaluated. Flow, nutrients, and sediment were measured at 3–5 instream locations in these two contrasting watersheds. These watersheds differed in primary crop, soil type, and size.

Differences in sediment and nutrients loads were measured between the two watersheds primarily due to differences in cropping practices and soil type. LSFB was dominated by rice farms and had more pollutant load per unit area but lower concentrations for all measured parameters except nitrate, whereas LRDB was dominated by cotton farms and had less pollutant load per unit area but higher concentrations. Turbidity increased considerably at LSFB, but it did not increase or decrease at LRDB as water traveled downstream. The median nitrate-N concentration at LRDB increased from 1.64 to $2.34\,\mathrm{mg\,L^{-1}}$ as watershed size increased, in contrast to no increase at LSFB. Total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations remained constant, but ammonium-N decreased as the water traveled downstream in both watersheds. Nitrate-N were high in spring and late fall at both watersheds. The annual loss of nitrate-N was 9.6 and $8.6\,\mathrm{kg\,ha^{-1}}$, sediment was 1604 and $1958\,\mathrm{kg\,ha^{-1}}$, and SRP was 0.8 and $0.9\,\mathrm{kg\,ha^{-1}}$, respectively from LRDB and LSFB. Source control in spring and late fall could be more effective in reducing agricultural pollution.

1. Introduction

Non-point source pollution due to agriculture is the leading source of water quality impairment in U.S. water resources (USEPA, 1996, 2009). Poor water quality due to non-point source pollution adversely affects aquatic, human health, and economic health. The effects include excessive growth of algae, planktons and macrophytes, oxygen depletion in water, loss of fish and other species, bad taste and odor, increase in turbidity, change in temperature, increase in treatment cost for drinking water, and decrease in aesthetics/tourism and economic value of water (Carpenter et al., 1998; Rabalais et al., 2002). Therefore, agricultural non-point pollution control is crucial to protect the nation's water.

The Mississippi River watershed is the third largest in the world, largest in the USA and one of three most productive zones on the planet. It provides drinking water for 18 million people, produces 92% of the country's agricultural exports, and supports 180 fish species unique to the river (LMRRA, 2015). Economically, the watershed creates $105 billion worth GDP and supports 2 million jobs directly and indirectly (LMRRA, 2015).

Hypoxia in the Gulf of Mexico due to nutrient loading from the Mississippi River watershed is well documented. Non-point source pollution from agriculture and urban activities are primary contributors to the hypoxic zone in the Gulf of Mexico and local waterways (Rabalais et al., 2002). Non-point sources contribute to 78% (42% from fertilizer) of nitrogen and 66% of phosphorus loads to the Gulf of Mexico (MWNTF, 2015). The hypoxic zone in the Gulf of Mexico is the largest in the USA covering as large as $22{,}007\,\mathrm{km}^2$ in 2002 (MWNTF, 2015; NOAA, 2015). Recognizing the extent and magnitude of the problem, the multi-agency Hypoxia Task Force (HTF) has set the revised goal. This goal includes a decrease of

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nitrogen and phosphorus loading by 20% of the average loading from 1980 to 1996 by 2025 and decrease of the hypoxic extent to less than 5000 km^2 by 2035 (LMRRA, 2015).

The Delta Region of Arkansas, a major agricultural area within Mississippi River Basin, produces a major quantity of row crops annually due to a combination of fertile alluvial soil, favorable land slope, shallow groundwater, and humid subtropical climate. The high production of crops in the region contributes to high national rankings among the states in the US. In 2013, Arkansas was ranked in the top 25 states in the production of 23 commodities that included rice (#1), cotton seed (#4), sorghum (#5), and soybean (#9) (UASDA, 2014). Consequently, agriculture contributed $20.1 billion to the Arkansas economy which is double the national average contribution to state GDP. Agriculture provided 280,959 jobs or one in six jobs and contributed 17% of the state's labor income (UASDA, 2014).

Due to the shallow water table of the Mississippi River Valley Alluvial Aquifer (MRVAA), groundwater has been increasingly used for irrigation and the estimated pumping has increased by 115% between 1985 and 2010 (Schrader, 2015). Irrigation and rainfall, in excess of infiltration, contribute to runoff events. Sediment, dissolved and adsorbed nutrients and pesticides leave the field with runoff water to drainage ditches, streams, Mississippi River, and finally to the Gulf of Mexico.

Gulf of Mexico HTF and Lower Mississippi River Conservation Committee have identified tributaries as the largest source of nutrients and sediment to the Mississippi River (LMRRA, 2015; MWNTF, 2015). They also cited the need for improved understanding of water quality and quantity at different spatial scales to develop a watershed management plan for wildlife and fish habitat management, hypoxia reduction and water quality improvement for recreation (LMRRA, 2015; MWNTF, 2015). Additionally, understanding of seasonal nutrient loadings is important as spring (Apr-Jun) load was recently found to be highly correlated to the increase of hypoxic zone area (MWNTF, 2008). Systematic and consistent monitoring is also required to choose the optimal resource management strategies in a watershed.

Multiple agencies are working together to improve understanding of sediment and nutrient loss from fields, and their transport and transformation across various scales of agricultural landscapes. The Mississippi River Basin Healthy Watersheds Initiative (MRBI) is one of the USDA-NRCS programs that monitors nutrients and sediment at the field scale (USDA-NRCS, 2009). However, there are no studies in the region that link edge-of-field (EOF) to patterns in larger watersheds. More specifically, there are no studies in the lower Mississippi River Basin that study nutrient and sediment transport at a small watershed scale. Additionally, lower order watersheds may have features such as riparian vegetation that could aid sedimentation and treatment by reducing velocity and increasing the retention time of water. The overall effect of the processes along the first or second order streams (often present as agricultural ditches) at different cross-sections needs further study.

Therefore, we examined the nutrients and sediment in two small agricultural watersheds in Northeast Arkansas with a goal of better understanding their transport and transformation along the streams (here ditches). The two watersheds differed in size, dominant crop type, and soil. The specific objectives were to:

I Assess spatial variation in nitrate, ammonium, phosphorus and sediment along the stream and evaluate their transport and transformation in both watersheds,
II Quantify monthly and seasonal trends in nitrate, ammonium, phosphorus and sediment in each watershed, and
III Compare two agricultural watersheds based on the flux of nitrate, ammonium, phosphorus, and sediment.

2. Methods

2.1. Study sites

Two predominantly agricultural watersheds with different cropping practices and soil (Fig. 1) were chosen for the study. The watersheds complement an ongoing field level study that measures nutrients and sediment at an EOF as part of a large state-wide MRBI network (Reba et al., 2013). The two watersheds, Little River Ditches Basin (LRDB) in Mississippi County and Lower St. Francis Basin (LSFB) in Poinsett County, each had five instream water quality monitoring stations (Fig. 1). The 30-year (1981–2010) annual mean precipitation near the basins obtained from the National Oceanic and Atmospheric Administration was 1277 mm.

Along LRDB, the stations at the mainstream were named W1, W5, and W9 for downstream, midstream and upstream location, respectively (Fig. 1). W3 and W7 were located on the primary tributary streams that drained to the mainstream. The size of the basin was 53.4 km^2 (13,200 acres). Land use in LRDB, according to National Land Cover Dataset in 2011, was greater than 87% area in row crops, primarily soybean, and cotton. The soil in LRDB according to USDA Web Soil Survey accessed on 09/28/2015 consisted of approximately 62.0% of the area with Routon-Dundee-Crevasse complex (silt loam), 14.1% with Tiptonville and Dubbs or Dundee silt loams, 7% with Dundee-Dubbs-Crevasse complex, 6.1% with Steele and Tunica soils, and 10.8% with others. Soil hydrologic groups included C/D (64.5%), C (21.2%), A (12.4%) and D (1.8%).

Along LSFB, the stations at the mainstream were named M2, M8, and M10 for downstream, midstream and upstream location, respectively (Fig. 1). M4 and M6 were located on the tributary streams that drained to the mainstream from the EOF fields. The size of the basin was 23.35 km^2 (5769 acres). Land use in LSFB, according to National Land Cover Dataset in 2011, was greater than 94% of the area in row crops, primarily rice and soybean. The soil in LSFB according to USDA Web Soil Survey accessed on 09/28/2015 consisted of approximately 62.2% of the area with Sharkey-Steele complex (Clay), 29.9% with Sharkey clay, and 7.9% others. Soil hydrologic groups included D (97.4%), C/D (2.2%), C (0.2%) and A (0.3%).

LRDB and LSFB have urban areas of approximately 10.86% and 5.17% of total area, respectively. Urban sewage and wastewater produced by approximately 3300 residents inside LRDB are collected and treated at a lagoon in the watershed. However, the effluent is disposed to water resources outside of the watershed [Personal Communication, January 2016]. Therefore, flow at the instream stations in LRDB includes only stormwater from the urban area. At LSFB, approximately five households reside within the watershed, and there is no centralized wastewater treatment system. Direct human influence on stream water other than from agricultural activities at LSFB is unlikely.

Mostly cotton-soybean rotation at LRDB and rice-soybean rotation at LSFB is in practice. Also, corn, grain sorghum and wheat are planted in a few fields each year. Conventional tillage practice is widespread in both watersheds. In both watersheds, approximately 100% of croplands are irrigated either by flooding/multiple inlet or sprinkler/pivot irrigation utilizing shallow alluvial aquifer as the source water. The fields drain via surface runoff to the ditch, and no subsurface drainage is in practice in the region. Fertilizers in the crop fields were applied according to LGU (Land Grant University) recommendations (Table 1). All fertilizer recommendations begin with an analysis of field-specific soil test results. Site-specific recommendations are then modified based on previous crop or soil type or a combination of both (Barber and McClelland, 2012; Hardke et al., 2014; Kelley and Lawson, 2014, 2015; Ross et al., 2014; Kelley et al., 2016). At the EOF fields, P fertilizer was applied