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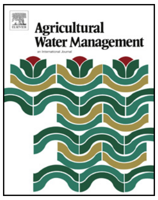

Characterizing nitrogen outflow from pre-harvest rice field drain events

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ABSTRACT

Tailwater recovery systems (TWR) provide an excellent testbed for examining nutrient loading from agriculture non-point sources, such as pre-harvest rice (*Oryza sativa* L.) field drains, on receiving waters. In this study, the focus was to use continuous sampling of nitrate-nitrogen (NO_3^--N) concentration, paired with discrete grab samples of water which were analyzed for total nitrogen and inorganic nitrogen species to (1) assess if rice paddies are a source of nitrogen loading to downstream systems; (2) monitor the diel cycles in NO_3^--N of rice paddies and TWR; and (3) describe the nitrogen capture capacity of TWR during these events. Five rice paddies within the Mississippi Delta with adjoining TWR were selected as case study locations. Both paddy and TWR were instrumented to continuously monitor nitrate, pH, dissolved oxygen, specific conductivity, and water temperature; discrete grab samples of water were also taken at deployment and collection. During the study, most TWR had total nitrogen concentrations <1 mg L^{-1}; the majority of nitrogen present at drain was organic (>51% for paddies, and >88% for TWR). The percent change in total nitrogen concentrations between draining paddies and post-drain TWR ranged from −14 to +178%; the percent of organic nitrogen increased between 5 and 24% in TWR following rice drains. Both nitrogen accumulation and dilution in TWR were observed during drain events. Diel cycles were apparent and were in phase with dissolved oxygen (average values between 3.7 and 13.2 mg L^{-1}). The average peak-to-peak amplitude in TWR was 0.101 mg NO_3^--N L^{-1}. Total nitrogen captured by TWR ranged from 0.009 to 0.610 kg ha^{-1}. Increases in NO_3^--N concentrations were observed in several TWR during drain events, but concentrations remained low and loads were determined to be of little consequence; this suggests limited detrimental impact of rice drains downstream.

1. Introduction

There is growing public awareness of nutrient loading from production agriculture systems. Within the United States alone, over 160,000 km of rivers and streams and over 400,000 ha of lakes, reservoirs, and ponds are impaired by excess nutrients (USEPA, 2014). Excessive nitrate–nitrogen (NO_3^--N) in agricultural runoff has been identified as a primary driver for the annual Gulf of Mexico hypoxic zone (Turner and Rabalais, 2003). As such, there remains a need for strategic implementation of scientifically-validated conservation practices within the agriculture landscape. A unique opportunity exists to quantify the ability of tailwater recovery systems (TWR) to mitigate nutrient loading from agriculture non-point sources. Tailwater recovery systems (described under National Resources Conservation Service practice code 447) are a conservation practice designed to capture surface water runoff and store the captured water for subsequent irrigation; it is anticipated they will additionally capture nutrients leaving the landscape. Tailwater recovery systems, when coupled with rice fields, provide an excellent testbed for examining the impact of rice (*Oryza sativa* L.) field outflows on receiving waters. Typical water levels are greater than 5 cm within the field during the growing season. Prior to harvest, rice fields must be drained, but the fate of downstream water quality resulting from rice drain events has not been investigated fully.

Moreover, studies on conservation practice efficacy typically measure NO_3^--N in agricultural runoff through use of grab samples, resulting in discrete "snapshots" of water quality. Stelzer and Likens (2006) have pointed to problems of bias associated with coarse sampling frequency due to the relationship between dissolved concentration and discharge. *In-situ* equipment, which allows for continuous data collection, can now be utilized and presents a more comprehensive picture of nutrients in field runoff.

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An understanding of diel cycles for NO_3^--N could have implications for development of conservation practices in agriculture catchments (Pellerin et al., 2009). Diel NO_3^--N cycles have been observed in larger aquatic systems including oceans (Johnson et al., 2006), rivers (Heffernan and Cohen, 2010), and streams (Pellerin et al., 2009) but have not yet been investigated in TWR. In this study, the focus was to use continuous sampling of NO_3^--N concentration, paired with discrete samples which were analyzed for total nitrogen and inorganic nitrogen species to (1) assess if rice paddies are a source of nitrogen loading to downstream systems; (2) monitor the diel cycles in NO_3^--N of rice paddies and TWR; and (3) describe the nitrogen capture capacity of TWR during these events.

2. Methods and materials

Five rice paddies with adjoining TWR were selected as case study locations within the Mississippi Delta, a region in northwest Mississippi created by alluvial deposition from the Mississippi and other rivers. These case study locations represent multiple areas within the Delta, with one site each in Humphreys, Bolivar, and Tunica Counties, and two sites in Sunflower County. Hectares drained and TWR dimensions were provided by producers and local National Resources Conservation Service personnel (Table 1). Predominant soil type for each catchment area was attained from the United States Department of Agriculture's Web Soil Survey (Table 1). Local weather conditions were obtained from the closest National Resources Conservation Service Soil and Climate Analyses Network and the National Oceanic and Atmospheric Administration's National Climatic Data Center monitoring locations for the dates represented by each study site (Table 2). All paddies in the study have been land leveled, surrounded with elevated berms, and outfitted with slotted pipes with removable riser boards by producers.

For data collection, both paddy and TWR were instrumented with a Submersible Ultraviolet Nitrate Analyzer V2 NO_3^--N meter (Sea-bird Coastal, Bellevue, WA) and a Hydrolab DS5 water quality multiprobe equipped with pH, dissolved oxygen (DO), specific conductivity, and water temperature sensors (Hach Company, Loveland, CO). Nitrate meters were powered with 12 V–12 amp hour batteries, with a solar panel and supply regulator. Nitrate meters were deployed from a floating buoy within TWR; when floating was not possible (occasionally in TWR, but always in paddies), NO_3^--N meters were deployed on a stable mount. Equipment was deployed in each paddy within the rice stand, away from outflow pipes; deployment in TWR was near the thalweg, away from sumps and inflow pipes. Due to the potential for damage from flowing debris, NO_3^--N meters were encased in plastic housing when deployed on a stable mount. The housing did not interfere with optics or wiper function and was open on each end and porous enough on the top and sides to avoid creating a microcosm by allowing adequate flow-through. Several locations in this project are monitored for other research projects and were already instrumented with OTT PLS pressure sensors (OTT Hydromet Ltd., Germany) which provide continuous water depth measurements of TWR. Other TWR which had no such mechanism and rice paddies used Hobo water level loggers (Onset, Bourne, MA), mounted similar to pressure sensors, directly (15.2 cm) above the sediment surface for water depth measurements. Pre-monitoring was done to attain baseline water quality levels and diel patterns of nitrate. All sites were monitored for a 4-to-5 day period prior to drain events.

Immediately prior to drain events, sites were re-instrumented with the same equipment. Nitrate meters and multiprobes (and level loggers, where necessary) were placed only in the TWR for the drain events. It was reasoned that continuous monitoring of paddies during the drain event was not as essential as the ability to monitor two simultaneous drain events; thus only TWR were continually monitored with nitrate meters during drain. However, discrete water samples collected from paddies where instruments had previously been located were assumed to indicate water quality immediately prior to the drain.

Discrete water samples of 250 ml were taken at instrument deployment and collection for both pre-monitoring and drain events. Unfiltered samples were collected and placed on ice before transport to the Water Quality Laboratory at Mississippi State University. Samples were analyzed for total nitrogen with TNT 826 kits (Hach Company, Loveland, CO). Samples were additionally filtered using 0.45-μm Whatman nitrate–cellulose membranes and preserved with sulfuric acid for analysis with a flow injection analyzer (Lachat FIA 8500, HACH, Loveland, CO). The flow injection analyzer was used to determine concentrations of nitrite (NO_2^--N), NO_x^--N (NO_2^--N + NO_3^--N), and ammonia (NH_3-N) in water samples. Concentrations of NO_2^--N and NO_x^--N were determined using the cadmium reduction method (QuickChem method 10-107-05-1-B, HACH, Loveland, CO). Nitrate concentrations were derived by subtracting the determined concentrations of NO_2^--N from the determined concentrations on NO_x^--N. Inorganic nitrogen was the summation of NO_x^--N and NH_3^--N. Organic nitrogen was attained by subtracting inorganic nitrogen (FIA) from total nitrogen (TNT kits).

Calculations for water holding and capture capacities were performed by applying dimensionality to depths. It was assumed that rice field would have a uniform flood depth of 10.16 cm (typical flood depth) immediately prior to draining. This depth was multiplied by the total paddy hectares drained into the TWR (reported in Table 1) to obtain the volume of *potential* water captured from fields. This value would represent the maximum volume of water leaving the field during the rice drain. As it may not be the case that a producer drains a field with average or above average flood depths, the volume of *actual* water captured from fields (*i.e.*, the difference in TWR volume post-drain minus TWR volume pre-drain) was also calculated using system dimensions and recorded water depth change in TWRs.

Water holding capacities were coupled with average nutrient concentrations for each location to calculate loads. Multiplying the average total nitrogen concentration by the perceived maximum outflow volume of water (*i.e.*, the potential water captured from field), the potential total nitrogen load was calculated. Additionally, the average total nitrogen concentration was multiplied by the total water holding capacity of the system to obtain the potential nutrient capture capacity of the TWR. These two values help to put the third calculation, representing actual total nitrogen load captured, into perspective. Actual total nitrogen load was calculated as the product of average total nitrogen concentration and actual water captured from fields by the TWR. These values were normalized by hectares drained (as specified in Table 1) for comparison purposes.

Finally, percent differences between system holding capacities for potential and actual total nitrogen load captured were compared to the total nitrogen holding capacity of the TWR to get a sense of the efficiency of each system. Potential efficiencies assume that TWR are empty at the commencement of drain events.

3. Results and discussion

3.1. Nutrient and dissolved oxygen concentrations

Mississippi rice fertility guidelines suggest split application of nitrogen, one-half to two-thirds prior to initial flooding, with the rest applied mid-season. Typical rates range from 168 to 202 kg