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Reducing drainage water phosphorus concentration with rice cultivation under different water management regimes

Mohsen Tootoonchi[a,b,*], Jehangir H. Bhadha[a,b], Timothy A. Lang[a], J. Mabry McCray[a], Mark W. Clark[b], Samira H. Daroub[a,b,**]

[a] Univ. of Florida, Everglades Research and Education Center, 3200 E Canal St. S, Belle Glade, FL, 33430, United States
[b] Univ. of Florida, Soil and Water Sciences Department, University of Florida, United States

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ABSTRACT

Phosphorus is a critical water quality indicator of farm drainage systems. In South Florida, rice (*Oryza sativa* L.) cultivation has the potential to reduce phosphorus concentration in drainage water through crop uptake under varying flooding systems. A two-year study was conducted to assess drainage water quality under four different flooding systems conventionally used for rice production – 15 cm continuous flood; 5 cm continuous flood; 15 cm with midseason drawdown; and 5 cm with midseason drawdown. In the first growing season, 15 cm continuous flood treatment had the highest reduction of total phosphorus and particulate phosphorus concentrations in drainage water. However, in the second growing season, we did not observe significant differences among water treatments, which was likely due to the release of phosphorus from other sources like soil and rice straw to the water column which masked treatment effects. On average, in both years, all flood treatments reduced total phosphorus concentrations by 42 ± 8% between inflow and outflow water. No phosphorus fertilizer was added and with each harvest, rice grain potentially removed 15.7 ± 3 kg phosphorus ha^{-1}. The results indicate that rice cultivation in fertile soils can successfully reduce phosphorus concentrations in drainage water under well managed water-flow conditions.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most widely grown cereals in the world and a staple food for more than 1.6 billion people. In the Everglades Agricultural Area (EAA) of South Florida, rice is produced together with sugarcane (*Saccharum* spp.), sod (*Stenotaphrum secundatum* [Walt.] Kuntze), and vegetables on 280,000 ha of organic soils. Rice in the EAA is often grown commercially in rotations with sugarcane and vegetables and from 2008 to 2015, rice production has increased more than 80% (Bhadha et al., 2016). Conventional rice production in the region does not include any nitrogen (N), phosphorus (P) or potassium (K) fertilization.

Two most important requirements of the Everglades Forever Act (EFA) are to restore and protect the Everglades ecological system, and reduce excessive levels of P. Nearly 1110 million m^3 of water discharges annually through the EAA soil and leaves the area in the south and southeast part (Bhadha et al., 2017). Therefore, a major concern in the EAA is improving drainage water quality by reducing P concentrations in drainage water. The long-term water quality objective for the Everglades is to implement the optimal combination of source controls, Stormwater Treatment Areas (STAs), Advanced Treatment Technologies, and regulatory programs to ensure that all waters discharged to the Everglades Protection Area achieve water quality standards consistent with the EFA. Therefore, as a major component of the EFA, STAs were constructed and operated in south Florida in addition to a mandatory best management practices (BMP) program in the EAA to remove P from upstream waters flowing into the downstream Everglades Protection Area (Chimney and Goforth, 2001; Daroub et al., 2009). Stormwater treatment areas retain P in different ways such as plant and microbial nutrient uptake, particulate settling, chemical sorption and ultimately accretion of plant and microbial biomass in the sediments (Andreotta et al., 2015). Planting rice as a cover crop is one of the BMPs EAA farmers can implement to reduce drainage in the wet season and reduce oxidation of the organic soils.

The soils of this region are predominately Histosols underlain by marl and limestone. Historically, these wetland soils have been flooded for a long time; therefore, accumulation of organic matter under anaerobic condition and slow decomposition provided an extremely

* Corresponding author at: University of Florida – Fort Lauderdale Research and Education Center, 3205 College Ave, Davie, FL 33314, United States.
** Corresponding author at: University of Florida – Everglades Research and Education Center, 3200 E Palm Beach Rd. Belle Glade, FL 33430, United States.
E-mail addresses: m.tootoonchi@ufl.edu (M. Tootoonchi), sdaroub@ufl.edu (S.H. Daroub).

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fertile soil with 50–90% organic matter content (Schueneman et al., 2008). The study site was in the Pahokee series (euic, hyperthermic Lithic Haplosaprist) which consists of very poorly drained, rapidly permeable soils formed in organic deposits of freshwater marshes (Janardhanan and Daroub, 2010). The soil series has 91–130 cm thick O horizon with less than 35% mineral material and a bulk density of about 0.47 g cm^{-3} with an underlying limestone layer. The pH of the soils is neutral ranging between 6.8–7.1. It is suggested that the depth of the soil and proximity to the limestone bedrock may have a direct implication on drainage and quality of drainage water leaving these soils (Daroub et al., 2011).

Rice can possibly accumulate nutrients during the summer season and immobilize the nutrients when the potential for nutrient-rich water runoff is the greatest (Jones et al., 1994). Rice cultivation has the potential to alleviate short-term nutrient loadings to the canals and has been identified as a BMP for nutrient removal in drainage water from surrounding fields (Izuno and Bottcher, 1991; South Florida Water Management District, 1997). However, no local research has been conducted on flooded rice systems to quantify net P reductions. Although P exists in several chemical forms (Dodds, 2003), earlier initiatives often adopted total P (TP) to support rehabilitation initiatives, such as the total maximum daily load analysis process (Prestigiacomo et al., 2016). Partitioning P into different forms such as particulate P (PP), total dissolved P (TDP), and soluble reactive P (SRP) provides valuable information for tracing P in environmental and agricultural systems.

In flooded rice cultivation, when O_2 becomes less available and soil redox potential becomes more reduced, slow organic matter decomposition may result in accumulation of dissolved organic carbon (DOC) (Moorberg et al., 2015) and affect drainage water quality. High concentrations of organic matter in the form of decomposed vegetation can drastically increase the availability of P because organic anions formed by decomposing organic matter can compete with P for the same adsorption sites, such as clays and Fe–Al minerals (Bhadha et al., 2014). De Groot and Van Wijck (1993) showed that when anoxic wetland soils were exposed to air, the ferrous sulfide previously present was rapidly oxidized to amorphous ferric oxyhydroxide. These ferric (oxy)hydroxides have both a large surface area and high affinity for SRP; however, extended periods of desiccation lead to a significant reduction of the SRP binding capacity of ferric hydroxides in both flooded and drained soils (Bhadha et al., 2010). Some growers apply a 2–4 week drainage period in the middle of growing season to reduce pumping costs which not only could alter P and carbon (C) status but also may release P into interstitial water. At the time of harvest, rice grain along with the husk is severed from the plant, and only the roots and a portion of the stem is cultivated back into the soil.

In the EAA, different water management scenarios need to be studied in order to select the most appropriate flooding system for rice fields. Reducing pumping costs and water conservation are also important concerns in increasing the production efficiency. Different flood depths and short-term field drainage in the middle of growing season (intermittent flood) might have the potential to affect drainage water quality and rice yield. Therefore, in this study we investigated the effects of four different flooding treatments on the quality of drainage water at a flooded rice field. We compared P concentration in water samples collected from inflows and outflows of each treatment in two growing seasons. To establish a P budget associated with the experimental rice field, P content was evaluated in the harvested grain, rice aboveground biomass, aquatic vegetation, and soil samples collected before and after each growing season.

The objectives of this study were to: 1) Assess effects of two different flood depths (15 cm and 5 cm flood) and a single midseason drawdown, on outflow drainage water P concentrations in the summer growing seasons of 2014 and 2015; 2) Estimate a P-budget associated with the rice production system in the EAA.

2. Materials and methods

2.1. Experimental design

This study was conducted during summers of 2014 and 2015 in 16 individual plots (84 m × 18 m) in a 2.4 ha field at the University of Florida, Everglades Research and Education Center (EREC). Each water treatment, 5 cm continuous flood (CF5), 5 cm intermittent flood (IF5), 15 cm continuous flood (CF15) and 15 cm intermittent flood (IF15) had 4 replications and common rice varieties in the EAA, Cheniere and Taggart, were planted within each plot. As a conventional method, both varieties were planted (dry-seeding) on 1:1 ratio using disk cultivator and fertilized with iron sulfate (112 kg ha^{-1}) in both years. No fertilizer with N, P and K or other chemicals except iron sulfate were applied to the experimental field.

2.2. Water management

Irrigation water was pumped from a nearby canal. An electric pump distributed the water through 16 individual irrigation lines to the plots. Each plot had a separate inflow valve to control irrigation flow rate into the plot and an outflow “box” to control the water depth within the plot (Fig. 1). All individual plots were separated by a 6 m levee (bund). In each growing season (16 weeks), flooding started 3 weeks after planting with initial flooding depth of 2 cm in all plots and gradually increased to proposed depths within 2 weeks.

The water table was maintained by controlling the flow of water into each individual plot; daily measurements of water height in individual plots were recorded to ensure steady stage height. By adding riser boards to the outflow box, the level of water in the plots was raised. The high discharge rates were necessary because evapotranspiration (ET) and seepage are high in this region. Evapotranspiration accounts for about 2 cm of water daily during the hot summer months. A portion of the discharge water is circulated back into the fields via the main canal and not all of it is discharged off-site. In order to maintain a steady stage after the rains, the raiser boards had to be removed and excess water allowed to drain off.

Hydrologic inputs to the system include irrigation (inflow), and rainfall, whereas the outputs include discharge (outflow), seepage, and ET. Depending on planting date of commercial rice in the EAA, a midseason drawdown is done between mid-May and end of July. For our study, in 2014 the drawdown was initiated on June 13th (60 days after planting), and in 2015 it was initiated on June 15th (68 days after planting) (Table 1).

2.3. Sampling collection and analysis

Water samples were collected 6 times in each growing season (biweekly) from inflow pipes and outflow boxes of all 16 plots (n = 192) (Fig. 1). All water samples from inflow pipes and outflow boxes were collected within 15 min into polyethylene bottles and immediately transported to laboratory. Unfiltered water samples were used for TP analysis, while filtered water samples (0.45 μm filters) were used for TDP and SRP analyses. Total P and TDP were manually digested with persulfate digestion method (APHA, 1998, SM4500-P) and analyzed using ascorbic acid colorimetric method (EPA, 1983a, Method 365.1), on an AA3 automated segmented flow analyzer (SEAL analytical, Mequon, WI). Particulate P was calculated by subtracting TP and TDP results (PP = TP-TDP). Soluble reactive P was determined using ascorbic acid colorimetric method (Murphy and Riley, 1962; EPA, 1983b, Method 365.2) on a spectrophotometer (880 nm). Dissolved organic phosphorus (DOP) was calculated by subtracting TDP and SRP results (DOP = TDP-SRP). Dissolved organic carbon (DOC) was measured using EPA Method 415.3 (EPA, 2003, Method 415.3) on a Total Organic Carbon Analyzer (TOC-VCPH/CPN. Shimadzu Corporation Kyoto, Japan).