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Evaluating the nutrient reduction and water supply benefits of an on-farm water storage (OFWS) system in East Mississippi

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ABSTRACT

An On-Farm Water Storage (OFWS) system is a structural Best Management Practice (BMP) that prevents downstream nutrient loading by capturing irrigation tailwater and storm runoff from agricultural fields. OFWS systems, as a result, also act as a source of water for irrigation with the potential to recycle nutrients captured in runoff events. A monitoring study was conducted for an OFWS system located on a corn and soybean farm in East Mississippi from June 2014 to August 2016 to analyze the effectiveness of the system for reducing downstream nutrient runoff, supplying water for irrigation, and recycling nutrients in captured water that is reapplied to the field. Nitrate and dissolved phosphorus (DP) concentrations in the storm runoff events captured by the OFWS system storage pond and prevented from going downstream measured as high as 179 mg L^{-1} and 0.69 mg L^{-1}, respectively. Water can be lost downstream from the storage pond overflow pipe when the pond is at its maximum capacity in March-April of each year, but nitrate concentrations were less than 10 mg L^{-1} in the storage pond in March-April for both years of the study, and DP concentration was less than 0.053 mg L^{-1} in the water that could be lost downstream, which showed that OFWS systems can be effective in reducing downstream nutrient loading by capturing storm runoff events. Over three growing seasons, roughly 357,000 m^3 of water was used for irrigation from the OFWS storage pond in a region which has traditionally been under dryland production. This shows that OFWS systems can serve a dual purpose of reducing nutrient runoff and providing water for irrigation in East Mississippi, where groundwater is not a cost-efficient source of water for irrigation. Irrigated corn yields were higher than non-irrigated corn yields by an average of 1532; 2285; and 3950 kg ha^{-1} in 2014, 2015, and 2016, respectively; and irrigated soybean yields were higher than non-irrigated soybean yields over the same years by an average of 302; 1411; and 800 kg ha^{-1}, respectively, demonstrating the importance of irrigation in East Mississippi. Analysis of nutrient concentrations in water samples collected simultaneously from both the irrigation system (sprinkler), which is fed from the bottom of the pond, and the storage pond grab samples showed that nitrate concentrations in the irrigation samples were lower than in the storage pond, but ammonia concentrations were higher in the irrigation water samples. Low nitrate concentrations and variability in nitrate concentration in the irrigation water as compared to the storage pond water showed that some of the nitrogen load is being recycled but not enough for the producer to reduce commercial fertilizer application.

1. Introduction

Substantial nitrogen (N) and phosphorus (P) application on croplands (Sims et al., 1998; Smith, 2003) has resulted in agricultural runoff rich in N and P, which is a major source of pollution to many surface waters including rivers, lakes, and oceans in the United States and around the world (Millennium Ecosystem Assessment, 2005; Richards, 1998; Smith, 2003). Intensification of agriculture to meet the demand of an increasing world population is expected to cause the global production of agricultural fertilizer to exceed 135 million metric tons by 2050 (Smith, 2003), further contributing to the increase of N and P in coastal and freshwater ecosystems. Elevated levels of N and P in surface waters can lead to eutrophication (de Jonge et al., 2002), which is the increase of organic matter in a water body due to the excess availability of nutrients (Nixon, 1995). Almost 60% of the rivers and half of the lake area in the U.S. are impaired because of eutrophication (EPA, 1996) resulting in an annual loss of approximately $2.2 billion (Dodds et al., 2008). Eutrophication is also one of the largest global

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pollution problems in marine waters (Howarth et al., 2002; Papadomanolaki et al., 2018; Xiao et al., 2018). Eutrophication can lead to turbid and foul smelling water, foaming, proliferation of macrophytes, and loss of amenities that surface water provides including drinking water and recreation (Dodds et al., 2008; Postel and Carpenter, 1997). Bacterial decomposition of organic matter requires oxygen, so when excessive amounts of organic matter decompose, the dissolved oxygen concentration (DOC) in water is reduced. The result is the development of hypoxic zones, which are areas in the water body where the DOC is below 2 mg L^{-1} (Rabalais et al., 2001). Hypoxic conditions can cause mass mortality of aquatic life (de Jonge et al., 2002; EPA, 2002), habitat loss, and a change in coastal ecosystem functioning (Xiao et al., 2018). Hypoxia is one of the key stressors of coastal systems, with eutrophication-induced dead zones present in more than 400 systems around the globe, affecting a total area of more than 245,000 km^2 (Diaz and Rosenberg, 2008).

Crop production is an important contributor to making agriculture the number one revenue-generating industry in the state of Mississippi (USGS, 2015), and like many areas with intensive agriculture, Mississippi is also facing problems of nutrients in agricultural runoff. The 2016 Mississippi Water Quality Assessment Report indicated that nutrients are among the major causes of impairment in Mississippi rivers and streams (MDEQ, 2016). Because N and P supply is highly associated with eutrophication of receiving waters, management of nutrient runoff from agricultural fields is very important in improving downstream water quality.

Irrigation can help increase crop yields, decrease the risk of yield loss (Tilman et al., 2002), and provide an avenue for crop diversification (Pingali and Rosegrant, 1995). Although Mississippi receives an average 1307 mm of rainfall annually, only 37% of the total rainfall occurs during the crop growing season, from May to September (Feng et al., 2016). Having access to a water source that can be used for irrigation is critical to maximizing yield. However, most of East Mississippi has traditionally been under dryland production until the recent increase in the construction of catchment ponds and lakes to use for irrigation (Delta FarmPress, 2012). The Black Warrior River aquifer that underlies East Mississippi must be drilled to a depth of more than 61 m to reach the water, making it very difficult and cost-prohibitive for farmers (Miller, 1990) to use groundwater for irrigation. In addition, there is no readily available natural surface water source for irrigation. The Mississippi River Valley Alluvial (MRVA) aquifer is the primary source of water for irrigation in eastern Arkansas and the Mississippi Delta, a very fertile and productive area in the northwest region of Mississippi with a total land area of about 16,188 km^2 (Snipes et al., 2005). However, the MRVA is under extreme stress because of excess withdrawals for irrigation. As a result, there is increasing interest in using surface water both in areas formerly dependent on groundwater for irrigation and also in areas like East Mississippi that have previously been in dryland production.

An On-Farm Water Storage (OFWS) system is a structural Best Management Practice (BMP) (Pérez-Gutiérrez et al., 2015) that has the primary goal of reducing downstream nutrient loading by capturing and storing runoff from agricultural fields. As OFWS systems conserve water by capturing surface water runoff from irrigation and rainfall events, the stored water can later be used for irrigation, increasing the popularity of this relatively new BMP with producers. The design of these systems can vary according to topography. In regions with a sloping landscape like that of East Mississippi, systems usually consist of constructed terraces in agricultural fields to direct runoff from the fields directly to the storage pond. Center pivots are the primary irrigation system used in regions like East Mississippi because of the sloping landscape. Therefore, there is little to no tailwater runoff from irrigation events, and the runoff captured by OFWS systems in this region is mostly limited to rainfall events. In the flat plains of the Mississippi River Valley (MRV) and in areas with similar topography, OFWS systems consist of a tail water recovery (TWR) ditch for temporary storage of surface runoff and a storage pond for permanent storage. Fields are usually precision levelled when these systems are implemented on flat topography, to direct the runoff from the fields to the TWR ditch. Irrigation tailwater and storm runoff are captured from the field in the TWR ditch and then pumped to a storage pond, where it is held until needed for irrigation.

While surface water storage is not a new concept, OFWS systems are a fairly new practice in East Mississippi (Delta FarmPress, 2012) and started appearing after first being implemented throughout the MRV (Carruth et al., 2014). These systems are privately funded by farmers in East Mississippi due to the current lack of financial assistance programs, and they are primarily established for irrigation. Although these systems were initially implemented in the MRV as a BMP to control non-point source agricultural nutrient runoff, there has been very little evaluation of the effectiveness of OFWS systems as a BMP to control nutrient loss or as a water source for irrigation. However, there have been separate studies that have highlighted the importance of capturing excess rainfall for increasing agricultural productivity (Oweis et al., 1999; Zimmerman, 1966) and the importance of irrigation to increase productivity (Wesley et al., 1993). The goal of this paper is to evaluate an OFWS system located in East Mississippi as a BMP for reducing downstream nutrient-rich runoff from agricultural fields and also as a source of water for irrigation. More specifically, the objectives of this paper were to 1) evaluate the ability of the OFWS system to reduce downstream nutrient runoff from agricultural fields; 2) quantify the amount of surface water provided by the OFWS system for irrigation; and 3) determine if the producer's commercial fertilizer application can be reduced because of the nutrient load in the storage pond water that is recycled for irrigation.

2. Methodology

2.1. Site description

The study area is located in the Mississippi Blackland Prairie-Major Land Resource Area (MLRA)-135 A (USDA-NRCS, 2014), also called the Black Belt, just outside of Brooksville in Noxubee county, MS (Fig. 1). It is located in the Middle Tombigbee-Lubbub watershed (HUC 0316106), which is part of the larger Tombigbee River Basin. Vertisols and Inceptisols are the dominant soil orders in the study region (USDA-NRCS, 2014, 1999). Inceptisols are also known as cambisols (IUSS Working Group WRB, 2015). The study area consists of Brooksville Silty clay (Soil Great Group-Hapluderts) and Vaiden Silty clay (Soil Great Group-Dystruderts) soils with slopes ranging from 0 to 5% (Soil Survey Staff, 2012; USDA-NRCS, 2014). Annual precipitation in the area is approximately 1307 mm, most of which occurs during the winter and early spring months (Feng et al., 2016). The average air temperature in the summer and winter is about 28 °C and 7 °C, respectively, and corn and soybean are the primary crops grown in the study area.

2.2. On-Farm Water Storage (OFWS) system

An OFWS system was established in the study area in 2012. A storage pond covering a surface area of approximately 6.88 ha was constructed in the southeast corner of field A (Fig. 1), and the pond is 7.6 m depth at its deepest point. Terraces and drainage ditches were built to direct runoff from the agricultural fields to the storage pond. Portions of three agricultural fields make up the two watersheds that drain to the OFWS system storage pond, and the total area that drains to the storage pond is roughly 45 ha over the two watersheds (Fig. 1). Nutrient concentrations and runoff were only monitored from the larger watershed for this study because the two watersheds had different flow paths to the inlet of the storage pond. The watershed that was monitored covers approximately 30.3 ha over the northern portion of field A and the southern portion of field B. The OFWS system provides irrigation water for three different center pivot systems which are located in fields