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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 nonpoint 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

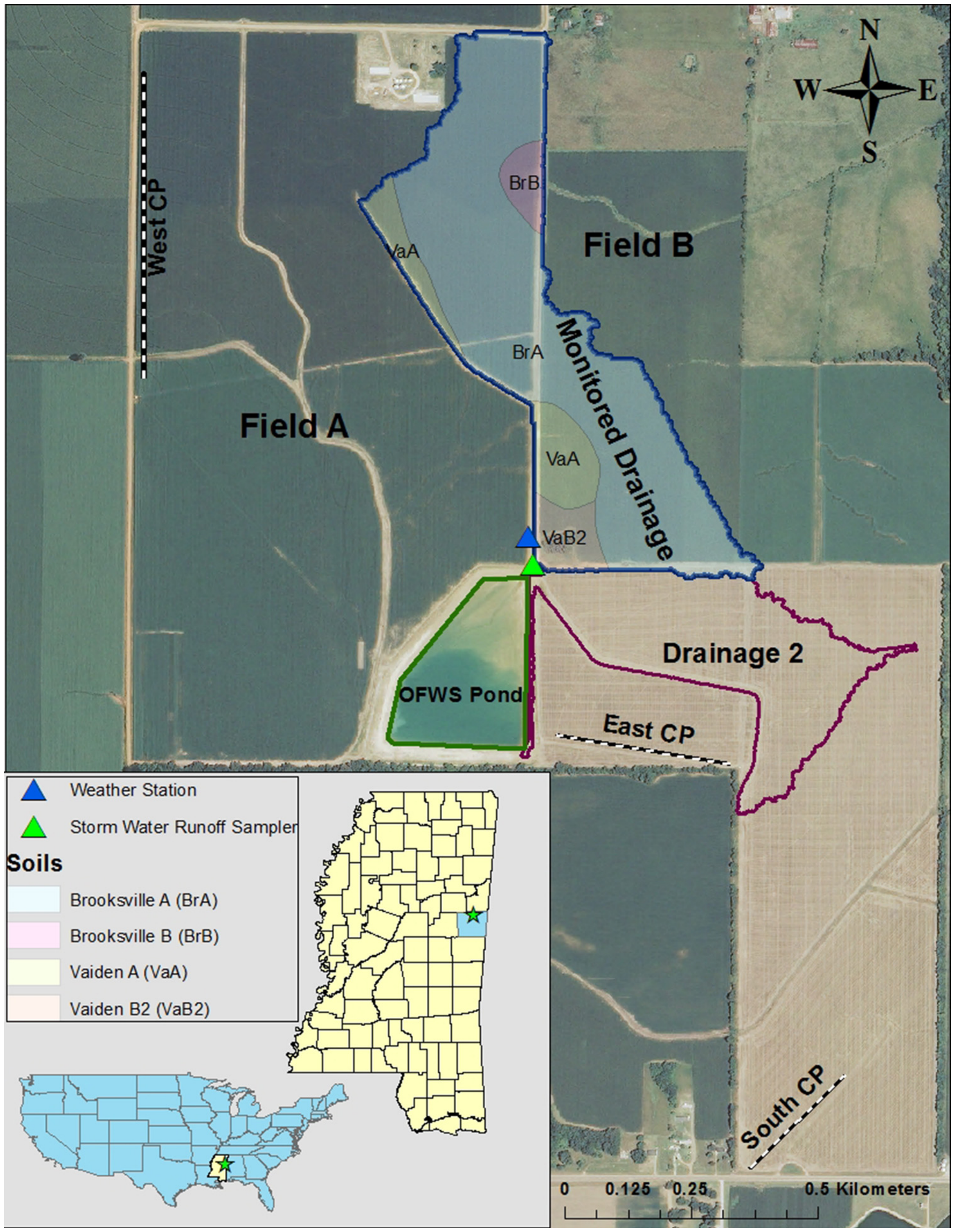

Fig. 1. Location and layout of the OFWS system in East-Central Mississippi including drainage areas and major soil types.

adjacent to the OFWS system storage pond (Fig. 1). These three pivot systems irrigate approximately 137.2 ha, resulting in a ratio of 3 ha of irrigated land for each drainage hectare.

2.3. Management information

The management schedules for the two agricultural fields (Fields A and B) in the monitored watershed (Fig. 1) were obtained from the farmers. During the monitoring period, corn was grown during the 2014 and 2015 growing seasons in field A (Fig. 1), while soybeans were grown in 2014 and corn was grown in 2015 in field B (Fig. 1). Soybeans were grown in both fields in 2016. In addition, both fields were conventionally tilled after harvest with subsoil tilling, disking, and bedding in both 2014 and 2015.

Directly after harvest and before tillage, 4485 kg and 3363 kg of poultry litter per hectare was applied on both fields in 2014 and 2015, respectively, in preparation for the next growing season. Starter fertilizer (7.2 kg ha^{-1} nitrogen, 24.2 kg ha^{-1} phosphorus), nitrogen sidedress (246.6 kg ha^{-1} nitrogen), and nitrogen at tassel (49 kg ha^{-1} nitrogen) were applied to corn for both the 2014 and 2015 growing seasons, while no fertilizer was applied on soybeans during any growing season over the monitoring period (Tables 1 and 2). Field A was irrigated from the west center pivot (West CP, Fig. 1) while there was no irrigation source for field B (Fig. 1). For the monitoring period, irrigation applications for field A and rainfall events greater than 10 mm during the growing season are also presented in Tables 1 and 2.

2.4. Monitoring system

The study site was monitored for a period of 27 months from June 2014 to August 2016. The monitoring system consisted of a portable automatic water sampler, a weather station, and three flowmeters. The locations of the weather station and autosampler within the study area are shown in Fig. 1. An ISCO (Lincoln, NE) portable automatic water sampler (model 6712) was installed at the outlet of the monitored watershed located near the inlet to the storage pond. Storm runoff

Table 1
Timeline of crop planting, fertilizer application, irrigation, rainfall events greater than 10 mm, and harvest for field A (Fig. 1).

Date	Management practice	Irrigation (mm)	Rainfall (mm) > 10 mm
4/23/2014	Corn planting		
4/25/2014	Starter fertilizer; 46.7 L ha^{-1} (11-37-0;N:P:K)		
5/25/2014	Sidedress fertilizer; 246.6 kg N ha^{-1}		
6/4/2014		6.1	
6/22/2014		15.8	
6/28/2014	Fertilizer tassel; 49 kg N ha^{-1}		
7/7/2014		19.6	
7/24/2014		13.2	
8/4/2014		19.6	
8/9/2014			14.9
8/30/2014			38.3
9/3/2014	Harvest		
9/16/2014	Poultry fertilizer; 4485 kg ha^{-1} (5.5% N, 3.8% P)		
5/5/2015	Corn planting		
5/7/2015	Starter fertilizer; 46.7 L ha^{-1} (11-37-0;N:P:K)		
5/13/2015		9.2	
5/17/2015			14.9
5/24/2015			11.9
5/27/2015			48.7
5/30/2015			10.1
5/31/2015			21.3
6/5/2015	Sidedress fertilizer; 246.6 kg N ha^{-1}		
6/12/2015			12.7
6/13/2015			13.9
6/28/2015		18.3	
7/8/2015	Fertilizer tassel; 49 kg N ha^{-1}		
7/10/2015		15.8	
7/15/2015			10.1
7/21/2015		15.8	
7/22/2015			12.1
8/1/2015		18.9	
8/6/2015			33.7
8/8/2015			19.3
8/15/2015			34.1
8/21/2015			18.7
9/15/2015	Harvest		
9/25/2015	Poultry fertilizer; 3363 kg ha^{-1} (5.5% N, 3.8% P)		
4/27/2016	Soybean planting		
5/2/2016			19.7
5/13/2016			18.7
5/31/2016		10.4	
6/4/2016			24.8
6/6/2016			16.1
6/18/2016			13.2
6/25/2016		20.9	
7/6/2016		20.9	
7/17/2016		20.9	
8/5/2016		19.5	

samples were collected and analyzed to determine the nutrient concentrations in the runoff draining to the storage pond from the agricultural fields. The sampler captured storm runoff events based on a uniform time spacing of 1 h, and the sampler was set to trigger when a water depth of 7.62 mm was measured in the drainage channel during storm events. The runoff depth and flow were monitored using an ISCO velocity flow module (model 750) attached to the ISCO sampler. When the sampler was triggered, 24 samples (500 ml each) were collected at hourly intervals, but only the odd-hour samples were analyzed. A total of 12 samples were analyzed for each storm event that was captured. A weather-station (model 9900 ET) from Spectrum technologies (Aurora, IL) was installed to record precipitation along with wind speed, air temperature, relative humidity, and solar radiation at 15-minute intervals. An IM3000 magnetic flowmeter from Growsmart (Omaha, NE) was installed on each of the three center pivots fed by the storage pond to record the amount and timing of irrigation water provided by the system.

Table 2
Timeline of crop planting, fertilizer application, rainfall events greater than 10 mm, and harvest for field B (Fig. 1).

Date	Management practice	Rainfall (mm) > 10 mm
5/5/2014	Soybean planting	
8/9/2014		14.9
8/30/2014		38.3
10/5/2014	Harvest	
10/15/2014	Poultry fertilizer; 4485 kg ha^{-1} (5.5% N, 3.8% P)	
5/3/2015	Corn Planting	
5/5/2015	Starter fertilizer; 46.7 L ha^{-1} (11-37-0;N:P:K)	
5/17/2015		14.9
5/24/2015		11.9
5/27/2015		48.7
5/30/2015		10.1
5/31/2015		21.3
6/8/2015	Fertilizer sidedress; 246.6 kg N ha^{-1}	
6/12/2015		12.7
6/13/2015		13.9
7/10/2015	Fertilizer tassel; 49 kg N ha^{-1}	
7/15/2015		10.1
7/22/2015		12.1
8/6/2015		33.7
8/8/2015		19.3
8/15/2015		34.1
8/21/2015		18.7
9/21/2015	Harvest	
9/28/2015	Poultry fertilizer; 3363 kg ha^{-1} (5.5% N, 3.8% P)	
4/29/2016	Soybean planting	
5/2/2016		19.7
5/13/2016		18.7
6/4/2016		24.8
6/6/2016		16.1
6/18/2016		13.2

Grab samples (1 L) were collected from the storage pond every 21 days during the study period, following the sampling protocol used by the Mississippi Department of Environmental Quality (MDEQ) as part of their Delta Water Monitoring Plan (MDEQ, 2009). Samples were collected to determine the nutrient concentrations in the pond, analyze the change in pond nutrient concentrations over time, and to compare the nutrient concentrations in the pond to those in the storm runoff samples and irrigation samples. In-situ measurements for temperature, dissolved oxygen, and conductivity were also taken using an ORION STAR A329 portable multi-parameter probe (Waltham, MA).

Grab samples (1 L) were also collected from the west center pivot (West CP, Fig. 1) during irrigation events, to evaluate the nutrients being recycled in irrigation water from the storage pond and determine if the producer's fertilizer application could be reduced as a result of nutrient recycling from irrigation water. Irrigation water samples from the pivot were compared to the grab samples retrieved from the OFWS pond on the same day, to better evaluate the difference in nutrient concentrations between the pond grab samples and the irrigated water grab samples. By comparing pond and irrigation grab samples taken almost simultaneously, it can be determined if nutrient concentrations in the storage pond are an accurate representation of nutrient concentrations in the irrigation water being applied from the pond.

2.5. Water quality analyses

The collected grab samples and storm runoff samples were placed immediately on ice, transferred to the lab, and stored at 4 °C. Dissolved Phosphorus (DP) was analyzed within 24 h of sample collection. The sample was then preserved by adding 2 mL of concentrated H_2SO_4 for every liter of sample and stored at 4 °C until analyzed for the remaining dissolved and particulate forms of N and P within 21 days of sample collection. Dissolved and total phosphorus were analyzed by the ascorbic acid method (HACH, 2007) using a HACH DR-2800 spectrophotometer (Loveland, CO). Samples were filtered through phosphorus-free 0.45 μm filter paper before being analyzed for DP. Ammonia and nitrate were analyzed using the salicylate and dimethylphenol methods, respectively (HACH, 2007). Persulfate digestion was used for the analysis of total nitrogen (TN) (HACH, 2007), and the sulfuric acid digestion method was used to analyze samples for Total Kjeldahl Nitrogen (TKN) (Kopp and McKee, 1979).

3. Results and discussion

3.1. Nutrient concentrations in surface runoff

The total rainfall during the study period was 2289 mm, generating a total surface runoff volume of about 204,000 m^3 from the monitored drainage area to the OFWS system storage pond over two non-growing seasons. Roughly 70% of the total rainfall during the study period occurred outside of the growing season (October to May). As a result, the storm runoff events that created enough flow to trigger the sampler during the study period were all in the off-season between October 2014-May 2015 of water year 2015 (seven runoff events captured) and October 2015-February 2016 of water year 2016 (four runoff events captured). An attempt was made to capture all storm runoff events during the monitoring period, but equipment malfunction and logistical challenges prevented the sampling of every runoff event. Although the captured runoff events provide important knowledge about the nutrient concentrations in the storm runoff events captured by the OFWS system storage pond over the two non-growing seasons, failure to capture and analyze all of the storm runoff events, especially in the non-growing season of water year 2016, prevented us from estimating the nutrient load draining from the agricultural fields to the storage pond over the whole monitoring period. Box plots (Figs. 2–7) have been used to describe the nutrient concentrations in the captured surface runoff events, where the whiskers show the minimum and maximum concentrations, and the bars show the range of concentrations from the first to the third quartile. The median concentration is indicated by the line through the bar.

3.1.1. Nitrate, Total Kjeldahl Nitrogen (TKN), ammonia, and total nitrogen (TN) concentrations in storm runoff events

Nutrient analysis of storm runoff samples showed that the highest nitrate and TN concentrations for both water years of the monitoring period were recorded in the October-November runoff events, while the lowest concentrations were recorded in the February-May runoff events (Figs. 2 and 3). The highest nitrate and TN concentrations of 86.4 mg L^{-1} and 22 mg L^{-1}, respectively, for water year 2015 (fall 2014-spring 2015) runoff events were measured on November 16, 2014 (73.1 mm rainfall), while the highest nitrate and TN concentrations of 179 mg L^{-1} and 44.4 mg L^{-1}, respectively, for water year 2016 (fall 2015-spring 2016) runoff events were measured on October 31, 2015 (46.7 mm rainfall).

High nitrate and TN concentrations observed during October and November runoff events of each year were most likely a result of nutrient loss from the fall-applied poultry litter fertilizer, which can contain an average of 21.5 kg of N per ton of poultry litter (Dettmann, 2001). A trend of decreasing nitrate and TN concentration from fall to spring, with the fall concentrations being considerably higher, likely indicate a substantial loss of fall-applied poultry fertilizer in the fall runoff events.

TKN concentration in the first runoff event (10/13/2014) was much higher than in the remaining storm events captured in water year 2015 (Fig. 4). The highest TKN concentration in the first runoff event was 11.7 mg L^{-1} (47.5 mm rainfall) with a median of 8.36 mgL^{-1}, while the maximum concentration in samples from subsequent storm events was only 3.9 mg L^{-1} (1/23/2015, 41.6 mm rainfall) with a median concentration of less than 2 mg L^{-1}. Poultry litter could also be the reason for the high TKN concentration in the first runoff event captured. However, the difference in TKN concentration between the first runoff event and subsequent storm runoff events captured in the fall 2015-spring 2016 (water year 2016) runoff events was not very big (Fig. 4), even though poultry litter fertilizer was also applied after harvest in 2015. The highest measured TKN concentration in the water year 2016 runoff events was 6.7 mg L^{-1} on February 2, 2016 (51.1 mm rainfall), but TKN concentrations measured in the remaining events in water year 2016 were around 2 mg L^{-1} (Fig. 4).

Ammonia concentrations ranged from 0.015 to 0.729 mg L^{-1} in the fall 2014-spring 2015 runoff events (water year 2015), and from 0.022 to 2.280 mg L^{-1} in the fall 2015-spring 2016 runoff events (water year 2016) (Fig. 5). This showed that organic nitrogen was the major contributor to TKN rather than ammonia. Ammonia concentrations in storm runoff events showed no trend from fall to spring as observed in nitrate (Fig. 5). The highest ammonia concentration in fall 2014-spring 2015 measured 0.729 mg L^{-1} on December 6, 2014 (45.5 mm rainfall), while the highest ammonia concentration in fall 2015-spring 2016 was 2.280 mg L^{-1} on February 2, 2016 (51.1 mm rainfall).

3.1.2. Dissolved and total phosphorus concentration in storm runoff events

Similar to nitrate and TN concentrations, highest DP concentrations were measured in the fall and winter runoff events while the lowest concentrations were measured in the spring runoff events (Fig. 6). The highest DP concentrations measured in water year 2015 and 2016 were 0.54 mg L^{-1} (10/13/2014, 47.4 mm rainfall) and 0.69 mg L^{-1} (10/31/2015, 46.7 mm rainfall), respectively (Fig. 6). High DP concentration in the early fall storm runoff events for both 2014 and 2015, again, is most likely a result of the fall poultry litter application after harvest, in preparation for the next growing season. Phosphorus in poultry litter averages 31.47 kg per ton of litter (Dettmann, 2001).

Unlike nitrate, TN, and DP, the highest total phosphorus (TP) concentrations were not recorded in the early fall storm runoff events captured in 2014 and 2015. Also, there was no discernable trend in

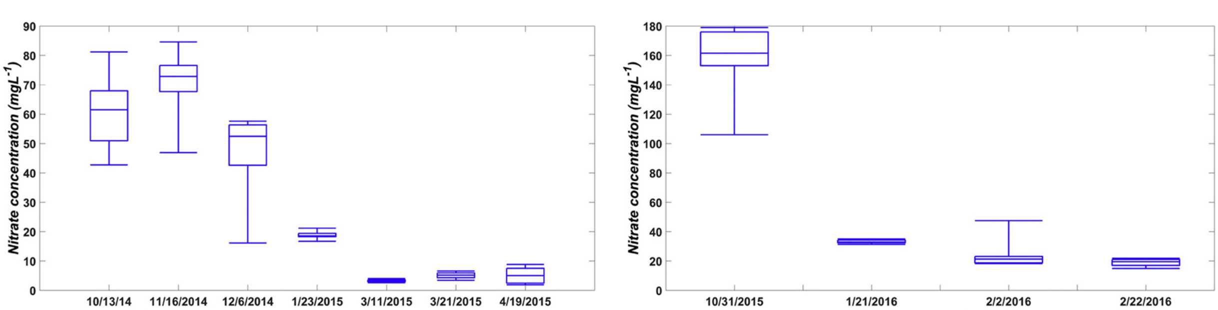

Fig. 2. Nitrate concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

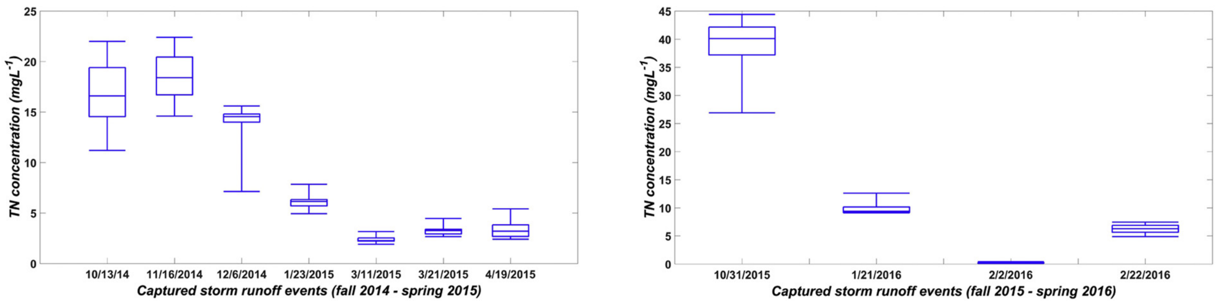

Fig. 3. Total nitrogen (TN) concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

concentration from fall to spring as observed for nitrate, TN, and DP (Fig. 7). TP concentrations measured during the fall of 2014 were only slightly higher than those observed during the spring of 2015 (Fig. 7). TP concentrations were fairly consistent for all runoff events for the fall 2015-spring 2016 runoff events (water year 2016), with the median concentration ranging from 0.4 to 0.8 mg L^{-1} (Fig. 7). It is also important to note that the highest measured DP concentration did not coincide with the highest measured TP concentration for either year of the study. TP concentration is greatly affected by the Total Suspended Solids (TSS) concentration in the storm events, and variability in the sediment loss during the storm events could be the reason for the highest measurements of TP and DP in different storm events for both years of study. The highest TP concentration recorded in water year 2015 was 1.48 mg L^{-1} (12/6/2014, 45.5 mm rainfall), and the highest TP concentration recorded in water year 2016 was 3.73 mg L^{-1} (2/2/2016, 51.1 mm rainfall).

Because the captured storm runoff events indicate a considerable amount of nutrient loss from adjacent agricultural fields, especially in the fall runoff events, management of these runoff events is critical to decreasing downstream nutrient loss. The nutrients lost downstream can lead to water quality degradation as well as become a human health hazard if such high concentrations of nutrients reach drinking water sources. Early fall is also the time when the OFWS system storage pond is at its lowest depth for the year, because the stored water has been used for irrigation during the growing season. Therefore, the OFWS storage pond has a high water holding capacity in early fall and is able to capture these critical runoff events with high nutrient concentrations, leading to reductions in downstream nutrient loss. These systems can be a useful BMP in reducing downstream nutrient runoff by capturing agricultural surface runoff not only in East Mississippi but also in the Mississippi Delta and regions with a similar climate that experience considerable rainfall in fall and winter months and high nutrient loss from agricultural watersheds (Pérez-Gutiérrez et al., 2015). The monitoring data also showed that fall application of poultry fertilizer in preparation for the next growing season might not be a good management practice in East Mississippi due to the considerable amount of nutrients likely lost from the fall-applied poultry fertilizer in subsequent runoff events, as indicated by the high nutrient concentrations in the runoff samples. Poultry fertilizer application during the growing season or at the beginning of the growing season, when rainfall events are much lower, can possibly help reduce nutrient loss in runoff events while providing nutrients to the crop, as demonstrated in the study conducted by Kwong et al. (2002).

3.2. OFWS system storage pond

3.2.1. Nitrate, TKN, ammonia, and TN concentrations in the OFWS system storage pond

Nitrate concentration in the OFWS system storage pond was 1.86 mgL^{-1} when the first sample was collected on July 16, 2014. Nitrate concentration in the grab samples collected from the pond continued to decrease until the storage pond began capturing runoff events in the fall of 2014, which had high measured nutrient concentrations. A similar trend was also observed in 2015, with low concentrations of nitrate at the end of the growing season, which then began to increase after the initiation of fall rainfall events (Fig. 8). Low nitrate concentrations in the pond during the early fall (August-September) of each year also coincided with the driest period of the year. The least amount of runoff occurred during this period, and the water level in the storage pond was at its lowest depth after irrigation during the growing season. Nitrate concentrations in the pond gradually increased over the winter, peaked in late winter and early spring, and started to decrease again around April of each year.

The highest nitrate concentration measured in the pond during the study period was 11.3 mg L^{-1} and occurred on June 16, 2015, but the nitrate concentration that was measured in the preceding sample was below 1 mg L^{-1} (Fig. 8). It is likely that the rainfall events between the two sampling events (140.5 mm) in combination with the application of starter fertilizer at planting could be the reason for the spike in nitrate concentration on June 16, 2015. Soybeans were grown in both fields during the 2016 growing season, and no fertilizer was applied to the soybean fields during the growing season. This could be the reason for the absence of a nitrate spike during the 2016 growing season versus the summer nitrate spike that was observed in the 2015 growing season.

The highest nitrate concentration in pond grab samples collected over the non-growing season of water year 2015 was 8.56 mgL^{-1} on March 29, 2015, and the highest concentration measured in the non-

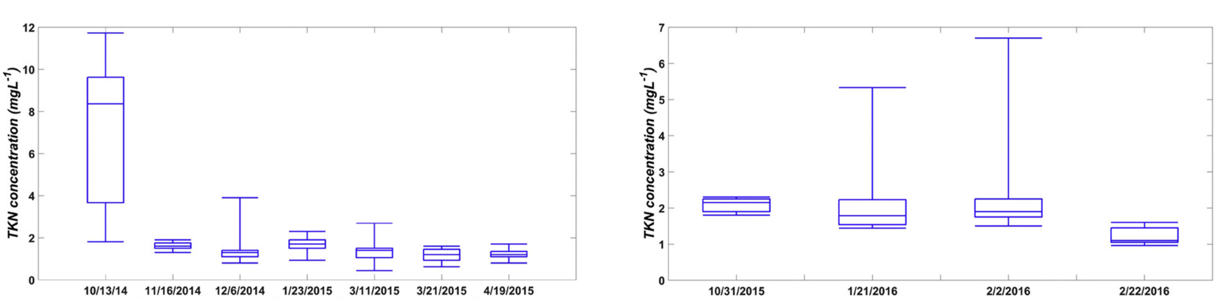

Fig. 4. Total Kjeldahl Nitrogen (TKN) concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

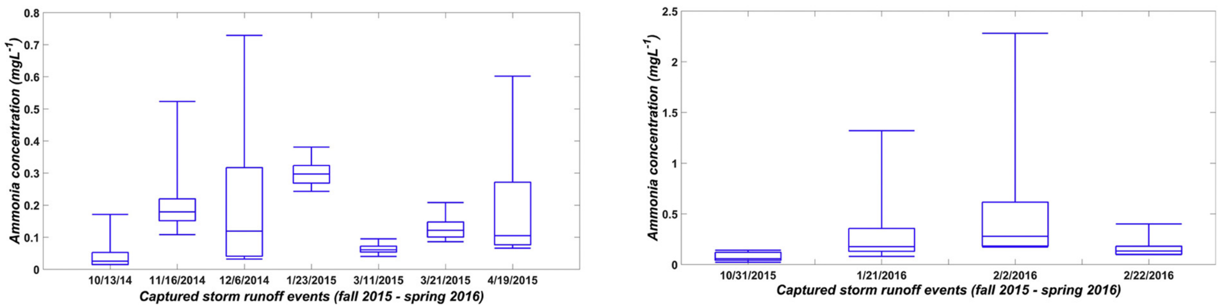

Fig. 5. Ammonia concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

growing season of water year 2016 was 5.77 mg L^{-1} on February 25, 2016.

Nitrate concentrations in the storage pond were considerably lower than in the storm runoff events captured at the pond inlet. Lower nitrate concentrations in the storage pond as compared to the storm runoff samples could be a result of dilution and also denitrification in the pond. Other studies have documented the process of denitrification in reservoirs with elevated nitrate levels (Dettmann, 2001; Jensen et al., 1992). While the storage pond was able to capture and store most of the runoff from the drainage watershed, some runoff was lost from the storage pond through the overflow pipe (located on the opposite side of the pond from the inlet) when the pond was at maximum capacity during March and April of each year. However, the nitrate concentration in the water that moved downstream was well below the concentrations in storm runoff samples, as demonstrated by monitoring data from grab samples collected from the pond.

TKN concentration in the pond was 2.15 mg L^{-1} when monitoring began in July 2014. The concentration then fluctuated in the first few months of the monitoring period ranging from 2.15 to 5.3 mg L^{-1} in the samples collected from July to October of 2014 (Fig. 9). Concentrations in samples collected over the remainder of the study period were lower than those observed in the initial months of sampling, with most concentrations measuring around 1 mg L^{-1}. The maximum measured pond TKN concentration of 5.31 mg L^{-1} occurred on October 29, 2014 and coincided with the runoff events captured during the fall of 2014. High TKN concentration was measured in the first storm runoff sample captured in fall 2014 but not in the first storm runoff captured in fall 2015, even though poultry litter was applied in both years (Fig. 4). This difference in TKN concentration in the storm runoff events is reflected in the TKN concentrations measured in the storage pond during October months of 2014 and 2015 (Fig. 9).

Ammonia concentrations were less than 0.1 mg L^{-1} for most of the monitoring period, except for the first few samples that were collected at the beginning of the monitoring period (Fig. 10). Ammonia concentrations fluctuated from 2.3 mg L^{-1} in the first sample collected on July 16, 2014 to less than 0.015 mg L^{-1} in the second sample collected on August 6, 2014 and back to 0.561 mg L^{-1} in the third sample collected on August 28, 2014. Similar to the storm runoff events, lower concentrations of ammonia indicate that organic nitrogen makes up most of the TKN concentration in the storage pond as well.

TN concentrations followed a similar trend to nitrate concentrations in the OFWS system storage pond. Concentrations were lowest in the fall of 2014 and 2015 and increased throughout the winter when most runoff occurred and was captured by the pond (Fig. 11). With the exception of a few pond samples collected in June 2015, TN concentrations decreased during the growing season over both years of the monitoring period when there was less rainfall. The highest TN concentration during the study period was measured at 7.02 mg L^{-1} in the sample collected on January 8, 2015.

3.2.2. Dissolved and total phosphorus concentrations in the OFWS system storage pond

DP concentrations in the storage pond were very low throughout the study period and measured below the detection limit of 0.05 mg L^{-1} (HACH, 2007) in 30 of the 35 grab samples that were collected and analyzed. The highest observed DP concentration was 0.09 mg L^{-1} in the sample collected on August 28, 2014, and this was the only sample collected during the 2014 growing season that had a DP concentration above the detection limit. Again, of all the grab samples collected during the 2015 growing season, only one sample had a DP concentration above the detection limit, collected on June 22, 2015 with a concentration of 0.07 mg L^{-1}. During the 2016 growing season, there were no samples analyzed with a DP concentration above the detection limit. Three additional samples had DP concentrations above the detection limit outside of the growing season in water year 2015, while there were no samples above the detection limit outside the growing season in water year 2016 of the monitoring period.

TP concentrations were below the detection limit for most grab samples collected from the pond during the 2014, 2015, and 2016 growing seasons. However, TP concentrations were above the method detection limit of 0.05 mg L^{-1} (HACH, 2007) in most of the grab samples collected from the pond outside the growing season for both years of the study, and 0.425 mg L^{-1} was the highest TP concentration measured during the study period in the sample collected on January 31, 2015.

DP and TP concentrations in the OFWS system storage pond were

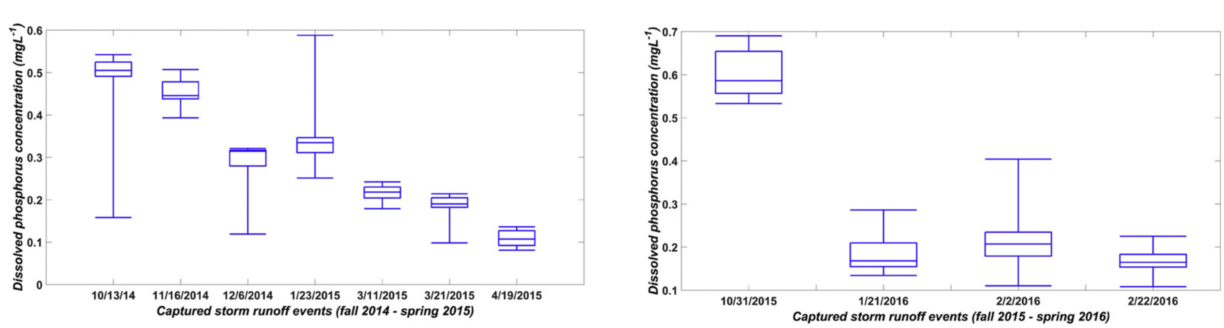

Fig. 6. Dissolved phosphorus (DP) concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

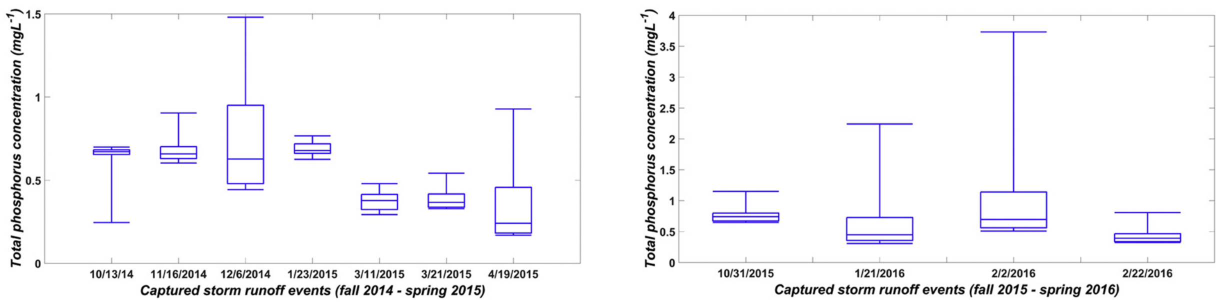

Fig. 7. Total phosphorus (TP) concentration in individual storm runoff events captured from fall 2014-spring 2015 (left) and fall 2015-spring 2016 (right).

also lower than the concentrations recorded in the storm runoff samples collected at the edge of the field. This reduction in concentration in the pond could again be attributed to dilution, as well as settling of the sediments. Similar to nitrate and TN, concentrations of DP and TP in water lost from the overflow pipe of the storage pond when the pond was at its maximum capacity was much lower than if storm runoff events were deposited directly downstream. Flow lost from the overflow pipe of the storage pond was not monitored as a part of this study, preventing an estimate of the nutrient loss downstream after the pond had reached its maximum holding capacity.

The efficiency of OFWS systems in reducing downstream nutrient runoff could possibly be increased with better placement of the storage pond in relation to the agricultural field even without increasing the maximum holding capacity. If more runoff from surrounding agricultural fields can be directed through the pond before flowing downstream, this would increase the runoff residence time for a larger volume of runoff and potentially decrease nutrient concentrations in runoff lost downstream (Dettmann, 2001; Jensen et al., 1992).

3.3. Water use from the OFWS system storage pond

The OFWS system storage pond was able to provide 112,000 m^3, 127,500 m^3, and 119,000 m^3 of water for irrigation during the 2014, 2015, and 2016 growing seasons, respectively, with additional water remaining in the storage pond each year at the end of the growing season (Fig. 12). A recent study by Feng et al. (2018) used the Structural Thinking and Experiential Learning Laboratory with Animation (STELLA) model to determine the irrigation water demand for soybean and corn in the Mississippi Blackland Prairie using rainfall records over the past twelve decades. Their work showed that over 122 years of weather data, soybean and corn required an average 0.18 m and 0.16 m of irrigation water, respectively, to meet the crop's water requirement. Water used from the OFWS system to irrigate corn at the study site was approximately 0.11 ha-m in 2014 and 0.09 ha-m in 2015, while water use for soybean in 2016 was 0.09 ha-m (Table 3). However, there was water remaining in the storage pond at the end of each growing season that was monitored during this study.

As the monitoring period did not include the captured runoff data used for irrigation for the 2014 growing season, an evaluation of total runoff captured and irrigation water use was conducted for the 2015 and 2016 growing seasons. Approximately 336,500 m^3 of water was collected in the storage pond from September 2014 to May 2016, with 203,230 m^3 from runoff from the monitored agricultural fields and 133,300 m^3 from direct precipitation into the pond. Additional runoff from the unmonitored watershed also accumulated in the storage pond over this time period. The total water used for irrigation over this period was 246,500 m^3. Hence, it was observed that a ratio of 3 irrigated hectares for every acre of drainage land was adequate to provide water for irrigation of both corn and soybeans in East Mississippi, even after assuming water loss through seepage and evaporation. This shows that, if properly designed, an OFWS system can easily provide water for irrigation in East Mississippi along with the benefits of reducing downstream nutrient runoff. However, as the runoff data was collected over two years, a long term analysis is required to determine the best drainage area to irrigated area ratio for adequate runoff collection to meet irrigation needs under different climatic conditions.

These systems can also provide a vital source of water for irrigation in other areas, where the weather pattern is similar to that of East Mississippi, with large amounts of precipitation occurring outside the growing season. Maximizing the use of surface water for irrigation,

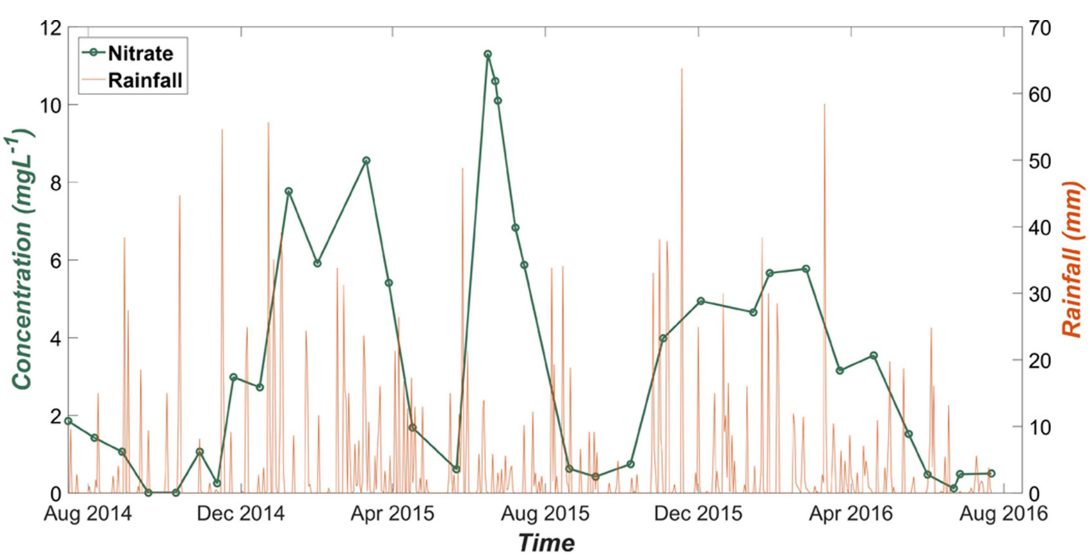

Fig. 8. Nitrate concentration in the OFWS system storage pond.

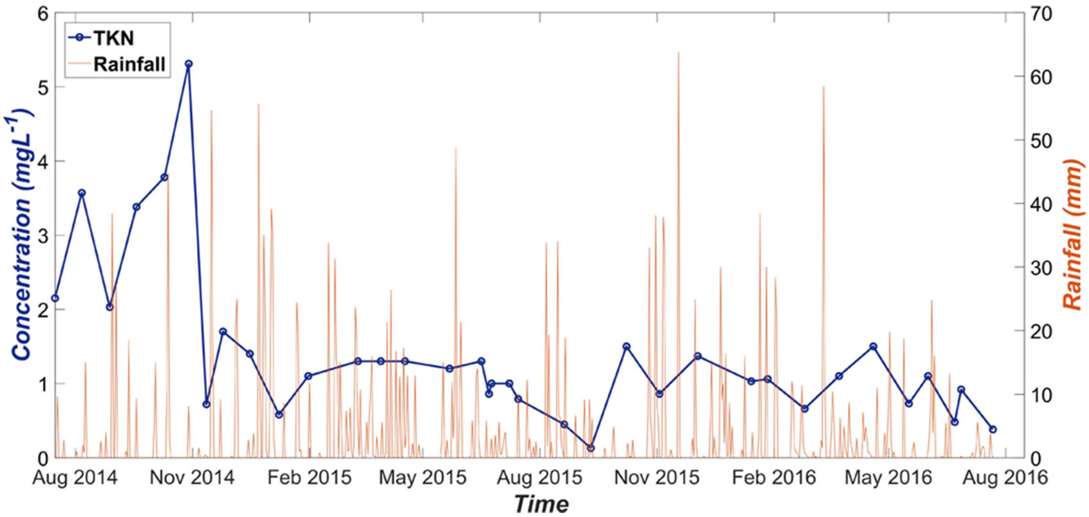

Fig. 9. Total Kjeldahl Nitrogen (TKN) concentration in the OFWS system storage pond.

especially capturing excess surface water during the winter season when it is plentiful, can potentially reduce pressure on overpumped aquifers and also reduce irrigation costs.

3.4. Yield variation between irrigated and non-irrigated acres

A comparison of average yields between non-irrigated acres and acres otherwise under the same management schedule but irrigated by the OFWS system during the monitoring period showed that irrigated corn yields were higher by an average of 1532 kg ha^{-1} than non-irrigated corn in 2014, by 2285 kg ha^{-1} in 2015, and by 3950 kg ha^{-1} in 2016 (Fig. 13). The yields on irrigated soybean acres were higher than soybean yields on non-irrigated acres by an average of 302 kg ha^{-1} in 2014, by 1411 kg ha^{-1} in 2015, and by 800 kg ha^{-1} in 2016.

Records obtained from the farmer on another field being irrigated with an OFWS system established in 2009 showed that average irrigated corn yields were approximately 3360 kg ha^{-1} higher than non-irrigated acres in both 2009 and 2010, and 6719 kg ha^{-1} higher in 2011. The average soybean yields were 739, 605, and 470 kg ha^{-1} higher for irrigated acres than for non-irrigated acres in 2009, 2010, and 2011, respectively.

Higher yields for irrigated corn and soybean acres show that even though East Mississippi receives roughly 1307 mm of rainfall annually, irrigation is important for maintaining stable yields from year to year, reducing risk, and increasing profit through higher yields. Crop yield data from the monitoring period also shows that an OFWS system could help pay for itself by increasing revenue from increased crop production, especially during years when crop prices are higher. In addition, OFWS systems reduce risk and can provide a higher net present value when the irrigation technology is used at its maximum efficiency (Agyeman, 2017).

3.5. Nutrient concentration in irrigation water

Grab samples were collected from the west center pivot during irrigation events in both the 2015 and 2016 growing seasons. Samples were also collected from the OFWS storage pond the same day of the irrigation events and within an hour of collecting the pivot grab sample. Sample analysis and comparison in the 2015 growing season showed that the nitrate concentration in the water from the center pivot was considerably lower than the nitrate concentration in the water sampled from the OFWS system storage pond at roughly the same time (Fig. 14). The center pivot irrigation system is fed from an intake at the bottom of the deepest part of the pond. Probable anoxic conditions from pond stratification, presence of nitrate, and organic matter in the bottom layers of the pond make an ideal environment for the denitrification

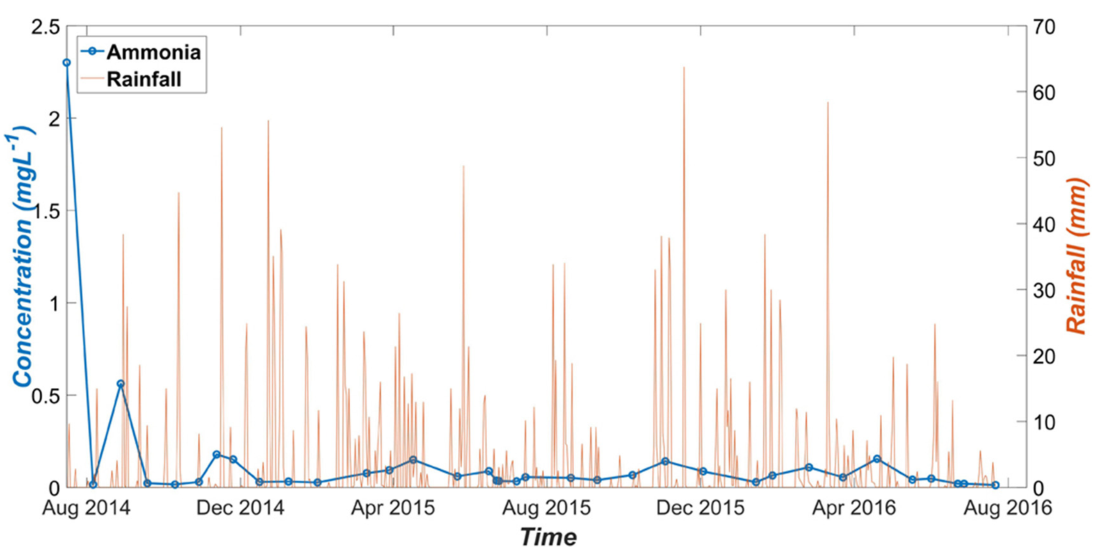

Fig. 10. Ammonia concentration in the OFWS system storage pond.

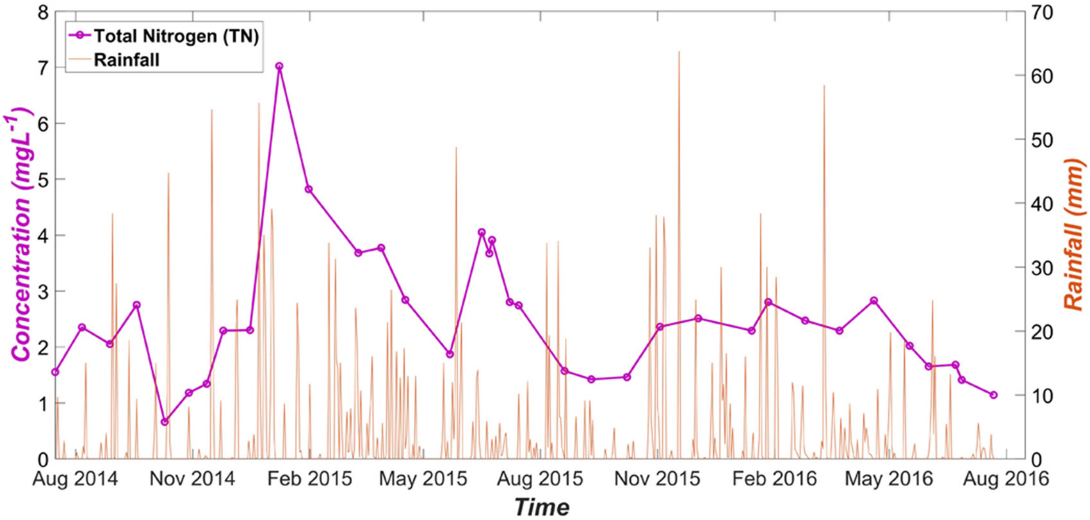

Fig. 11. Total Nitrogen (TN) concentration in the OFWS system storage pond.

process (Seitzinger et al., 2006), possibly contributing to the decreased nitrate concentrations in water from the center pivot. Nitrate concentrations in the samples from the center pivot and the difference in nitrate concentrations between the center pivot and the grab samples from the OFWS system storage pond also varied greatly in the two sets of samples taken over the 2015 growing season (Fig. 14). The nitrate concentration in the storage pond was less than 1 $mg\,L^{-1}$ during the entire 2016 growing season. Hence, almost no nitrate was recycled from the storage pond to the agricultural fields in 2016 (Fig. 14).

Ammonia levels, however, were much higher in irrigation grab samples collected from the center pivot when compared to the grab samples from the storage pond over both growing seasons (Fig. 14). Decaying organic matter in the bottom of the pond could result in eutrophic conditions, and this along with high pH levels (above 9 for most of the monitoring period) could be the reason for higher ammonia concentrations in the irrigation water sampled from the pivot. Also, there was almost no phosphorus present in the irrigation water sampled from the pivot over both growing seasons (Fig. 14).

While some nutrients are being recycled through the re-application of water captured by the OFWS system, fluctuation in the nitrate concentration in the storage pond as well as the irrigation water has shown that it is very difficult to accurately and consistently estimate the nitrate load that is being recycled. Also, even if a high nitrate concentration is recorded in the storage pond sample, the nitrate concentration in the water being applied for irrigation could be much lower

Table 3
Corn and soybean irrigation water use in Field A with 74.8 irrigated hectares (Fig. 1).

Year	Crop	Total water use (m^3)	Water use (ha-m)
2014	Corn	83,861.4	0.11
2015	Corn	67,099.5	0.09
2016	Soybean	69,633.1	0.09

due to denitrification as shown by the samples collected during the 2015 growing season. Although high ammonia concentrations indicate the presence of ammonium ions in the irrigation water, it is difficult to estimate the exact amount present. So, while some nitrate is being reapplied to the field through the irrigation water, recycled nitrate levels are insufficient and too inconsistent to justify a reduction in commercial fertilizer application. This research also demonstrated that the nutrient concentration in the storage pond varied greatly over the two growing seasons, and the pond nutrient concentrations also varied with the nutrient concentrations in the irrigation water sampled from the pivot at roughly the same time. The comparison of nutrient concentrations in pond and irrigation samples shows that it is difficult to use the storage pond nutrient concentrations as a predictor for the nutrient load being recycled back to the field. Collection and analysis of more and frequent irrigation samples and at different depths of the pond may help provide a better estimation of the nutrient load being recycled from the OFWS

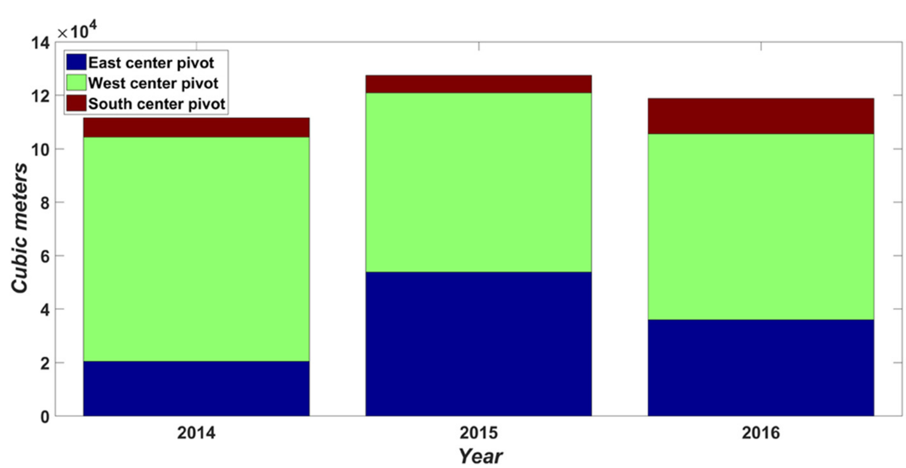

Fig. 12. Water use from the OFWS system storage pond during the 2014, 2015, and 2016 growing seasons.

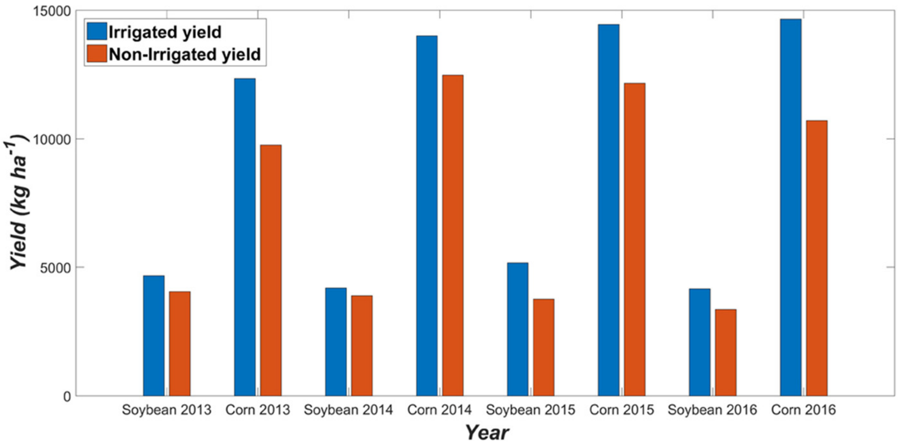

Fig. 13. Irrigated vs non-irrigated corn and soybean yields for the study period.

system.

4. Conclusions

This research to evaluate the potential benefits of the OFWS system in East Mississippi has shown that these systems can be effective in reducing downstream nutrient loss from agricultural watersheds by capturing nutrient-rich runoff from storm events. It was also evident that storm runoff events that occurred after the fall fertilizer applications were more critical to downstream nutrient losses, as these events produced runoff with higher nutrient concentrations. Even though water could be lost downstream when the storage pond was at its maximum capacity, the nutrient concentrations in any water lost was considerably lower than in the edge-of-field runoff draining to the pond, demonstrating a reduction in downstream nutrient runoff even when water from the pond is lost downstream. The value of a fall, post-harvest poultry litter fertilizer application in preparation for the next growing season, however, can be questioned in East Mississippi, as there was substantial loss of nutrients in storm runoff events occurring over the dormant season, and especially in those runoff events directly following the fertilizer application. Consideration should be given to altering the timing or the method of application for poultry litter, or implementing a cover crop, to help reduce nutrient loss and ensure the producer is receiving the maximum crop benefit for the poultry litter fertilizer application.

Higher yields for irrigated corn and soybeans when compared to the non-irrigated corn and soybeans also demonstrated the importance of irrigation in East Mississippi for increasing and stabilizing yield. Thus, OFWS systems can potentially reduce risk and provide increased economic benefits from higher yields, in addition to the environmental benefits.

The monitored OFWS system was able to provide a total of more than 357,000 m^3 of water over the 2014, 2015, and 2016 growing seasons, demonstrating that these systems can be an effective water harvesting system and a reliable source of water for irrigation in regions like East Mississippi and elsewhere that experience sufficient annual rainfall but have inadequate rainfall during the growing season. Under the climatic conditions observed in this study, OFWS systems can provide surface water for irrigation where there is no other feasible water source for irrigation. However, when using OFWS systems as the sole source of water for irrigation, it is important that storage systems are designed to hold sufficient water to irrigate the designated area and crop for the entire growing season. Water use data over three growing seasons and comparison to the long-term irrigation demand for corn and soybean in Mississippi has shown that a ratio of one drainage hectare for every three irrigated hectares was adequate to capture water for irrigation of corn and soybeans in East Mississippi. Because the weather in East Mississippi is very similar to that in other parts of the southeastern region, these systems can also be used in other areas of Mississippi and in neighboring states to potentially decrease the dependency on ground water and allow critical aquifers to recharge. With the changing world climatic conditions expected to increase extreme weather events, including droughts and intense precipitation events (Rosenzweig et al., 2001), it is important, more than ever before, to have supplemental irrigation sources to protect crops against drought conditions and maintain yield for profitability. OFWS systems can simultaneously provide a dual benefit of reducing downstream nutrient runoff and providing needed water for irrigation.

Although some of the nutrient load, particularly nitrate, is recycled back to the agricultural field from the use of OFWS system pond water for irrigation, it is difficult to estimate nutrient concentrations and loads in the recycled water because of fluctuations in the nutrient concentrations of water samples taken from the pivot and the difference in concentration when compared to the storage pond samples.

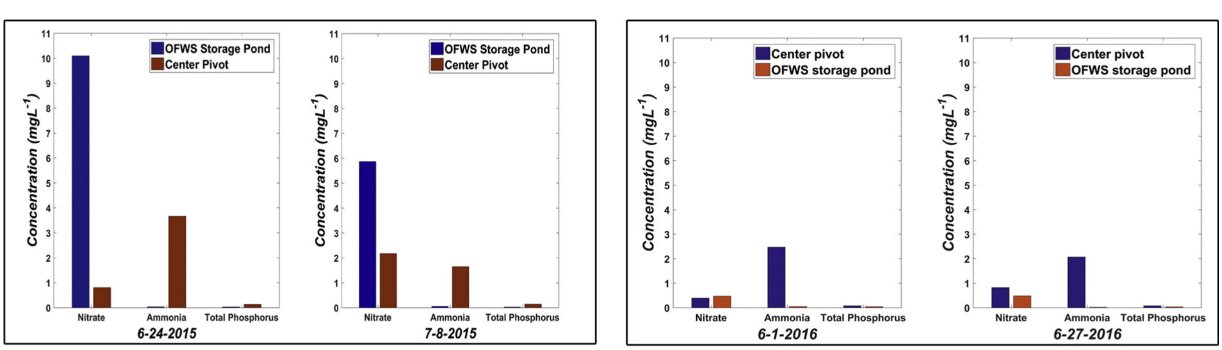

Fig. 14. Nutrient comparison between west center pivot (Fig. 1) and OFWS system pond grab sample in the 2015 growing season (left) and 2016 growing season (right).

Consistent long-term monitoring of irrigation samples collected from the pivot is needed to better estimate nutrient concentrations and loads in the recycled water. Additional samples collected at different depths of the storage pond would also provide insight on the occurrence of denitrification in the pond. Results to date indicate that nutrient concentrations in the recycled water are too low to allow a reduction in the rate of commercial fertilizer applied to the field.

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References

Agyeman, D.A., 2017. On-Farm Water Storage (OFWS) as Tool to Reduce Risk. ProQuest Diss. Theses. pp. 140.
Carruth, G.W., Paz, J.O., Tagert, M.L.M., Guzmán, S.M., Oldham, J.L., 2014. Reusing Irrigation Water from Tailwater Recovery Systems: Implications on Field and Stream-Level Nutrient Status. ASABE Paper No. 141913747. ASABE. St. Joseph, MI. https://doi.org/10.13031/aim.20141913747.
de Jonge, V.N., Elliott, M., Orive, E., 2002. Causes, historical development, effects and future challenges of a common environmental problem: eutrophication. Hydrobiologica 475/476 (2002), 1–19.
Delta FarmPress, 2012. Cotton on the Upswing in East Mississippi as Irrigation Increases. (Accessed 3 March 2017). http://www.deltafarmpress.com/cotton/east-mississippi-irrigation-and-cotton-acres-increase.
Dettmann, E.H., 2001. Effect of water residence time on annual export and denitrification of nitrogen in estuaries: a model analysis. Estuaries 24, 481–490.
Diaz, R.J., Rosenberg, R., 2008. Spreading dead zones and consequences for marine ecosystems. Science 321, 926–929. https://doi.org/10.1126/science.1156401.
Dodds, W.K., Bouska, W.W., Eitzmann, J.L., Pilger, T.J., Pitts, K.L., Riley, A.J., Schloesser, J.T., Thornbrugh, D.J., 2008. Eutrophication of US freshwaters: analysis of potential economic damages. Environ. Sci. Technol. 43, 12–19.
EPA, 1996. Environmental Indicators of Water Quality in the United States. Office of Water (4503F). US Govt. Printing Office Washington, DC Rep no. 841-R-96-002.
EPA, 2002. National Water Quality Inventory: 2000 Report. Washington DC. Rep no. EPA841-F-97-003. .
Feng, G., Cobb, S., Abdo, Z., Fisher, D.K., Ouyang, Y., Adeli, A., Jenkins, J.N., 2016. Trend analysis and forecast of precipitation, reference evapotranspiration, and rainfall deficit in the blackland prairie of Eastern Mississippi. J. Appl. Meteorol. Climatol. 55, 1425–1439. https://doi.org/10.1175/JAMC-D-15-0265.1.
Feng, G., Ouyang, Y., Adeli, A., Read, J., Jenkins, J., 2018. Rainwater deficit and irrigation demand for row crops in Mississippi blackland prairie. Soil Sci. Soc. Am. J. 82, 423. https://doi.org/10.2136/sssaj2017.06.0190.
HACH, 2007. DR 2800 Spectrophotometer Procedures Manual.
Howarth, R.W., Sharpley, A., Walker, D., 2002. Sources of nutrient pollution to coastal waters in the United States: implications for achieving coastal Water quality goals. Estuaries 25, 656–676.
IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, Update 2015 International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, World Soil Resources Reports No. 106. Rome IT. https://doi.org/10.1017/S0014479706394902.
Jensen, J.P., Jeppesen, E., Kristensen, P., Christensen, P.B., Søndergaard, M., 1992. Nitrogen loss and denitrification as studied in relation to reductions in nitrogen loading in a shallow, hypertrophic lake (Lake søbygård, Denmark). Int. Rev. der Gesamten. Hydrobiol. und Hydrogr. 77, 29–42.
Kopp, J.F., McKee, G.D., 1979. Methods for chemical analysis of water and wastes. Natl. Tech. Inf. Serv. Springfield, Va. 32319, 490 Rep. No. PB 297686.
Kwong, K.F.N.K., Bholah, A., Volcy, L., Pynee, K., 2002. Nitrogen and phosphorus transport by surface runoff from a silty clay loam soil under sugarcane in the humid tropical environment of Mauritius. Agric. Ecosyst. Environ. 91, 147–157.
MDEQ, 2009. ADDENDUM TO Quality Assurance Project Plan for the Data Collection and Analyses to Support Nutrient Criteria Development and Use Attainability Analyses in the Mississippi Delta. Jackson, MS.
MDEQ, 2016. State of Mississippi Water Quality Assessment 2016 Section 305(b) Report. Jackson, MS.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being: Opportunities and Challenges for Business and Industry. Washington, DC. .
Miller, J.A., 1990. Ground water atlas of the United States: Alabama, Florida, Georgia, and South Carolina. U. S. Geol. Surv. Hydrol. Invest. Atlas 730-G.
Nixon, S.W., 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41, 199–219.
Oweis, T., Hachum, A., Kijne, J., 1999. Water Harvesting and SupplemEntal Irrigation for Improved Water Use Efficiency in Dry Areas. IWMI.
Papadomanolaki, N.M., Dijkstra, N., van Helmond, N.A.G.M., Hagens, M., Bauersachs, T., Kotthoff, U., Sangiorgi, F., Slomp, C.P., 2018. Controls on the onset and termination of past hypoxia in the Baltic Sea. Palaeogeogr. Palaeoclimatol. Palaeoecol. 490, 347–354.
Pérez-Gutiérrez, J.D., Paz, J.O., Tagert, M.L., Karki, R., 2015. Seasonal Variation of Water Quality in On-Farm Water Storage Systems: Case Study of a Mississippi Delta Agricultural Watershed. ASABE Paper No. 152190473. ASABE, St. Joseph, MI. https://doi.org/10.13031/aim.20141913747.
Pingali, P.L., Rosegrant, M.W., 1995. Agricultural commercialization and diversification: processes and policies. Food Policy 20, 171–185.
Postel, S., Carpenter, S., 1997. Freshwater Ecosystem Services. Nature's Serv. Soc. Depend. Nat. Ecosyst. pp. 195.
Rabalais, N.N., Turner, R.E., Wiseman, W.J., 2001. Hypoxia in the Gulf of Mexico. J. Environ. Qual. 30, 320–329.
Richards, R.P., 1998. Estimation of Pollutant Loads in Rivers and Streams: A Guidance Document for NPS Programs. Proj. Rep. Prep. Under Grant X998397-01-0. US Environ. Prot. Agency, Reg. VIII, Denver, pp. 108.
Rosenzweig, Cynthia, Iglesias, Ana, Yang, X.B., Epstein, Paul R., Chivian, Eric, 2001. Climate change and extreme weather events - implications for food production, plant diseases, and pests. Global Change Hum. Health 2 (2), 90–104.
Seitzinger, S., Harrison, J.A., Böhlke, J.K., Bouwman, A.F., Lowrance, R., Peterson, B., Tobias, C., Van Drecht, G., 2006. Denitrification across landscapes and waterscapes: a synthesis. Ecol. Appl. 16, 2064–2090.
Sims, J.T., Simard, R.R., Joern, B.C., 1998. Phosphorus loss in agricultural drainage: historical perspective and current research. J. Environ. Qual. 27, 277–293.
Smith, V.H., 2003. Eutrophication of freshwater and coastal marine ecosystems a global problem. Environ. Sci. Pollut. Res. 10, 126–139.
Snipes, C.E., Nichols, S.P., Poston, D.H., Walker, T.W., Evans, L.P., Robinson, H.R., 2005. Current agricultural practices of the Mississippi delta. MAFES Bull. 1143, 18.
Soil Survey Staff, 2012. Web Soil Survey. Available online at. USDA Natural Resources Conservation Service, Washington, DC. https://websoilsurvey.nrcs.usda.gov/.
Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671.
USDA-NRCS, 1999. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd Edn. USDA Handbook No. 436.
USDA-NRCS, 2014. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin, MLRA 135A - Alabama and Mississippi Blackland Prairie. USDA-NRCS. USDA Handbook No. 269.
USGS, 2015. Mississippi Agriculture Overview. (Accessed 15 March 2017). https://www.mdac.ms.gov/agency-info/mississippi-agriculture-snapshot/.
Wesley, R.A., Smith, L.A., Spurlock, S.R., 1993. Economic analysis of irrigation and deep tillage in soybean production systems on clay soil. Soil Tillage Res. 28, 63–78.
Xiao, W., Liu, X., Irwin, A.J., Laws, E.A., Wang, L., Chen, B., Zeng, Y., Huang, B., 2018. Warming and eutrophication combine to restructure diatoms and dinoflagellates. Water Res. 128, 206–216.
Zimmerman, J.D., 1966. Irrigation. John Wiley and Sons, Inc, New York, London, Sydney.