

Hydrologically Managed Seasonal Wetland Conditions Reduce Runoff, Drainage, and Nitrate Transport from a Corn/Soybean Agroecosystem using Water Table Management*

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ABSTRACT

This project focuses on a water quality remediation approach using a coupled wetland agricultural ecosystem, producing corn and soybeans, conducted at the Piketon Research and Extension Center in Southern Ohio. In this modified agroecosystem, the cropland is maintained under productive management using subirrigation and controlled during the growing season, and then converted into seasonal wetland conditions during the non-growing season by controlled drainage. More than three years of hydrologic, nitrate, and ammonia transport data from the replicated plots with conventional subsurface drainage and the coupled-wetland agroecosystem have been characterized and analyzed. For analysis, the hydrology of this managed system has been separated into four periods where different water table management levels are active. Results indicate that the coupled-wetland agroecosystem management scheme substantially reduced runoff, subsurface drainage, and associated nitrate and ammonia losses from the system to surface waters, compared to corn-soybean systems with conventional subsurface drainage. For example, there was a 50-60% reduction in total annual flow from the SI/CD treatment compared to the SSD treatment. The SI/CD treatments produced a 40-65% reduction in subsurface drain flow and a 55-56% reduction in runoff from the SSD treatments. The results for nitrate and ammonia reductions were similar in magnitude. There was a 45-75% reduction in annual flow-weighted $\text{NO}_3\text{-N}$ concentrations with the SI/CD treatment compared to the SSD treatment. $\text{NO}_3\text{-N}$ concentrations were lower in runoff than in subsurface drainage. $\text{NH}_3\text{-N}$ concentrations were much lower than $\text{NO}_3\text{-N}$ concentrations in subsurface drain flow in both water table treatments, and thus $\text{NH}_3\text{-N}$ loads were much smaller. Overall, there was up to a 77% reduction in $\text{NO}_3\text{-N}$ loads for the SI/CD treatments compared to the SSD treatment.

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Introduction

The Coupled Wetland AgroEcosystem (CWAES) was established to evaluate the potential water quality benefits of a subirrigation/controlled drainage water table management strategy when linked with a seasonal wetland-like managed hydrology scenario. This system is being compared to a similar system with a conventional subsurface drainage only management practice. The overall objective of this paper is to provide an overview of the impact of this system in regards to the hydrology and nitrate and ammonia loading.

Methods

The study was conducted at the Ohio State University Piketon Research and Extension Center (PREC) located about 110 km south of Columbus, Ohio. The predominant soil type, Omulga silt loam (fine silty, mixed, mesic Aeric Fragiaqualf), is somewhat poorly drained with a weak fragipan located at a depth of approximately 75 cm below ground surface. A seasonal high water table exists at 30 to 60 cm from November to May. The available water holding capacity of the soil is low. The major limiting factor for the soil is the high water table which can be controlled with subsurface drains making the land suitable for cropland and pasture (Hendershot, 1990).

Twelve research plots were established in 1990. The plots are 15 m wide in the east-west direction and 30 m long in the north-south direction, and there is a 2% natural slope running west to east. The subsurface drainage system consisted of three parallel 10-cm corrugated plastic drains installed at or above the fragipan at a 5-m spacing. The laterals were connected by a 10-cm non-perforated PVC pipe that outlets into a manhole. Runoff was collected from an 8-cm dia. collector that also outlets into the manhole. Each manhole was equipped with electricity and metered water.

In 1994 and 1995, plastic barriers were placed around each plot to minimize lateral seepage and soil berms were constructed around the plot edges to minimize surface water movement to and from the plots. Each plot can be operated in a drainage only, controlled drainage or subirrigation mode. Six plots (211, 212, 222, 223, 233, 243) were operated in the subirrigation/controlled drainage (SI/CD) mode, and six plots (213, 221, 231, 232, 241, 242) were operated in a conventional subsurface drainage only (SSD) mode. In the SI/CD treatment, plots were subirrigated during the growing season, followed by free drainage to lower the water table for harvest, after which the drainage and runoff outlet weirs were raised above ground elevation to induce wetland-like hydrologic and anaerobic conditions during late fall and winter. In early spring the SI/CD plots were switched to free drainage mode to lower the water table for improving trafficability conditions and enabling farming activity.

The cropping system under evaluation was a corn-soybean rotation established in 1995 under no till conditions. Each year (1996-1997) the four treatment-combinations (3 replications per treatment-combination) were corn phase with drainage only (SSD-corn), soybean phase with drainage only (SSD-soybean), corn phase with subirrigation and controlled drainage (SI/CD-corn), and soybean phase with subirrigation and controlled drainage (SI/CD-soybean). A 4-acre reservoir and pumping system located adjacent to the research plots was used for water supply.

Tipping bucket devices were used to estimate and sample subsurface drainage and runoff. The tipping buckets were constructed of stainless steel and were calibrated for their unique flow tip relationship. The number of tips was automatically recorded by a pulse counter connected to a CR10X data logger (Campbell Scientific, Inc.) and downloaded weekly. The tipping buckets are also capable of sampling water in proportion (1%) to the flow. Glass jars were placed at the outlet of these tipping bucket devices to collect water samples for analyses. Samples were transferred to 60-ml polyethylene bottles and transported to the laboratory where they were frozen until analysis, and then filtered using a Whatman 4 filter paper to remove suspended particles. The samples were then analyzed for NO_3 , NH_3 , and Br (tracer) using an ion selective electrode (ISE) (Orion model 720A). $\text{NO}_3\text{-N}$ and $\text{NH}_3\text{-N}$ concentrations were determined using an Orion model 95-12 Ammonia Electrode. $\text{NH}_3\text{-N}$ was determined in an alkaline reagent to convert NH_4 to NH_3 . NO_3 was reduced to NH_3 by Titanous Chloride and the $\text{NO}_3\text{-N}$ concentration was determined as the difference between the two measurements $[(\text{NH}_3 + \text{NO}_3) - (\text{NH}_3 = \text{NO}_3)]$.

Two water table observation wells were installed in each plot, one above the drain line and the other midway between two adjacent drains. Pressure transducers in the observation wells were connected to data loggers and water table elevations recorded hourly. Midnight water table elevations (2300 hour) recorded above and midway between two adjacent drain lines are being analyzed.

To study and understand the hydrology of the system the calendar year was divided into 4 periods. Period A includes about 90 days of controlled drainage to induce ponded wetland conditions during winter and early spring and the 30 day free drainage period for lowering the water table to improve trafficability conditions and seedbed preparation. Period B includes about 40-60 days of free drainage (gravity flow) during late spring for farming activity including planting and seedling emergence. Period C includes the 80-100 days of subirrigation during the growing season in summer. Period D includes 30 days of free drainage for lowering the water table before harvest and the 60-80 days of controlled drainage for the remainder of the year.

Overview of Hydrology Results

Precipitation at the site by hydrologic period is provided in Table 1. The annual precipitation in 1996 (102.90 cm) and 1997 (102.74 cm) were above the normal precipitation of 94.5 cm. In 1996 and 1997, the corn treatment consumed more water (46.8 and 38 cm, respectively) than the soybean treatment (44.2 and 32.1 cm, respectively). The reduction in SI water consumption in 1997 was because of the greater precipitation recorded during period C in 1997 than in 1996. The increase in precipitation between the two years (13.6 cm) is close to the average reduction in SI water consumed (10.2 cm) between the years.

Subsurface drain flows for the four treatments by period for the two years are given in Table 2. In 1996, subsurface drainage flows were greater for the SSD treatments than the SI/CD treatments. There was an average 48% reduction in annual subsurface drain flow from the SI/CD treatments (15.4 cm) compared to the SSD treatments (29.8 cm). Most of the flow (60-70%) occurred during the non-growing season during periods A and D for the SSD treatment, and overall subsurface drainage accounted for 22-36% of the incident annual rainfall. The SI/CD treatments had more subsurface drain flow during the growing season (period C) than the SSD treatments because of the

higher water table with subirrigation. The largest annual drain flow was from the SSD-soybean treatment (36.7 cm) and the smallest annual flow was from the SI/CD-corn (14.3 cm) treatment.

In 1997, the annual subsurface drain flow was smaller than in 1996 for all four treatment-combinations, although annual precipitation was essentially the same for both years. There was a difference in rainfall distribution between the two years within the four hydrologic periods. The largest annual drain flow in 1997 was from the SSD-corn treatment (23.3 cm) while the smallest annual drain flow was from the SI/CD-corn treatment. There was a 62% reduction in annual subsurface drain flow with the SI/CD treatments over that from the SSD treatments. Most of the subsurface drain flow (75-84%) occurred during periods A and D for the SSD treatment. The SI/CD treatments had larger flows during period C than did the SSD treatments, and there were larger flows during period C in 1997 than in 1996.

Runoff from the four treatment-combinations by period for the two years is summarized in Table 3. In 1996, annual runoff from the SSD treatments was greater than from the SI/CD treatments. The largest annual runoff (11.2 cm) was recorded for the SSD-corn treatment, with the smallest being 3.5 cm from the SI/CD-soybean treatment. In 1996, there was a 33-68% reduction in annual runoff from the SI/CD plots over the SSD plots. Most of the runoff (54-66%) occurred during the non-growing season (periods A and D) for the SSD treatments. For the SI/CD treatments 90% of the runoff occurred during the periods B and C, largely because of the higher water table in period C with subirrigation, and the precipitation during the free drainage portion of period B. In 1997, annual runoff from the SSD treatments was greater than from the SI/CD treatments. The largest annual runoff (17.4 cm) was recorded from the SSD-soybean treatment; the smallest runoff (5.2 cm) was recorded from the SI/CD-soybean treatment. Most of the runoff (63-71%) in 1997 occurred during periods A and D for the SSD treatments. For the SI/CD treatments most of the runoff (97-99%) occurred during periods B and C. The annual average runoff from the SSD treatments for 1997 (11.9 cm) was greater than in 1996 (8.9 cm). The annual average runoff from the SI/CD treatments for 1997 (5.2 cm) was greater than in 1996 (4.0 cm). The increase in runoff for the SSD treatments in 1997 was influenced by an 11.2-cm storm on Julian Day 62.

Total flow (sum of subsurface drain flow and runoff) recorded from the four treatment-combinations was calculated. In 1996, the largest annual flow (43.4 cm) was collected from the SSD-soybean treatment plots, and the smallest (18.8 cm) was from the SI/CD-corn treatment. The annual total flow from the SI/CD treatments (19.43 cm) was smaller than that from the SSD treatments (38.7 cm). There was a 50% reduction in annual total flow with the SI/CD treatments from that from the SSD treatments. Most of the total flow (69-74%) for the SSD treatments occurred during periods A and D. The 1997 total flows for all four treatment-combinations were smaller than the total flows observed in 1996. The largest 1997 total flow (34.4 cm) was recorded for the SSD-corn treatment; the smallest total flow (12.8 cm) was recorded from the SI/CD-corn treatment. Most of the 1997 total flow (73-75%) from the SSD treatments occurred during periods A and D. There was a 60% reduction the average annual total flows from the SI/CD treatments over that from the SSD treatments.

Overview of the Nitrate and Ammonia Load Results

In 1996, NO₃-N concentrations were larger than the NH₃-N concentrations from subsurface drainage flow for all the treatments. NH₃-N concentrations in subsurface drainage were small and somewhat similar for both water table treatments (SI/CD and SSD) during both years. Annual NO₃-N concentrations observed from the SSD treatments were much larger than those from the SI/CD treatments, with a 46-72% reduction in NO₃-N concentrations between the two. The larger NO₃-N concentrations for the SSD treatment were observed during the non-growing periods. In 1997, the annual NO₃-N concentrations in subsurface drainage were larger for the SSD treatments than the SI/CD treatments. The reduction in NO₃-N concentrations between these two water table treatments was somewhat lower (6-49%) in 1997 than in 1996.

For runoff, annual NO₃-N concentrations for all the treatments were larger than NH₃-N concentrations during both the years. Annual NH₃-N concentrations in runoff were larger than those from subsurface drainage in both years. In 1996, the largest annual NO₃-N concentration from runoff (3.8 mg/l) was observed from the SI/CD-corn treatment, and was probably a result of the 120 Kg/ha side dress during the subirrigation period and the corresponding large NO₃-N concentrations during period C and period D. The smallest NO₃-N concentration (0.79 mg/l) was observed in the SI/CD-soybean treatment. The average of the annual flow weighted mean concentrations for the SI/CD treatments (2.3 mg/l) are similar to the average for the SSD treatments (2.2 mg/l). In 1997, the largest annual NO₃-N concentration (2.7 mg/l) was observed from the SI/CD-corn treatment; the smallest (1.4 mg/l) was observed in the SI/CD-soybean treatment.

NO₃-N and NH₃-N loads from subsurface drainage are given in Table 4. NH₃-N loads were very small compared to the NO₃-N loads for all treatments in both years. The largest NO₃-N load (38.0 kg NO₃-N/ha) was from the SSD-corn treatment in 1996. The load values were lower in 1997 for all the treatments. NO₃-N loads for the soybean treatments were lower than the corn treatments. With runoff (Table 5), NO₃-N loads were greater than NH₃-N loads for all treatments for both years. Annual NO₃-N loads were smaller for the SI/CD treatments than the SSD treatments. There was a 77% overall reduction in total NO₃-N loading (subsurface drainage + runoff) from the SI/CD treatments over the SSD treatments in 1996. In 1997, there was a 68% reduction in total NO₃-N loads from SI/CD compared to SSD, and 60% reduction in total flows from the SI/CD treatments.

Summary

At this stage in the analysis of these data, the results of these field studies suggest that the SI/CD treatments substantially reduced total flow compared to the SSD treatments in this corn-soybean agroecosystem. There was a 50-60% reduction in total annual flow from the SI/CD treatments compared to the SSD treatments. Most of the total flow (69-75%) from the SSD treatments was recorded during the non-growing season (periods A and D). There was a 48-62% reduction in subsurface drain flow from the SI/CD treatments over the SSD treatments, and a 55-56% reduction in runoff. The NH₃-N loads were much smaller than the NO₃-N loads in subsurface drainage for both the water table treatments. There was a significant reduction in NO₃-N loads from the CD/SI treatments. The NO₃-N loads were lower for the soybean treatments over the corn treatments. . There was a 68-77 % overall reduction in NO₃-N loads exported from the field.

Further analysis of our extensive database will show that our coupled wetland agroecosystem involving water table management and seasonal wetland-like conditions can *significantly* reduce total flows from the agricultural field in comparison to the subsurface drainage only water table management strategy commonly practiced in the Midwestern U.S. Our results will also show that this innovative system, when properly managed, can *significantly* reduce nitrogen loads from the agricultural field, especially during the non-growing season, and increase crop yields and farming profitability. This system has great potential for water conservation and for reducing agricultural discharges to surface waters, which is of major environmental concern throughout the U.S.

Table 1. Precipitation recorded in 1996 and 1997 at the Piketon Research and Extension Center, Southern Ohio, by hydrologic period.

Hydrologic Period	Precipitation (cm)	
	1996	1997
A	34.39	39.17
B	25.45	14.43
C	19.66	33.27
D	23.39	15.88
Annual	102.90	102.74

Table 2. Subsurface drainage flows with the CWAES and SSD systems in 1996 and 1997.

Period	Ppt (cm)	Subsurface drainage flow (cm)			
		SI/CD- corn	SI/CD- soybean	SD- Corn	SD- soybean
1996					
A	34.39	2.17	1.98	11.39	21.71
B	25.45	10.8	11.92	6.65	8.28
C	19.66	0.56	0.85	0.02	0.03
D	23.39	0.8	1.66	4.84	6.67
Total	102.9	14.33	16.41	22.9	36.69
1997					
A	39.17	0.57	0.43	16.13	12.22
B	14.43	3.6	2.57	2.66	1.18
C	33.27	3.08	4.17	3.07	1.56
D	15.88	0.31	0.52	1.44	1.99
Total	102.74	7.56	7.69	23.3	16.95

Table 3. Runoff flows with the CWAES and SSD systems in 1996 and 1997.

Period	Ppt. (cm)	Runoff flow (cm)			
		SI/CD- corn	SI/CD- soybean	SD-corn	SD- soybean
1996					
A	34.39	0.13	0.26	5.13	2.47
B	25.45	2.24	1.98	3.07	2.86
C	19.66	1.76	1.2	0.73	0.2
D	23.39	0.31	0.09	2.27	1.13
Total	102.9	4.44	3.53	11.2	6.66
1997					
A	39.17	0.11	0.03	4.45	10.3
B	14.43	0.8	1.01	0.47	1.92
C	33.27	4.26	4.17	1.38	4.55
D	15.88	0.03	0.02	0.15	0.66
Total	102.74	5.2	5.23	6.45	17.43

Table 4. NO₃-N and NH₃-N loads from subsurface drainage with the CWAES and SSD systems in 1996 and 1997.

Period	Load (kg/ha) from subsurface drainage							
	CD/SI-corn		CD/SI-soybean		SSD-corn		SSD-soybean	
	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃
1996								
A	1.305	0.013	0.778	0.012	26.342	0.11	12.088	0.065
B	5.666	0.053	3.806	0.046	7.312	0.03	5.376	0.03
C						0.01		
D	0.263	0.006	0.037	0.006	4.361	0.06	4.954	0.025
Total	7.234	0.072	4.621	0.064	38.015	0.21	22.418	0.12
1997								
A	0.153	0.004	0.387	0.002	9.68	0.05	6.921	0.077
B	2.912	0.023	1.741	0.013	1.11	0.01	2.347	0.027
C	0.633	0.01	1.839	0.012	1.104	0.01	0.951	0.009
D	0.019	0.002	0.115	0.003	2.633	0.01	0.184	0.013
Total	3.717	0.039	4.082	0.03	14.527	0.07	10.403	0.126

Table 5. NO₃-N and NH₃-N loads from runoff with the CWAES and SSD systems in 1996 and 1997.

Period	Load (kg/ha) from runoff							
	CD/SI-corn		CD/SI-soybean		SSD-corn		SSD-soybean	
	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃
1996								
A	0.023	0.003	0.018	0.005	1.613	0.02	1.146	0.693
B	0.123	0.035	0.282	0.017	0.139	0.01	0.201	0.078
C	1.793	0.397	0.056	0.009	0.015	0.01	0.154	0.209
D	0.348	0.004	0.001	0	0.235	0.02	0.578	0.189
Total	2.287	0.439	0.357	0.031	2.002	0.07	2.079	1.169
1997								
A	0.012	0	0.005	0.007	1.913	0	1.749	0.002
B	0.13	0	0.072	0.001	0.55	0	0.056	0.001
C	0.729	0.003	0.818	0	0.472	0	0.383	0
D	0.006	0	0.004	0	0.06	0	0.049	0
Total	0.877	0.003	0.899	0.008	2.995	0	2.237	0.003