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Comparison of Free Drainage, Controlled Drainage, and Subirrigation Water Management Practices in an Ohio Lakebed Soil

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Abstract. *Agricultural drainage is an essential management practice for farmers and ranchers in order for them to achieve economically viable production levels in humid regions with slowly permeable soils and in arid irrigated regions. Historically, drainage systems have been installed and allowed to function by relying on gravity or pumping to convey all the water that reached the pipes and ditches away from the area needing the drainage improvement. Over time it has become apparent that there are offsite effects caused by drainage waters and their constituents. Drainage effluent is now known to increase the quantity of offsite flows and to contain soluble nutrients, agrichemicals, or salts that can negatively impact the receiving stream or water body. Environmental and ecological impacts may result from these pollutants such as increased flooding, lake eutrophication, development of hypoxic zones, loss of habitat, reproductive failures in wildlife species, and contamination of drinking water supplies. Control of subsurface drainage system outlets is a recommended water quality BMP in North Carolina to protect the Neuse River estuary system, and is perceived to provide at least a partial solution for hypoxia in the Gulf of Mexico if applied widely throughout the Mississippi River basin. A replicated field plot experiment was conducted to examine the hydrology, water quality, and crop yield impacts of controlled drainage, uncontrolled drainage, and subirrigation drainage on Hoytville silty clay soil in Ohio. Drainage volume, nitrate content of drainage water, nitrate content of vadose zone water, and crop yields were measured to compare and contrast the water management treatment impacts. Controlled drainage resulted in less water and nitrate released offsite and a lower concentration of nitrate in the vadose zone water than with uncontrolled drainage. Control of drainage outlets to manage drainage discharges and water quality will necessitate changes in the design and installation of drainage systems. Some research and educational programs will be required to encourage this new approach to drainage management and to assist growers to understand and apply the additional management skills that will be required.*

Keywords. Drainage water management, water quality, hydrology, nitrate nitrogen

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Introduction

What is the potential for reducing nitrate delivery to streams by applying novel agricultural drainage water management practices? In North Carolina, controlled drainage has been shown to be effective and has become a cost-shared practice available to producers to achieve state guidelines for allowable nitrate loss from agricultural fields (Gilliam et al., 1979; Evans et al., 1991; North Carolina Register, 1998). In the Midwest US, considerable evidence exists to indicate that subsurface drainage waters contribute large amounts of nitrate to streams and rivers draining to the Gulf of Mexico, and that this nitrate is the major cause of the extensive presence of hypoxic conditions in the Gulf (Goolsby et al., 1999; Rabalais et al., 1996). The Midwest is the most intensively drained region of the US due to the fertile, slowly permeable soils and the cool, humid climatic conditions (Pavelis, 1987; Zucker and Brown, 1998). Research on novel drainage water management practices and their hydrologic and water quality impacts are lacking for this region. The objective of this study was to measure the drainage volume, the nitrate concentration of the drainage water and the shallow ground water, and the crop yields for three drainage water management practices: outlet open continuously (unmanaged); outlet closed and water supplied to maintain a constant water table level at approximately 0.3 m depth for 100 days during the growing season with outlet open during the remainder of the year (subirrigation); and outlet open at drain depth only during tillage, planting, and harvesting periods and open at 0.3 m depth during the remainder of the year (controlled drainage).

MATERIALS AND METHODS

This research was conducted as part of a long term water management and water quality experiment at the Northwest Branch of the Ohio Agricultural Research and Development Center (OARDC) (41°13' N and 83° 46' W) in Wood County, Ohio. The elevation above sea level is 213.4 m (700 ft). Average annual rainfall is 84 cm. The average annual temperature is 10° C (50° F), average wind speed is 3.7 m/s (8.3 mph), and the average solar radiation is 328 Wm⁻² (www.oardc.ohio-state.edu/weather).

The dominant soil at this location is the Hoytville soil series, which can be found throughout northwestern Ohio, northeastern Indiana, and southeastern Michigan and covers approximately 344,000 ha (www.statlab.iastate.edu/soils). This soil formed mainly from fine and moderately fine textured glacial till. The landscape was leveled by wave action on the Maumee lake plain and has an average slope of 0-1%. The Hoytville soil series (Fine, illitic, mesic Mollic Epiaqualfs) is deep very poorly drained soil with moderately slow permeability (www.statlab.iastate.edu/soils). The soil texture of the A horizon at this site is silty clay.

The area chosen for this field experiment did not have a subsurface drainage system in place, at least since 1954. There was evidence of a few random drain lines that existed prior to 1954, but these were destroyed when the research farm was established and large management blocks with and without subsurface drainage were established. The selected area had improved surface drainage and this was maintained when the new experiment was established. Subsurface drains were installed in 1991 in a pattern that created twelve plots, each with its own outlet through a control structure where water table management could be implemented (Figure 1). The drain lines were installed at 80 cm below the surface and are spaced 6 meters apart.

The three water table management treatments during 1999 through 2003 were: (A) unrestricted subsurface drainage year round; (B) subirrigation during the growing season (approximately June 15 to September 30 each year) to maintain a constant water table at 0.3 m

below the surface and unrestricted subsurface drainage during the remainder of the year; and (C) unrestricted subsurface drainage from April 1 until June 15 and from September 15 to November 15 and restricted drainage (outlet set at 0.3 m below the soil surface) during the remainder of the year.

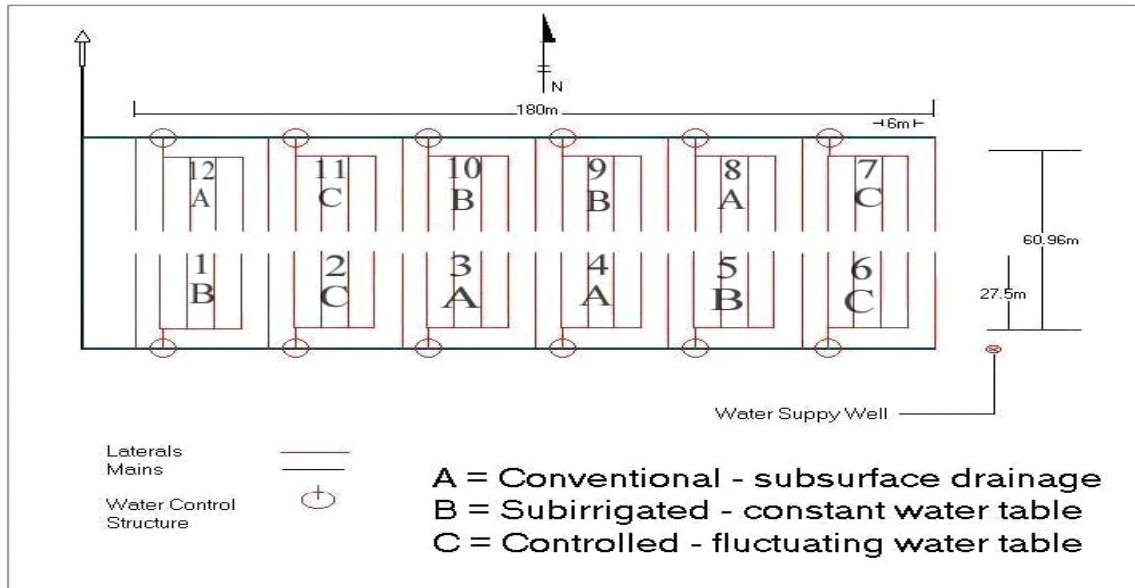


Figure 1 Experimental plot layout map of the water table management research facility.

Both phases of a corn-soybean rotation were present each year. One crop phase was planted in the north tier of plots and the other phase was planted in the south tier of plots, and the location of the crop phases was reversed each year yielding the corn-soybean rotation in each plot. Management of the plots included fall chisel plowing in the east-west direction. In the spring, a field cultivator was used to level the soybean half before planting. Crop varieties were selected for high yield potential, and seeding rates and fertility were maintained at a high level to take advantage of the unlimited water supply in the subirrigation treatment. Subirrigation began typically about day 170 and continued for approximately 100 days. Crop yields were determined annually based on machine harvest of selected crop rows with adjustment to a uniform grain moisture basis.

The experimental design was a three (water management) by two (crop rotation phase) factorial creating six treatments. There were two replications of each treatment. STATGRAPHICS Plus 5 software was used to perform analysis of variance to determine statistical difference between treatment means (Manugistics, Inc., 2000).

Water samples were taken from piezometers at 1, 2, and 3 meter depth in the center of each plot and midway between two adjacent drains. The samples were obtained using a bailer, transferred to glass jars, and transported to the laboratory in ice. Samples were taken every two weeks during the growing season and every six weeks during the remainder of the year during the period from January 1999 through June 2003. During this period of 54 months, there were 48 sampling dates. Water samples were also taken from the drain outlets whenever drain flow was occurring and personnel were on site to perform the collection. Grab samples of the drain flow were obtained using glass jars and transported to the laboratory in ice. Not all drain flow events were sampled. There were only 25 drainage water sampling dates during the study period. The water samples were stored at 2°C in the laboratory until analyzed. Water nitrate-N

analysis was done using a Lachat Flow Injection Analyzer and following Lachat Method # 10-107-04-1-A for determination of Nitrite/Nitrate in surface and wastewaters.

Drain flows were measured with mechanical flow meters that were read at the same time interval as the shallow ground water samples were collected.

RESULTS AND DISCUSSION

Annual precipitation during the study period ranged from 629 mm to 1040 mm and the average was 845 mm. Growing season (May-September) precipitation ranged from 285 mm to 613 mm and the average growing season precipitation during the study period was 428 mm. Approximately 400 mm of additional water was applied annually to the subirrigated water management treatment.

Drain flow distribution and amount varied within and between the studied years depending upon the precipitation pattern; an example is shown in Figure 2 for 2002, a normal rainfall year.

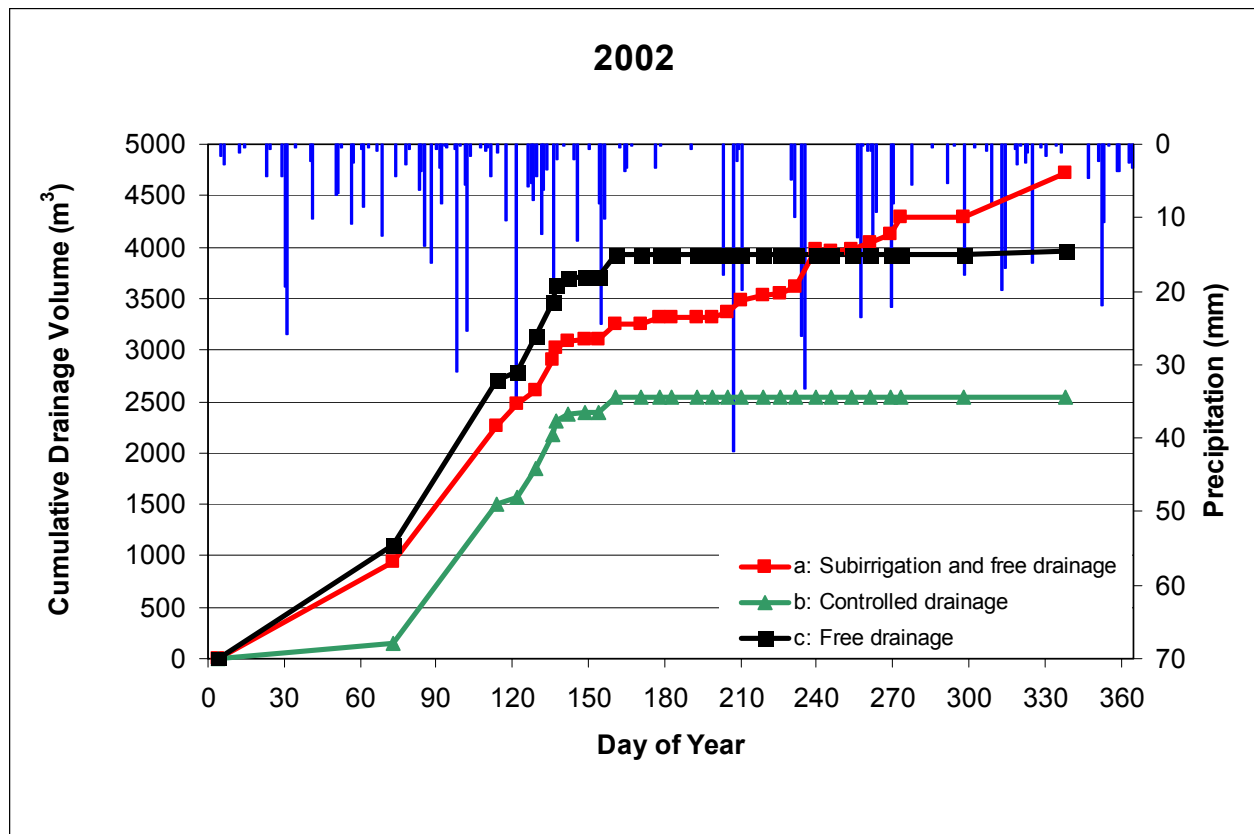


Figure 2 Example precipitation and cumulative drain flow by water management treatment.

Average annual drain flow volume and average annual nitrate-N concentration in the drainage water are shown in Table 1. The drain flow volume is reported as depth (mm) of water per unit area and the concentration of nitrate-N is reported as mg/L. There were significant differences at the 95% level of probability in the annual drain flow volumes by treatment. The volume of drainage water was significantly less from the controlled drainage treatment than from the other water management treatments. The greatest annual drain flow volume was from the subirrigated soybean treatment and the least was from the controlled drainage soybean

treatment. Averaged across crop phases and using the free drainage volume as the baseline, the relative flow volume from the subirrigated treatments was approximately 115% of the free drainage flow volume, while the controlled drainage flow volume was approximately 60% of the free drainage flow volume.

Table 1 Average annual drain volume (mm), nitrate-N concentration (mg/L), and load (kg/ha) by treatment.

Treatment	Drain Volume, mm	NO ₃ -N Concentration, mg/L	NO ₃ -N Load, kg/ha
Subirrigated – soybeans	191 a*	9.5 c	18.1
Free drainage – soybeans	166 a	15.9 a b	26.4
Controlled drainage – soybean	91 c	15.5 a b	14.1
Subirrigated – corn	162 a b	10.9 c	17.6
Free drainage – corn	146 b	16.4 a	24.0
Controlled drainage – corn	92 c	14.4 b	13.3

* Values followed by the same letter within each column are not different at the 95 % level of significance according to the LSD comparison.

Concentration of nitrate-N in the drainage water was significantly lower in the subirrigated treatments than in any other treatments at the 95% level of probability (Table 1). Nitrate-N concentrations in the free drainage treatments were higher than in the controlled drainage treatments, but the difference was significant at the 95% level of probability only for the corn crop.

Annual loads were calculated using the annual average flow volumes and nitrate-N concentrations (Table 1). Loads were highest with the free drainage water management and lowest with the controlled drainage water management. Average annual load of nitrate-N in the drainage water was 25.2 Kg/ha, 17.8 Kg/ha, and 13.7 Kg/ha for free drainage, subirrigation, and controlled drainage treatments, respectively. Controlled drainage reduced the N load by more than 45% compared to free drainage and by more than 23% compared to subirrigation.

The effect of water management treatment on the average concentration of nitrate in the shallow ground water by depth is shown in Table 2. Because there were no differences between crop phases with the same water management treatment, the statistical analysis was performed as if there were only three treatments and four replications. Nitrate-N concentration in shallow groundwater is significantly lower with subirrigation water management at all depths than with either controlled drainage or free drainage water management. Also nitrate-N concentration in the shallow groundwater at 2 m and 3 m depths with controlled drainage water management is significantly lower than with free drainage water management. The persistent high water table maintained by subirrigation during the growing season clearly results in lower nitrate-N in the shallow ground water.

Crop yields were not significantly different due to water management treatment during this study period at this site. For the 1999 through 2002 growing seasons, average corn yields were 9.85 Mg/ha and average soybean yields were 3.70 Mg/ha. Yields varied substantially from year to year due to precipitation amount and distribution.

Table 2 Average concentration of nitrate-N (mg/L) in shallow groundwater by water management treatment and depth.

Depth (m)	Water Management Treatment		
	Subirrigation	Controlled Drainage	Free Drainage
1	16.6 a A*	32.8 a B	33.1 a B
2	9.7 b A	23.0 b B	34.3 a C
3	1.5 c A	13.3 c B	17.8 b C

* Statistical differences are indicated by capital letters within rows and lower case letters within columns. Values followed by the same letter are not different at the 95 % level of significance according to the LSD comparison.

IMPACT

Controlled drainage, as used here, means a practice where the drainage system outlet is open at the drain depth only during tillage, planting, and harvesting periods and is open at 25 cm depth below the land surface during the remainder of the year. When this practice was compared to free drainage, where the outlet is open at drain depth all year, the volume of drainage water was reduced by 40% and the load of nitrate-N transported out of the drainage system was reduced by more than 45%.

Results such as these have fostered the participation of individuals from government agencies, universities, and the drainage industry to meet together and develop the Agricultural Drainage Management Systems Task Force and an associated Agricultural Drainage Management Systems Coalition to promote research, education, and adoption of “controlled drainage” as an innovative practice that can reduce the delivery of nutrients to streams. Designers and installers of drainage systems will need new tools and approaches. Growers will need guidance on the proper operation of controlled drainage systems. Much research effort will be required to provide the knowledge for the proper application of controlled drainage. More information about the Task Force can be found as a link from the following URL: <http://www.ag.ohio-state.edu/~usdasdru/>.

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