Drainage Management for Humid Regions

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Abstract

Surface and subsurface drainage are essential agricultural management practices in humid regions with slowly permeable soils to achieve economically viable production levels. Drainage water is known to increase the quantity of offsite flows and to contain soluble nutrients, agrochemicals, and salts that can negatively impact the receiving 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 fa ilures in wildlife species, and contamination of drinking water supplies. Drainage management has the potential to reduce these offsite effects. A replicated field plot experiment was conducted to examine the hydrology, water quality, and crop yield impacts of drainage management practices including controlled drainage, uncontrolled drainage, and subirrigation drainage on Hoytville silty clay soil in Ohio. Annual subsurface drainage volume was greatest with subirrigation drainage and least with controlled drainage. The concentration of nitrate in the subsurface drainage water was greatest with uncontrolled drainage and least with subirrigation drainage. Annual load of nitrate in the subsurface drainage water was least with controlJed drainage and greatest with uncontrolled drainage. The concentration of nitrate in the shallow ground water was least beneath subirrigation drainage and greatest beneath uncontrolled drainage.

Keywords: Drainage management practices, humid regions, irrigation, ground water.

1. Introduction

Agricultural drainage improvements in humid regions involve accelerating the removal of excess water from the soil surface and from the upper part of the soil profile to create trafficable conditions for farming equipment and to minimize anaerobic conditions within the crop root zone (Fausey, 2002). Research in Ohio has previously shown the relative amount of water delivered off site by surface drainage, subsurface drainage, and combined surface and subsurface drainage systems during March through September to be approximately 100, 125, and 150 mm, respectively (Schwab, et al., 1985); and that substantial amounts of nutrients and sediments were carried with the drainage waters. Over time it has become apparent that there are offsite effects caused by drainage waters and their constituents, and interest has developed in applying novel agricultural drainage water management practices for reducing nutrient delivery to streams.

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).

2. 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 Mollie Epiaqualfs) is deep very poorly drained soil with moderately slow permeability (www.statlab.iastate.edu/soils). The soil texture of the surface (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 (Fig. I). Each plot had a surface area of 660 m2 (24 m wide by 27.5 m long). The drain lines were installed at 80 cm below the surface and spaced 6 m 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. Subirrigation began typically about day 170 and continued for approximately 100 days. Well water was used as the subirrigation water supply, and the concentration of nitrate in the well water was consistently below detection limits.

Both phases of a com-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. 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. Crop yields were determined annually based on machine harvest of selected crop rows with adjustment to a uniform grain moisture basis.

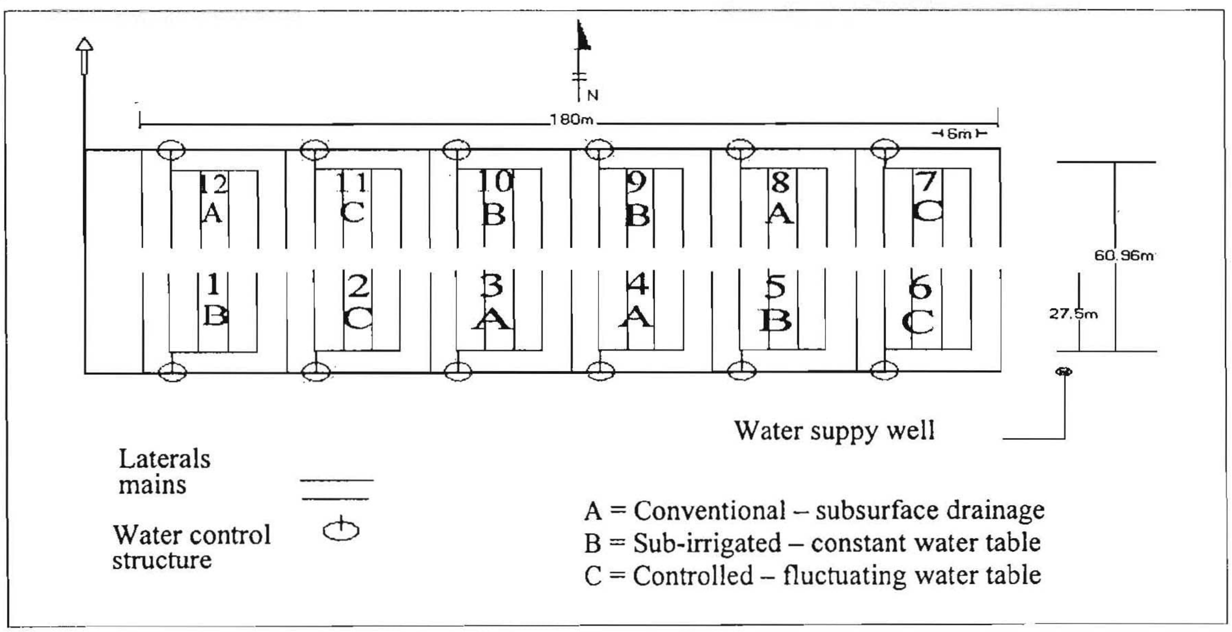

Fig. 1: Experimental plot layout map of the water table management research facility

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 routed through a pipe with a submerged section where flows were measured by means of accumulating mechanical flow meters similar to those used to measure domestic water use. The meters were read at the same time interval as the shallow ground water samples were collected.

3. 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 amount varied within the studied years depending upon the precipitation amount and pattern. An example is shown in Fig. 2 for 2002.

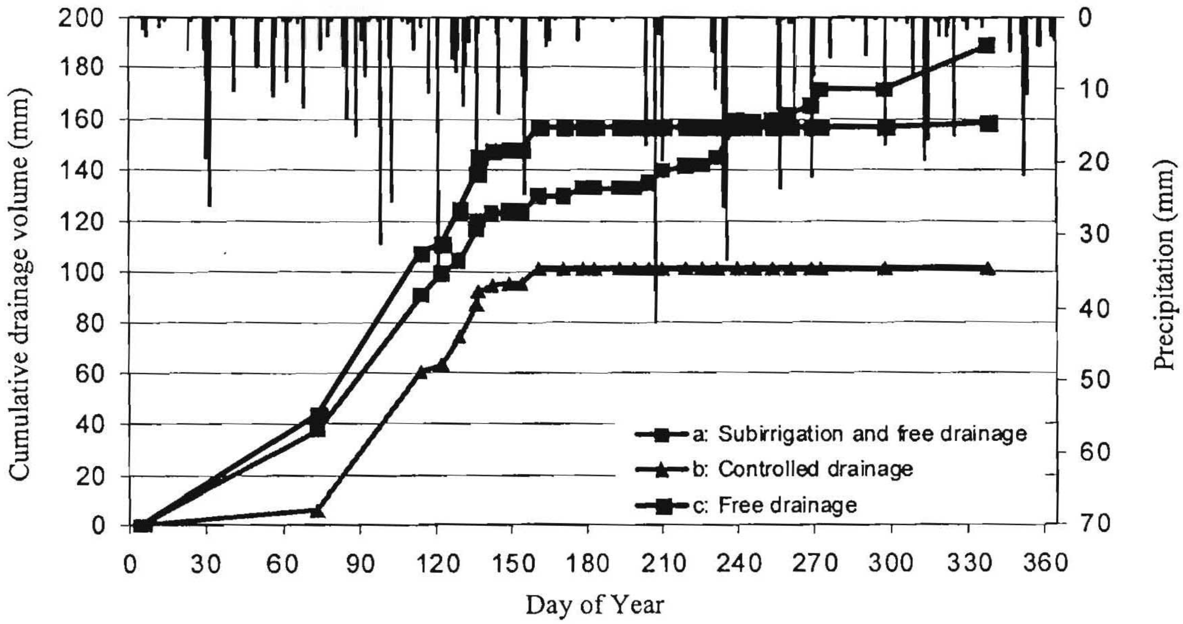

Fig. 2: Example precipitation and cumulative drain flow by water management treatment, 2002

Table 1: Average annual drain volume, mm, nitrate-N concentration, mg/L, and load, kg/ha by water management treatment during the period 1999 through 2003

Treatment	**Drain volume (mm)**	**NO3-N concentration (mg/L)**	**NO3-N load (kg/ha)**
Sub-irrigated - soybeans	191 a	9.5 c	18.1
Free drainage - soybeans	166 a	15.9 ab	26.4

Controlled drainage - soybean	91 c	15.5 ab	14.1
Sub-irrigated - corn	162 ab	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.

Average annual drain flow volume and average nitrate-N concentration in the drainage water are shown in Table I. 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 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 sub-irrigated 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.

The average concentration of nitrate-N in the drainage water was significantly lower in the subirrigated treatment than in any other treatments at the 95% level of probability (Table 1). Average nitrate-N concentration in drainage water was higher in the free drainage treatment than in the controlled drainage treatment, 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 average nitrate-N concentrations (Table 1). Load was 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 the three water management 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 was 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. This low nitrate-N may be a consequence of the absence of nitrate in the subirrigation supply water as well as the greater thickness of the reduced zone created by the high water table.

Crop yields were not significantly different due to water management treatment during this study period at this site. Yields for all treatments varied substantially from year to year due to precipitation amount and distribution. In one year with ample, well distributed rainfall events during the growing season, corn yields exceeded 15 Mg/ha in all drainage water management treatment. In another year with several prolonged periods during the growing season with excessive precipitation, com yields were less than 8 Mg/ha in all drainage water management treatments. For the 1999 through 2003 growing seasons, average com yields were 11.47 Mg/ha and average soybean yields were 4.22 Mg/ha.

Table 2: Average concentration of nitrate-N, mg/L, in shallow ground water by water management treatment and depth during the period 1999 through 2003

Water management treatment			
Depth (m)	Sub irrigation	Controlled drainage	Free drainage
1	16.6 aA	32.8 aB	33.1 aB
2	9.7 bA	23.0 bB	34.3 aC
3	1.5 cA	13.3 cB	17.8 bC

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.

4. Conclusion and Impact

Subsurface drainage is required for economically viable agricultural production under the climatic and soil conditions prevalent in the humid Midwest U.S. Subsurface drainage accelerates the removal of the excess water in the soil that impedes trafficking on the soil and may limit root growth and development. Continuous free drainage removes water from the soil even during seasons when trafficability and crop protection are not required. Soluble nutrients are transported from the soil with the drainage water, and these nutrients contribute to non-point source pollution of streams and other receiving waters. The research results reported here apply to flat landscapes with poorly drained soils having a flow restricting layer within the upper 2 m of the soil profile.

Subirrigation drainage, as used here, means the drainage system outlet is open at the drain pipe depth except for a 100 day period beginning in mid June during which time the outlet is raised to 30 cm depth below the land surface and water is added back into the drainage system to create and maintain a soil water table for subirrigating the crop. When this practice was compared to continuous free drainage, annual drainage volume increased approximately 15% and the load of nitrate transported out of the drainage system was reduced by 30%. While subirrigation drainage reduced the nitrate-N loads in subsurface drainage water, its' adoption by farmers is limited due to the lack of available water supply. Drainage water recycling (capture, storage, application for irrigation) is feasible (Allred et. al., 2003), but controlled drainage management seems more likely to be adopted in the short term.

Controlled drainage, as used here, means the drainage system outlet is open at the drain pipe depth only during tillage, planting, and harvesting periods and is raised to 30 cm depth below the land surface during the remainder of the year. When this practice was compared to continuous free drainage, 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%. Both subirrigation drainage and controlled drainage management elevate the soil water table and create a reduced zone closer to the bottom of the root zone than would occur with continuous free drainage. The reduced conditions promote greater denitrification and lower nitrate concentration in the shallow ground water.

Results such as those presented here 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. More information about the Task Force can be found as a link from the following URL: http://www.ag.ohiostate.edu/-usdasdru/.

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.

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References

1. Allred, B. J., Brown, L. C., Fausey, N. R., Cooper, R. L., Clevenger, W. B., Prill, G. L., LaBarge, G. A., Thornton, C., Reithman, D. T., Chester, P. W., and B. J. Czartoski (2003). Water table management to

enhance crop yields in a wetland reservoir subirrigation system. Applied Engineering in Agriculture, 19(4):407-421.
2. Evans, R. 0., Gilliam, J. W. and R. W. Skaggs (1991). Controlled drainage management guidelines for improving water quality. Publication No. AG-443. North Carolina Cooperative Extension Service.
3. Fausey, N. R. (2002). Drainage, aeration and trafficability. Lal, R. (Ed.). Marcel Dekker, New York, NY. Encyclopedia of Soil Science. pp. 361-363.
4. Gilliam, J. W., Skaggs, R. W. and S. B. Weed (1979). Drainage control to diminish nitrate loss from agricultural fields. Journal of Environmental Quality, 8(1):137-142.
5. Goolsby, D. A., Battaglin, W. A., Lawrence, G. B., Artz, R. S., Aulenbach, B. T., Hooper, R. P., Keeney, D. R. and G. J. Stensland (1999). Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin. Topic 3 Report. Submitted to the White House Science and Technology Policy Committee on Environment and Natural Resources, Hypoxia Work Group, Washington, DC.
6. Manugistics, Inc. (2000). ST A TGRAPHICS Plus 5.
7. North Carolina Register (1998). Proposed rules. North Carolina Department of Environmental, Health and Natural Resources. 15 August 1996, pp. 824-838.
8. Pavel is, G. A. (1987). Economic survey of farm drainage. In: Farm Drainage in the United States: History, Status, and Prospects, ed. by Pavelis, G. A. Econ9mic Research Service, Washington, DC, pp. 110-136.
9. Rabalais, N. N., Turner, R. E., Justic, D. D., Dortch, Q., Wiseman, J. W. Jr. and B. K. Sen Gupta (1996). Nutrient changes in the Mississippi River and system response on the adjacent continental shelf. Estuaries, l 9(2B):3 85-407.

10. Schwab, G. 0., Fausey, N. R., Desmond, E. D., and J. R. Holman (1985). Tile and surface drainage of clay soils. Research Bulletin 1166. Ohio Agricultural Research and Development Center, pp. 29.
11. Zucker, L. A. and L. C. Brown (Eds.) (1998). Agricultural drainage: water quality impacts and subsurface drainage studies in the Midwest. Ohio State University, Extension Bulletin 871, pp. 40.