Historically, drainage systems were not primarily installed as water quality management tools, but they do have an impact on soil and chemical transport. Where it has been necessary to drain agricultural land for production, research has shown that drainage systems can have a positive impact on some nonpoint source pollution problems in comparison to agricultural land without drainage. For example, under certain conditions artificial drainage acts to lower soil erosion by increasing the movement of water through the soil profile and thus reducing runoff. However, subsurface drainage expedites the transport of nitrate-nitrogen (nitrate-N) from the soil zone to surface waters.

Based upon the published literature, research results on the water quality impacts of drainage can be summarized by the following statements that compare agricultural land with subsurface drainage to that without subsurface drainage:

- The percentage of rain that falls on a site with subsurface drainage and leaves the site through the subsurface drainage system can range up to 63%.
- The reduction in the total runoff that leaves the site as overland flow ranges from 29 to 65%.
- The reduction in the peak runoff rate ranges from 15 to 30%.
- Total discharge (total of runoff and subsurface drainage) is similar to flows on land without subsurface drainage, if flows are considered over a sufficient period of time before, during, and after the rainfall/runoff event.
The reduction in sediment loss by water erosion from a site ranges between 16 to 65%. This reduction relates to the reduction in total runoff and peak runoff rate.

The reduction in loss of phosphorus ranges up to 45%, and is related to the reductions in total runoff, peak runoff rate, and soil loss.

In terms of total nutrient loss, by reducing runoff volume and peak runoff rate, the reduction in soil-bound nutrients is 30 to 50%.

In terms of total nitrogen (N) losses (sum of all N species), there is a reduction.

However, nitrate-N, a soluble N ion, has great potential to move wherever water moves. Numerous studies throughout the Midwest and southeast U.S., and Canada document that the presence of a subsurface drainage system enhances the movement of nitrate-N to surface waters. Proper management of drainage waters along with selected in-field BMPs helps reduce this potential loss.

These results indicate that subsurface drainage is a management tool that reduces the potential for erosion and phosphorus enrichment of surface waters from agricultural activities. However, nitrate-N loadings exported from drainage conduits to surface waters continue to be a major water quality concern. The following pages provide information on agricultural drainage research conducted in individual states of the North Central Region. Climate, geography, landform, and potential natural vegetation differ between regions so that research results are unique, yet they are relevant to similar circumstances.

First, the basic concepts of water table management are reviewed so that research in individual states can be better understood.

Under certain conditions, artificial drainage acts to lower soil erosion
rates and amounts by increasing the movement of water through the soil profile and reducing peak and total runoff.
Water table management is a package of management practices and strategies that can be used by agricultural producers and land managers to manage drainage waters. In simple terms, water table management is the management or regulation of soil-water conditions in the profile of agricultural soils. Water table management consists of three basic practices. These are conventional subsurface drainage, controlled drainage, and subirrigation. Controlled drainage and subirrigation are relatively new techniques that have demonstrated increased crop yields.

**Conventional Drainage**

The most common form of water table management used in the Midwest is conventional drainage. A system of drainage pipes (corrugated plastic tubing, clay or concrete tile, etc.) that outlet into a ditch or stream acts to lower the water table level equal to the drain depth through gravity.
Controlled Drainage

For controlled drainage the traditional system of drainage pipes is intercepted by a water control structure. This allows the drainage outlet to be artificially set at any level between the ground surface and the drains. Raising the outlet after planting helps keep water available for plant use longer than does "free," uncontrolled subsurface drainage. This practice can also be used to recharge the water table between growing seasons. Research conducted in North Carolina indicates that controlled drainage may provide some reduction in nitrate-N losses over conventional drained cropland.
Subirrigation Mode

With subirrigation, one system provides both the drainage and irrigation requirements for the crop. The water table level in the field is regulated through the subsurface drainage system using control structures. The subsurface drain spacing for subirrigation is usually 30 to 50 percent denser than that used for conventional subsurface drainage. Irrigation occurs below the ground surface, thus raising and maintaining the water table at an appropriate depth in the crop root zone.
Agricultural Drainage

Bulletin 871-98

Ohio

Research, Engineering, and Science-Based Education

The management of Ohio's agricultural drainage waters has important consequences for agricultural productivity and profitability, and for environmental quality. The focus of most current work in Ohio is water table management, a package of management practices and strategies that can be used by agricultural producers and land managers to manage drainage waters. Educational efforts focus on balancing production and environmental goals.

Numerous researchers and agencies are actively involved in water table management research and demonstration throughout the State. This work is largely conducted as cooperative multi-institutional, multi-agency, interdisciplinary efforts that include agricultural, environmental, and industrial stakeholders.

Studies of subsurface drainage and water table management have demonstrated significant gains in crop yield with these practices. Solute transport through drainage systems to surface water is also affected by water table management. New technologies that manage the loss of agrichemicals are being tested. In particular, subirrigation of crops through subsurface drainage systems is under study for its effect on crop yield and agrichemical fate and transport.
Agricultural Drainage Field Studies

Research from two long-term field studies documents significant corn and soybean yield increases with subsurface drainage on poorly drained soils compared to no subsurface drainage on these same soils.

Studies conducted on Toledo silty clay at the North Central Branch Station of the Ohio Agricultural Research and Development Center (OARDC) in Sandusky County evaluated crop yields, soil physical properties, and water quality parameters over a 20-year period for undrained conditions compared to surface drained, subsurface drained, and combination conditions. Yields increased and variation in yield decreased as drainage intensity increased (see graphs).
Research conducted on Hoytville silty clay at the Northwest Branch Station of OARDC in Wood County (near Hoytville) evaluated the effects of drainage, rotation, and tillage practices on corn and soybean yield. Results from the 11-year study indicated that subsurface drainage improved corn yields by 20 to 30 bu/acre and soybean yields by 7 to 14 bu/acre, on both plow and ridge tillage treatments regardless of tested crop rotation. Crop rotation treatments included continuous corn, continuous soybean, and corn-soybean rotation.

**Soil Conditions**

Soil conditions evaluated after 16 years of research on Toledo silty clay, comparing surface and subsurface drained conditions, indicated that subsurface drainage promoted better movement of water through the soil, mellower soil conditions, less crusting and cracking, more drainable porosity, and a better environment for soil-improving crops such as alfalfa and grasses, resulting in greater yields.

**Water Quality**

Drainage water quality evaluated over a 14-year period on Toledo silty clay, indicated that subsurface
drainage reduced the losses of sediment, phosphorus and potash by 40, 50, and 30 percent, respectively, compared to surface drained cropland. However, nitrate-N losses increased by 40 percent. Over a 17-year period, runoff from land that was subsurface drained was lower than that from land that was not subsurface drained, and peak runoff was reduced by about 32 percent.

Educational efforts have increased awareness, demonstrated new and improved technologies and strategies, and encouraged adoption of practices that reduce nonpoint source impacts on water resources.
Subirrigation research by the USDA-ARS at Wooster and Hoytville indicates that for certain soils, this practice can be very efficient if the system is properly designed for the site and soil conditions. Most importantly, crops respond well to subirrigation when other production management factors are not limiting. Research has considered factors such as water table depth, row spacing, and cultivars. At Wooster, soybean and corn yields were on average 43% and 30% greater, respectively, for subirrigation/drainage systems compared to subsurface drainage alone. Subirrigated corn and soybean yields averaged 203 and 65 bu/acre, respectively, over 6 years of research. Results of five years of subirrigation research at Hoytville (1992-1996) indicate a 21% increase in soybean yields, and a 12% increase in corn yields over that produced from subsurface drained cropland.
Drop logs in a water control structure are adjusted in order to control the water table level in a subirrigation/drainage system.

- A daily water quality modeling methodology using remotely sensed data, a field scale process model, and a GIS to assess flow, sediment and agrichemical discharges on small agricultural watersheds has been developed and evaluated. The model incorporates ADAPT (Agricultural Drainage and Pesticide Transport) and has been used on the Rock Creek and Darby Creek watersheds. The method gives good estimates of streamflows, but overpredicts pesticide losses. The potential to predict sediment and nitrate losses was illustrated, but a dynamic delivery ratio and improved denitrification algorithms need to be incorporated into the model. New studies are linking this agricultural model to the SWMM model which better accounts for urban land uses, and to the REMM model which was developed for riparian land uses.

Comparison of predicted average nitrate-N loadings at the watershed outlet for different tillage and drainage practices using a watershed approach that incorporates ADAPT.
A working group of over 50 state and federal agency and agricultural organization personnel are developing a new, comprehensive Agricultural Water Management Guide, which includes consideration of: soils, drainage, subirrigation, irrigation, operation and management of drainage systems, constructed wetlands, environmental assessment and impact, and economics. The overall focus is to help users design and implement water management strategies and technologies to meet existing and future environmental and agricultural production goals. The guide uses a new approach that provides water management specifications and guidance based on potential economic and environmental response to proposed water management strategies.

For over 45 years, Ohio Drainage Schools have taught land improvement contractors and agency personnel technical skills in the design and management of soil and water conservation systems, with primary focus on water table management practices.

A set of field and watershed scale decision aids, simulation models, and expert systems are being developed to evaluate the hydrologic responses of water management systems. The foundation is the ADAPT field scale model, developed as an extension of the GLEAMS model. GLEAMS hydrology was augmented with subsurface drainage, infiltration, snowmelt and macropore flow algorithms. ADAPT gives daily estimates for pesticides and nutrients in subsurface drainage as well as the normal GLEAMS output. The model has been evaluated with data from Ohio and North Carolina, providing good predictions of runoff, drainage and water table changes. ADAPT predicts water table changes similarly to the models DRAINMOD, SWATREN, and PREFLO. Model enhancements include multimedia capabilities, a decision support system, expert knowledge databases, and an expert system. ADAPT is also being linked to the soybean model SOYGRO as part of a multi-institutional project lead by the University of Florida and funded by the United Soybean Board.

Multifaceted agricultural water management research is underway at the Piketon Research and Extension Center (PREC) in Southern Ohio. In addition to the subirrigation/controlled drainage work, researchers are studying nitrogen management and drainage strategies for microirrigated blueberry, melon and pepper production, and the impact of controlled drainage on corn and soybean yields.
Wetland Reservoir Subirrigation Systems link a wetland and water supply reservoir to a network of subirrigation/subsurface drainage pipes that can be used to irrigate crops through the root zone. Proper linkage and management of these components has the following benefits:

1. supplies water to the crop, eliminating drought stress, improving plant nutrient use, and sustaining yields;

2. collects and recycles runoff and drainage waters, reducing the amount of sediment and plant nutrients lost from the cropland to surface waters; and

3. increases wetland acres, vegetation, and wildlife habitat.
A properly designed system has the potential for zero-discharge to streams, with the option to release clean water at a later date, helping to reduce peak flows downstream.

During and after a rain, runoff and subsurface drainage waters flow into the wetland. A water control structure in the wetland is used to maintain a ponded water depth of one to two feet. Vegetation that grows in the water, on the bank, and in the adjacent habitat area helps filter out sediment and nutrients from the flow. Water that flows from the wetland is pumped to the water supply reservoir for storage. Water in the reservoir can then be pumped to the subirrigation/subsurface drainage system to irrigate crops during the growing season. Subirrigation improves crop yields because crops receive a steady supply of water throughout the growing season. From the field, water drains back into the wetland, and the cycle starts again.
Two components of a wetland reservoir subirrigation system: (1) a wetland (top photo), and (2) a water-storage reservoir (bottom photo) at the Defiance County demonstration site.
Demonstration and research sites were established in the Maumee River watershed following subirrigation/drainage systems research conducted by the USDA - ARS. This research was conducted cooperatively with The Ohio State University at the Wooster Branch Station of OARDC and the Northwest Branch Station of OARDC in Hoytville. There are three demonstration projects in the Maumee River watershed in Northwestern Ohio; one each in Defiance, Van Wert, and Fulton counties. Each site contains a constructed wetland (installed on prior converted cropland), a water supply reservoir, and a field-scale corn/soybean production system where the crop is irrigated through a subirrigation/drainage system.

In addition, an interdisciplinary, multi-institutional research team is evaluating a coupled subirrigated corn and soybean production and seasonal wetland system in Pike County at the PREC. Plots in the coupled wetland-agricultural system are drained in the spring for planting, subirrigated during the growing season, drained in the fall for harvest, and converted to wetland hydrology from late fall to early spring. This integrated system may provide sustained corn and soybean yields, and help remediate excessive nitrate-N levels in drainage waters.
The privately owned and operated Fred Shininger farm in Fulton County contains 20 acres of subirrigated cropland, a newly constructed 1.5 acre wetland (water surface and adjacent habitat area), and an existing 2.0 acre water-supply reservoir.
Subirrigation is a form of water table management that provides both drainage and irrigation requirements for crops with one subsurface system. Nitrate-N and atrazine concentrations were measured in shallow ground water beneath conventional subsurface drainage and subirrigation/drainage systems for corn and soybean from 1991 to 1997 at the Northwest Branch Station of OARDC near Hoytville, Ohio. Corn and soybean grown in rotation were fall chisel-plowed followed by field cultivation in the spring. Nitrate-N concentrations in the shallow ground water at 3.3, 6.6, and 9.8 ft depths were lower when subirrigation was applied during the growing season compared to when no subirrigation was applied. This reduced concentration was seen during both the growing and non-growing seasons.

There was a 76% reduction in nitrate-N concentrations in ground water at the 9.8 ft depth (lowest depth sampled) when subirrigation was used instead of conventional drainage. The lowest concentrations were reported for subirrigation with a constant water table under both corn and soybean. Water table levels maintained at a constant level beneath growing crops resulted in a 74% greater reduction in nitrate-N than a management regime of fluctuating water table levels.

Atrazine was not detectable in most of the shallow ground-water samples. When detected, atrazine concentrations were less than 0.1 mg/L (1 mg/L equals 1 ppm).

Water Table Management Scheme

Drainage water quality beneath the following water table management schemes was tested for nitrate-N...
concentration: conventional subsurface drainage; subirrigation/drainage with a constant water table; and subirrigation/drainage with a fluctuating water table. Subirrigation consistently showed lower nitrate-N concentrations in drainage water compared to conventional drainage. Conventional subsurface drains were always open to allow free drainage. Subirrigation/drainage systems used to maintain a constant water table level were closed for approximately 100 days beginning in mid-June. Water was added to maintain the water table at 10 in. below the ground surface and the drains were opened as necessary to lower the water table following rainfall events.

Subirrigation/drainage systems used to maintain a fluctuating water table were also closed for approximately 100 days beginning in mid-June. Again, water was initially added to raise the water table level to 10 in. below the ground surface. A fluctuating cycle was implemented where the water table level was not raised until the water table fell to 31.5 in. below the ground surface. This cycle was repeated over the growing season.

**Ohio Management Systems Evaluation Area**

Ohio MSEA activities occur on research sites, demonstration farms, and in watersheds. Research sites are used to evaluate different farming systems and their impacts on water quality. Demonstration farms show how agricultural management practices can be economically profitable to farmers. Results from site studies are used to model watershed processes and develop expert systems.

Cooperation between the Ohio MSEA and the PREC water quality program in south-central Ohio was established in 1990 to monitor the impacts of agricultural management systems on productivity, profitability, and ground-water quality. Phase II of Ohio MSEA, initiated in 1994, had its scope broadened to include water table management and watershed research in northern Ohio, with more emphasis on development of decision aids and expert systems. New directions for the Ohio MSEA education component includes riparian ecosystems, agricultural water management, integration of wetlands into agricultural production systems, development of a comprehensive agricultural water management guide, and addressing the Gulf of Mexico hypoxia issue.

The Ohio MSEA is a cooperative research and educational effort supported by: Ohio Agricultural Research and Development Center and Ohio State University Extension, The Ohio State University; USDA-ARS Soil Drainage Research Unit, the USDA-Cooperative State Research, Education and Extension Service, USDA-NRCS, the U.S. Geological Survey, and U.S. EPA, in cooperation with other local, state and federal agencies.

**Wetland Reservoir Subirrigation Systems**

The Maumee River Watershed Demonstration Project will take five years to fully implement and evaluate. Construction began during the fall of 1994. System evaluation and monitoring will begin in 1998. The work conducted at the demonstration sites is coordinated through the Maumee Valley Resource Conservation and Development Area in Defiance County. However, there are over 50
cooperators and collaborators actively involved in the project. The project is primarily funded by USEPA/GLNPO, with support funding from the Lake Erie Protection Fund, OARDC, Ohio State University Extension, Ohio Sea Grant Program, North Central Region Water Resources Research Program, and numerous agencies and associations.

Average nitrate-N concentration (mg/L) in drainage water - Spring 1997.

USDA-ARS researchers found that nitrate-N concentrations in water sampled at subsurface drain outlets during February through May 1997 were lower when subirrigation had been used during the previous growing season than when subirrigation had not been applied. The graphs above show nitrate-N concentrations in drainage water observed for each drainage treatment during the spring season of 1997. The numbers shown are the seasonal average nitrate-N concentrations for each treatment method.
Agricultural Drainage

Bulletin 871-98

Ohio

Contacts For Further Information

THE OHIO STATE UNIVERSITY
Food, Agricultural, and
Biological Engineering
590 Woody Hayes Dr.
Columbus, OH 43210-1057
Fax: (614) 292.9448

Larry C. Brown, Associate Professor
and Extension Agricultural Engineer
Phone: (614) 292.3826
Internet: brown.59@osu.edu

Andrew D. Ward, Professor
Phone: (614) 292.9354
Internet: ward.2@osu.edu

Scott Subler, Research Scientist
OSU Soil Ecology Laboratory
Phone: (614) 292.0086
Internet: ssubler+@osu.edu
School of Natural Resources
2021 Coffey Rd.
Columbus, OH 43210-1085
Fax: (614) 292.7432

Rattan Lal, Professor
Phone: (614) 292.9069
Internet: lal.1@osu.edu

Terry J. Logan, Professor
Phone: (614) 292.9043
Internet: logan.4@osu.edu

Piketon Research and Extension Center
1864 Shyville Road
Piketon, OH 45061
Fax: (740) 289.4591

Peter Bierman,
Research & Extension Associate
Soil & Water Resources
Phone: (740) 289.2071
Internet: bierman.2@osu.edu

USDA AGRICULTURAL RESEARCH SERVICE
Soil Drainage Research Unit
590 Woody Hayes Dr.
Columbus, OH 43210-1057

Norman R. Fausey, Research Leader
Phone: (614) 292.9806
Internet: fausey.1@osu.edu

USDA NATURAL RESOURCES CONSERVATION SERVICE
Bernie Czartoski, Coordinator
Maumee Valley Resource Conservation and Development Area
Phone: (419) 784.3717
Fax: (419) 784.0643
Internet: mvrcd@defnet.com
Subsurface drainage has been used on large areas of Indiana's cropland for many years, and guidelines for drain spacings, sizes, and systems are well established for most soils. More recent research on subsurface drainage and crop yield has occurred on a major soil type that was traditionally not recommended for subsurface drainage due to low permeability and problems with silting-in of the drains. The Clermont silt loam soil ("buckshot ground," "crawdad flats") and similar soils in southeastern Indiana and southwestern Ohio are wet in spring, causing delayed planting, shallow rooting, and subsequent drought stress later in the summer. Surface drainage, primarily by land leveling (and shallow surface ditches) has been the recommended practice. In 1983, new studies were begun at the Southeast Purdue Agricultural Center (SEPAC) in Jennings County to test the effectiveness of per-forated plastic drain tubing for drainage and subsequent crop growth and yield. In one 6 acre experimental area, plots were established under subsurface drained (50 ft spacing) and undrained conditions for comparisons of tillage system, cover crops, manure application, and rotation with a hay crop. Surface drainage on these plots was fair, with pockets of ponded water persisting in some areas for several days after a rainfall. Corn yield differences between subsurface-drained and non-subsurface drained plots over an 8 year period averaged 14 to 23 bu/acre, depending on the particular treatment. Most of the measurable improvements in soil tilth and organic matter in the cover crop and rotation treatments were greater in the presence of subsurface drainage than in its absence, and no-till treatments performed better with subsurface drainage.
Perhaps the most significant benefit of subsurface drainage is in areas of a field where surface drainage is poor— in some years the swales without subsurface drainage had enough ponded water to destroy the crop in that area, whereas drained plots were able to more quickly remove the ponded water.

In an adjacent 12 acre area of the same field, plots with 4 different drain spacings were established in order to determine the optimal spacing. This area of the field had excellent surface drainage. Results from 10 years of continuous corn showed the widest spacing (132 ft, considered to be an "undrained" control for this soil) to average 10 bu/acre (6.4%) lower yields than the narrowest spacing (see graph). Optimal drain spacing for this soil based on yield appears to be somewhere between 33 and 66 ft. Some of the yield advantage of the narrower spacing is due to the more timely planting possible on the drained plots. The 10 bushel average yield difference between the narrowest (16 ft) and widest (132 ft) spacing was less than expected, and may reflect both the excellent surface drainage of this site and the fact that the 132 ft spacing is not truly "undrained."
The 10-year average corn yields recorded at the SEPAC site for four different drainage spacings.
Agricultural Drainage

Bulletin 871-98

Indiana

Drainage and Chemical Transport

Two field-scale studies are evaluating movement of agricultural chemicals through soil into subsurface drainage water. The SEPAC site in Jennings County began in 1983 and the Water Quality Field Station (WQFS) in Tippecanoe County began in 1993. The WQFS uses 5 ft deep clay wall barriers to isolate each plot from surrounding plots, ensuring that water and chemicals measured in each drain accurately represent the particular treatment on that plot. Objectives at the WQFS include evaluating both short- and long-term rotations, fertilizer practices, manure applications, and pesticide treatments, and comparing all of the treatments to a background control treatment of reestablished native prairie grass (bluestem). At SEPAC the impact of four drain spacings, all receiving the same crop and soil management practices, is evaluated.

Drainage water samples are collected before, during, and after storms, and analyzed in the laboratory at Purdue University.
Small amounts of pesticide move quickly through the soil into subsurface drainage water during the first several rainstorms after application. The amounts are usually very small on non-sandy soils (less than 1% of what was applied and often less than 1/10%), while the majority of the pesticide is sorbed and/or degraded in the topsoil. The rapid movement of small amounts of chemicals is called "preferential flow" and is due to flow through natural cracks and channels in the soil. Preferential flow of pesticides occurs during the first month or two after pesticide application in the spring (see diagram).

Nitrate-N is present in subsurface drain water at all times that drainage occurs (see diagram). Since most of the drainflow occurs during the "off-season" (November -May) in Indiana, most of the nitrate-N losses also occur then. Nitrate-N losses in drainage water vary with drain spacing as well as crop rotation and fertilizer treatment. In preliminary data from the WQFS, crop rotation appears to be the most significant factor for nitrate flux. In systems where roots are present year-round, such as in the bluestem prairie grass plots, the nitrate-N flux is very low. Summer annual crops like corn and soybean have more limited time periods with active roots, and thus nitrate-N flux increases.

Pesticide and nitrate-N leaching losses occur at different times and by different mechanisms, and therefore management practices to reduce these losses will be different. Although it may appear to be obvious, the difference in the major loss period for pesticides and nitrate-N means that practices developed to minimize pesticide leaching, for example, will have little impact on nitrate-N leaching, and vice versa. For non-sandy soils, pesticide management research should focus on the time period immediately after application, since almost no losses are detected in drainage water in the off-season. For nitrate-N, research is needed on ways to keep N in the soil or return it to the air. Winter cover crops
Nitrate-N is present in drainage water whenever there is subsurface drainage flow. Pesticides are present only during the first month or two after pesticide application (April or May).
Agricultural Drainage

Bulletin 871-98

Indiana

Contacts For Further Information

PURDUE UNIVERSITY
Agronomy
1150 Lilly Hall
West Lafayette, IN 47907-1150
Fax: (765) 496.2926

Eileen Kladivko, Professor
Phone: (765) 494.6372
Internet: kladivko@purdue.edu

Ron Turco, Professor
Phone: (765) 494.8077
Internet address: rturco@purdue.edu

Sylvie Brouder, Assistant Professor
Phone: (765) 496.1489
Internet: sbrouder@purdue.edu

Agricultural and Biological Engineering
1146 ABE Building
West Lafayette, IN 47907-1146
Fax: (765) 496.1115

Jane Frankenberger, Assistant Professor
Phone: (765) 494.1194
Internet: frankenb@purdue.edu

SOUTHEAST PURDUE
AGRICULTURAL CENTER
4425 E Co. Rd. 350 N
Butlerville, IN 47223-0216
Phone: (812) 458.6977

Web pages on Indiana's subsurface drainage research sites:
http://www.agry.purdue.edu/agronomy/water/fieldstn/sepacwat.html
http://www.agry.purdue.edu/agronomy/water/fieldstn/wqfswat.html
Agricultural productivity in Illinois relies on the practice of drainage. Subsurface drainage systems remove excess water from fields, but in the process agrichemicals such as nitrate-N are carried along a system of surface ditches and streams to potential drinking water supplies. Drainage research in Illinois is primarily concerned with reducing nitrate-N and pesticide loadings to ground and surface water outlets. Projects in Illinois have focused on the following topics: locating subsurface drainage systems; estimating nitrate-N loading from fields with random or irregular subsurface drainage systems; evaluating the effects of cropping management systems on the movement of nitrate-N; constructing wetlands to remove nitrate-N and other agrichemicals from subsurface drainage waters; and predicting surface flow and nitrate-N loading at the outlets of subsurface-drained watersheds.
Several projects have been conducted in the Little Vermillion River in east-central Illinois. The Little Vermilion River (LVR) drains approximately 190 mi² of agricultural land before forming the Georgetown Reservoir which serves as the primary water supply for a population of 5000. Since 1991, 15 sites have been established to track important water quality parameters in the river, subsurface drainage, field runoff, and effluent from filter strip and wetland test areas.

An initial study compared water quality from the various subsurface-drained sites. Of particular interest is the difference in nitrate-N concentrations in drainage from corn-soybean fields versus a field in continuous meadow for over 10 years: drainage from the seven fertilized fields had concentrations averaging 10 times greater than those measured in meadow drainage. The meadow will soon be placed back into corn-soybean production and monitoring will continue to observe changes in nitrate-N output.

Additional study focused on the effectiveness of N application and tillage methods in reducing the movement of nitrate-N to surface and subsurface water outlets. Nitrate-N concentration from the seven cropped fields varied considerably depending upon the management systems used and, in particular, the level of N fertilizer applied. Preplant, anhydrous-N application systems with average annual application of 96 lbs/acre had a mean concentration of 16.8 mg/L; while side-dress and manure application systems, with average annual N application of 82 lbs/acre had a mean concentration of 10.2 mg/L. The mean concentration of nitrate-N from the continuous meadow was 1.1 mg/L.

In a third study, flow and nitrate-N outputs from the field tile systems were compared to outputs
measured in the drainage ditch in the upper reach of the LVR. Field subsurface drainage was found to be a useful predictor of surface ditch flow and nitrate-N loading. Ditch response was considered as a combination of contributions from field drainage systems and from flow entering directly from the sides and bottom of the ditch itself. Runoff appears to play a minor role in the LVR watershed. Attempts have been made to model the two flow components using Hooghoudt's equation. The relative contributions of field drain flow and direct ditch flow may be a function of the distribution of different soil types in the watershed and may also vary over time with rainfall. Contributions of N from direct ditch flow are unknown.

Although many questions remain concerning how to predict nitrate-N response at the watershed outlet and eventually reduce concentrations at the Georgetown Reservoir, educational efforts are under way to help encourage reduced applications of nitrogen fertilizer. The Champaign County Soil and Water Conservation District recently interviewed producers in the Champaign County portion of the LVR watershed to determine the extent to which University of Illinois fertilizer recommendations were being followed. Interview results were examined with LVR monitoring data for the period from May 1993 to December 1995. It was determined that the N applied in excess of the recommended amount (the quantity in excess of the economic optimum application rate) was close to N load measured in the drainage ditch at the outlet of the Champaign County LVR subwatershed.

Flow in the Little Vermillion River (which, for the most part is a man-made ditch) is considered as a combination of inputs from field subsurface drainage systems and from the sides and bottom of the channel itself. Overland flow contributions are assumed to be minimal.
Comparison of mean nitrate-N concentration observed in subsurface drainage below fields fertilized with differing rates of N and application methods, and continuous meadow.
Agricultural Drainage

Bulletin 871-98

Illinois

Highlights

- In the Embarras River watershed, nitrate-N in subsurface drainage waters and rivers has been closely linked to intensive agricultural production. Wetlands that intercept agricultural drainage are being evaluated as a method to reduce agrichemical inputs to rivers and reservoirs used as drinking water supplies, while maintaining agricultural production. Five wetlands were constructed 15 miles south of Urbana/Champaign along the Embarras River. Drainage water is diverted into the wetlands. Drainage water volume and agrichemical concentrations are measured entering and leaving the wetlands, with agrichemical removal rates then evaluated. Preliminary results indicate that most of the nitrate-N can be removed during spring and summer periods. Nitrogen removal is less during winter (too cold) and during extremely high flow events anytime of the year. The timing of precipitation events, soil and water temperatures, and the role of seepage from the wetlands must all be studied to determine overall wetland effectiveness over a multi-year period. In the future, the removal of nitrate-N, phosphorus and atrazine will be evaluated. In addition, detailed studies will be made of how the wetlands actually process chemicals in order to improve their design and function.

- In most areas where subsurface drainage is used, there are very few records of the actual locations of many drainage systems, especially those installed more than 75 years ago. The unavailability of accurate maps makes it difficult to locate nonfunctioning drains, or even to determine the position of functional systems in cases where additional drains are to be installed. Color infrared aerial photographs and geographic information system (GIS) analysis were used to map drains in Vermilion County, Illinois. The method appears to be a promising and cost effective tool as compared to conventional probe methods. The drain mapping procedure is based on the fact that
the soil over subsurface drains dries faster than the soil at other locations in the field and has higher reflectance in the infrared region of the radiation spectrum. Color infrared aerial photographs for the study area, taken several days after a major spring rain event, were converted to digital format. A GIS package was used to overlay soil data, hydrological parameters, topography, and vegetation cover. The combination of these map layers made it possible to identify the layout of functional subsurface drainage systems.

- A method for using subsurface drain outflow rates to estimate drain spacing for incomplete drainage systems was developed and applied to four fields in the Little Vermilion River watershed. An optimization routine was used to determine the drain spacing that minimizes the difference between observed and DRAINMOD-simulated drain outflows. Under the prevailing conditions of the watershed, DRAINMOD performance was relatively insensitive to surface storage, the depth of the impermeable layer from the ground surface, diameter of the drains, and the lateral hydraulic conductivities in all the soil layers of the soil profile, with the exception of the layer in which the drains were located. The drain spacing information was used to estimate nitrate-N loading per unit area based on an appropriate region of influence for the irregular drainage systems. The region of influence of a single drain in a random subsurface drainage system on Drummer/Flanagan soils of east-central Illinois, estimated with the optimization routine and a graphical method, is 300 ft.

- Subsurface drainage systems are important, if often overlooked modifiers of flood peaks and flood-water quality in rivers, ditches and streams. Most existing watershed-scale flood models do not include the effects of subsurface drainage systems, while subsurface drainage models tend to focus on single fields. Research is being conducted to develop improved models for simulating flood flows and nutrient transport in the flat, subsurface drained watersheds that are typical in central Illinois. These models will provide planners and policy makers with a better tool to be used in decision making in floodplain areas. The models can also be used in the development of flood mitigation schemes and to evaluate the effects of changes in land use and urbanization on flood peaks. In the long run, the models can also be used to improve predictions of flood-water quality.
The top illustration is an aerial photograph taken in the spring of 1985 in the Embarras River watershed. The photograph shows variations in soil moisture caused by subsurface drainage. The bottom illustration was generated by processing the photograph in a GIS. The result is a vector file of subsurface drain locations.
Agricultural Drainage

Bulletin 871-98

Illinois

Contacts For Further Information

UNIVERSITY OF ILLINOIS
AT URBANA CHAMPAIGN

Agricultural Engineering
332 AESB
1304 W Pennsylvania Avenue
Urbana, IL 61801
Fax: (217) 244.0323

Michael C. Hirschi, Associate Professor/
State Extension Water Quality Coordinator
Phone: (217) 333.9410
Internet: mch@sugar.age.uiuc.edu

J. Kent Mitchell, Professor
Phone: (217) 333.4913
Internet: jkm@sugar.age.uiuc.edu

Richard A. Cooke, Assistant Professor
Phone: (217) 333.0944
Internet: r-cooke@uiuc.edu
Sharyl E. Walker  
Postdoctoral Research Associate  
Phone: (217) 333.0945  
Internet: sew7924@sugar.age.uiuc.edu  

Natural Resources  
and Environmental Sciences  
Turner Hall, 1102 South Goodwin Avenue  
Urbana, IL 61801  
Fax: (217) 244.3219

Gregory McIsaac, Assistant Professor  
Phone: (217) 333.9411  
Internet: gmcisaac@uiuc.edu

F. William Simmons, Associate Professor  
Soil and Water Management  
Phone: (217) 333.4424  
Internet: fsimmons@staff.uiuc.edu

Mark B. David, Professor  
Phone: (217) 333.4308  
Internet: m-david@staff.uiuc.edu

Landscape Architecture  
101 Temple Hall, 611 E Loredo Taft Drive  
Champaign, IL 61820  
Fax: (217) 244.4568

David A. Kovacic, Associate Professor  
Phone: (217) 333.0176  
Internet: dkovacic@staff.uiuc.edu

SPRINGFIELD EXTENSION CENTER  
P.O. Box 8199  
Springfield, IL 62791  
Fax: (217) 782.8886

George F. Czapar, Extension Educator  
Phone: (217) 782.6515  
Internet: czaparg@idea.ag.uiuc.edu
Although the percentage of cropland drained in Minnesota is lower than other Midwestern states, the 1985 National Resource Inventory estimate for total cropland acres drained (6,370,000) is significant. The state boasts a rich history of drainage related hydrologic and water quality research and educational activities.

Key drainage and water quality research results are summarized in the following points: 1) the amount of growing season rainfall and the distribution of rainfall during the year greatly affects drainage volume, nitrate-N concentrations, and nitrate-N losses; 2) nitrate losses from the landscape are highly related to cropping system; 3) nitrate-N losses to subsurface drainage are greatly influenced by rate of nitrogen application and moderately influenced by time of nitrogen application; 4) the placement method of nitrogen and tillage have minimal effects on nitrate losses in drainage; and 5) best management practices (BMPs) used by farmers reduce nitrate losses to subsurface drainage. However, mineralization of high organic matter soils still contributes significantly to nitrate losses.

To address agricultural issues related to increased flooding in recent years, Extension specialists and researchers are providing research-based information on design criteria, economic feasibility and environmental impacts of agricultural drainage to producers, drainage contractors, landowners, soil and water resource planners, and others.

National Resource Inventory data from 1985 indicated that 20% of Minnesota's cropland had undergone surface or subsurface drainage improvements. Anecdotal evidence suggests that an even higher
percentage of cropland is actually drained.
Agricultural Drainage

Nitrogen Loading to Surface Waters

Agriculture has been identified frequently as a major contributor of nitrate-N to surface water. The transport of nitrate-N to surface waters can occur through subsurface drainage systems or base flow. The amount of drainage water leaving the landscape largely depends on climate and soil properties (i.e., rainfall, soil texture, soil infiltration rate).

Nitrogen is a naturally occurring element that is essential to plant growth and crop production. In a soil system nitrate-N is continually supplied through mineralization of soil organic matter. Other sources of N include fertilizers, animal manures, municipal sewage wastes, agricultural and industrial wastes, atmospheric deposition, and nitrogen fixation, all of which either occur as nitrate-N or have been converted to nitrate-N through mineralization and nitrification.

In Minnesota, research on the effects of agricultural drainage on water quality has centered on the following factors: climatic conditions, rate and time of nitrogen application, cropping systems, source of nitrogen, and tillage. These research efforts primarily focus on the transport and movement of nitrate-N to surface waters because it is highly soluble, and thus susceptible to movement through the drainage system.

Impact of Climate Conditions

Long-term research in Minnesota has demonstrated a strong relationship between precipitation and subsurface drainage volume. When wet years follow very dry years, a substantial amount of nitrate-N
from soils high in organic matter is susceptible to loss in subsurface drainage. For instance, flow-weighted nitrate-N concentrations in subsurface drainage were measured for four years (1973-1976) from continuous corn that received 18 lbs N/acre per year near Lamberton, MN. Mean annual concentrations were 13, 19, 19 and 0 mg/L during the four year period and no drainage occurred in 1976. In 1977, nitrate concentrations averaged 28 mg/L with slightly above average rainfall.

In a study at Waseca, four plots were fallowed (no crop grown and no N applied) from 1987 through 1993. The plots were tilled periodically to control weeds. Following three dry years, the 1990 nitrate-N concentrations in subsurface drainage water averaged 57 mg/L. Concentrations decreased in 1991, 1992, and 1993 to 38, 25, and 23 mg/L, respectively.

Based on data from these studies it appears that high concentrations of nitrate-N can easily be lost to subsurface drainage from high organic matter soils even if no N or very small amounts of N are applied, especially when dry weather limits crop production. These losses occur regardless of soil or nutrient management practices. Results like these suggest agricultural drainage may contribute to water resource quality problems downstream, especially from nitrate loadings that occur after flood events like those of 1990-1993 following the widespread drought in 1988 and 1989.

Additional research related to climate was undertaken to find out whether or not there is scientific evidence for long-term trends toward increased stream flow in the Minnesota River. The study involved an investigation of the impact of climatic variations on stream flow. Daily stream flow records from the U.S. Geological Survey for the Minnesota River at Mankato were analyzed from 1904-1994. Modelling results show the direct effect of climate change accounts for a significant increase in maximum monthly stream flow of 40 cfs annually since 1904. The climatic model explained about 70% of the yearly variation in the log of monthly maximum stream flow.

After compensating for the effects of climate, the remaining increase in stream flow was also significant. The most likely sources for the remaining stream flow increase include drainage of wetlands and installation of subsurface drainage, channelization of streams and loss of floodplains, changes in vegetation and cropping systems, expansion of urban areas, and climatic effects not accounted for by the climate model. These results offer strong scientific evidence for increases in maximum monthly stream
flow (and hence flooding) that are largely driven by an increasingly wetter climate. The effects of non-climatic influences (i.e., changing land use and drainage of wetlands) on increased stream flow is less important than climatic changes, but not negligible.

**Cropping and Tillage Systems**

Studies in Iowa and Minnesota have shown that cropping system type (crop type and rotation) has more impact on nitrate-N concentrations found in drainage water than differences in tillage system. At Lamberton, MN, a comparison was made of drainage water nitrate-N concentrations between row crop systems (continuous corn and a corn-soybean rotation) and perennial crops (alfalfa and a Conservation Reserve Program grass-alfalfa mix). When N was applied based on a soil nitrate-N test, nitrate-N concentrations beneath the row crops averaged between 14 and 40 mg/L. Nitrate-N concentrations beneath the perennial crops ranged from 0.3 to 4 mg/L. The smaller concentrations beneath perennial crops are due to a longer period of greater root activity where cycling of N is optimized. In addition, nitrate-N losses from the row crop fields were greater because of higher flow volumes from the plots. Nitrate-N losses from the row crops were 30 to 50 times higher than from the perennial crops.

An 11-year study of the effects of tillage at Waseca showed that a switch from conventional tillage to no tillage had a minimal impact on nitrate-N losses to subsurface drain flow. The results show that nitrate-N losses from no-tillage plots were slightly lower than from the conventional tillage plots, however slightly more water and thus more nitrate-N drained from the no-till plots making the difference in nitrate-N losses negligible.
crops like corn (top) than beneath perennial crops like alfalfa (bottom). In addition, row crop production results in higher nitrate-N runoff losses because of higher flow volumes leaving the field. Cropping systems that can maintain profitability while including a perennial crop are one possible method of limiting nitrate-N losses to surface waters.

Source of Nitrogen

Nitrogen losses to surface waters through drainage systems has been documented in a number of research studies including some conducted at Lamberton and Waseca. These studies primarily showed that N losses depend upon the N application rate and amount of precipitation. Time of application (see next page) and the type of crop grown have also been shown to influence nitrate-N loss to drainage systems. However, little information is available on N losses to drainage systems when different sources of N are applied.

At Waseca, a study was begun in 1994 to study the movement of N from two different sources through the soil and into drainage systems. The two N fertilizer methods included the application of liquid dairy manure and urea. Similar application rates were calculated for each source of N. The results show that N source had no effect on nitrate-N concentration in drainage water and nitrate-N content in the top five feet of the soil profile in the fall.
Rate and Timing of Nitrogen Application

Results of several studies in Minnesota reveal that fertilizer N management, particularly the rate and time of application, plays a large role in the loss of nitrate-N to surface waters. Nitrogen is often applied as a fertilizer for corn in the form of anhydrous ammonia. Fall application for corn soon after soybean harvest has been a desired time of application for many farmers. A problem with fall application is the length of time between application and the use of nitrogen by plant uptake the next summer. High discharge volumes in late winter and early spring can result in the loss of N to surface waters.

Producers apply N in the fall for several reasons: (1) more time is available after harvesting soybean, and prior to or during corn harvesting; (2) fall N application frees up time in the spring to enhance the timeliness of planting (crucial to yields); (3) the soil is usually in better condition to receive N in the fall, especially following soybean where primary tillage is not required; and (4) less soil compaction occurs in the fall, and surface compaction that does occur can be relieved by freezing and thawing over winter. However, there are agronomic, economic, and environmental advantages to spring application of N.

In a 3-year study beginning in 1976, nitrate-N concentrations in drainage waters, loss from drainage systems, and accumulation in soil profiles, were determined following annual application rates of 18, 100, 200, and 400 lbs N/acre to continuous corn. There was relatively little increased nitrate-N accumulation in the soil profile or loss from drainage systems at the recommended application rate of 100 lbs N/acre compared to the lower rate of treatment (18 lbs N/acre). The total loss of nitrate-N to drainage systems over the 3-year study is shown in the graph (at right). Nitrate-N losses occurred when available N exceeded plant requirements.
Total loss of nitrate-N to subsurface drainage water related to field application rates (3-year study period). The recommended rate based on soil testing was 100 lbs N/acre.

A study was begun in 1986 at Waseca to address the economic and environmental concerns of fall application of N compared to spring application. The study focused on the effects of application timing on nitrate-N losses to drainage systems, and on yield and N uptake by continuous corn. The 5-year annual loss of nitrate-N to drainage water and the annual average corn yield are shown in the chart below for three different rates of N application (0, 120, and 180 lbs/acre). Nitrogen was applied as ammonium sulfate near November 1 for fall application and May 1 for spring application. The results show that nitrate-N losses to subsurface drainage are greatly influenced by rate of N application and moderately influenced by time of N application.

<table>
<thead>
<tr>
<th>Nitrogen (lbs/ac)</th>
<th>Annual Loss of Nitrate-N in Drainage (lbs/ac)</th>
<th>5-Year Yield Average (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>120</td>
<td>Fall</td>
<td>27</td>
</tr>
<tr>
<td>120</td>
<td>Spring</td>
<td>29</td>
</tr>
<tr>
<td>180</td>
<td>Fall</td>
<td>34</td>
</tr>
<tr>
<td>180</td>
<td>Spring</td>
<td>26</td>
</tr>
</tbody>
</table>
A Technical Forum on the hydrologic impacts of drainage has been developed by the University of Minnesota and scientists within federal and state agencies, and universities. The goals of the Technical Forum include establishing a dialogue among scientists to enable a better understanding of the effects of drainage on the hydrology of watersheds. A particular concern in areas of the Midwest is the degree to which agricultural drainage contributes to flooding. Presentations suggested that:

- Precipitation is the factor responsible for most of the variation in large-river flows including flows associated with Minnesota's most extreme floods;

- The floods of 1993 and 1997 occurred in the context of a long-term increase in average annual precipitation which began in 1940;

- The impact of drainage is difficult to quantify, but it appears to be less important for extreme floods of major basins such as those that occurred in 1993 in the Minnesota River Valley, and in 1997 in the Red River Valley; and

- It is important to ensure that adequate drainage capacity exists before drainage system expansion. Some areas of Minnesota have experienced an overload on existing drainage outlets.
Future dialogues of the Technical Forum will be expanded to explore impacts of agricultural drainage on water quality.

- South-central Minnesota's landscape consists mainly of flat agricultural fields with numerous small depressions. These depressions typically consist of poorly-drained soils and require some type of modification to remove excess water. A widely used method is installation of a surface drainage inlet, usually a vertical pipe that connects the land surface to a subsurface drainage system allowing water to drain quickly out of the depression. The cumulative hydrologic and water quality impacts of these inlets are being evaluated with the hydrologic and sedimentologic model called DROPLETS (Drainage Response Of Pothole Landscapes and the Erosion and Transport of Sediment). In DROPLETS, complex watersheds are broken down into simpler, idealized landscapes. The response of these landscapes are simulated and then combined to simulate the overall response of the watershed.

- Herbicide loss in subsurface drainage from agricultural land is not well understood. Research was conducted to assess atrazine and alachlor losses in subsurface drainage during and after long-term use on Webster clay loam soil at Waseca under typical agricultural management conditions. Annual alachlor and atrazine use was initiated in 1974 and 1975, respectively. Alachlor use was continued through 1991 while atrazine use was terminated after the 1988 application. Subsurface drainage water was collected and analyzed for atrazine and alachlor beginning in October 1985. Alachlor was detected in only 2% of the samples from 1985 through 1991. Atrazine or a degradation product that analyzes as atrazine was detected in 97% of the samples from 1985 through 1990. There was little fluctuation in atrazine concentration during any year. Tillage systems had minimal impacts on atrazine concentrations in drainage waters. Low concentrations of atrazine may be detected in subsurface drainage water during and after long-term use, and may persist for several years after use is stopped. Concentrations of alachlor in drainage waters from these high organic matter, fine-textured soils appears to be minimal.

- Soil compaction by heavy agricultural equipment is a serious problem on wet agricultural soils. Although compaction caused during tillage and harvesting can sometimes be reduced by the natural processes of freezing-thawing and wetting-drying, compaction on many soils in Minnesota may be getting worse, and there is no evidence that these natural agents have a large-scale effect. Compaction research conducted by the USDA and University of Minnesota is providing new insight into how soil water content affects the potential for soil compaction. This research points to the benefits of subsurface drainage to reduce compaction, and furthermore the need to maintain existing drainage systems.

**Northern Cornbelt Sand Plain Management Systems Evaluation Area (MSEA)**

The goal of the Northern Cornbelt Sand Plain MSEA is to evaluate the impact of ridge-tillage and various combinations of chemical management on ground water beneath a corn-soybean cropping
system. Research and educational activities are headquartered in Minnesota and extend to three sand plain regions in North Dakota, South Dakota, and Wisconsin. The main research site in Minnesota is located about 55 miles northwest of the Twin Cities in Sherburne County near Princeton. The 160-acre site is situated on the Anoka Sand Plain, which covers an area of about 1,700 square miles in east-central Minnesota. The Anoka Sand Plain is characterized by extremely porous sandy soils, shallow depth to the water table (12 ft at the site), flat topography and low runoff.

Elevated concentrations of nitrate, chloride, and the triazine group of herbicides (i.e., atrazine) have been detected in the ground water of irrigated areas of the Anoka Sand Plain. Much of this ground water recharges into streams which eventually empty into the Mississippi River, a major source of drinking water for the Twin Cities metro area. Analysis of more than 2,600 water samples at Princeton, MN show that, with careful management, corn and soybean can be grown on sandy soils without exceeding EPA drinking water standards. Atrazine was detected only occasionally and concentrations were less than 1 micro-g/L (1 micro-g/L equals 1 ppb). The EPA drinking water standard is 3 micro-g/L. Nitrate-N concentrations ranged between 10 and 20 mg/L, which were only slightly higher than background concentrations.

Educational opportunities have increased in recent years with producers interested in improving existing drained fields, and others concerned about increased flooding in major river valleys. Extension specialists and researchers from the University of Minnesota have responded through increased educational programs at county cluster meetings, station field days, and a newly initiated annual farmland drainage design workshop.
Agricultural Drainage

Bulletin 871-98

Minnesota

Contacts For Further Information

UNIVERSITY OF MINNESOTA
Southern Experiment Station
35838 120th Street
Waseca, MN 56093-4521
Fax: (507) 835.3622

Gyles W. Randall, Soil Scientist and Professor
Phone: (507) 835.3620
Internet: grandall@soils.umn.edu

West Central Experiment Station
P.O. Box 471
Morris, MN 56267
Fax: (320) 589.4870

Jerry Wright, Associate Professor and Extension Engineer
Phone: (320) 589.1711
Internet: wrightja@caa.mrs.umn.edu

Biosystems and Agricultural Engineering
Agricultural Drainage, Bulletin 871-98 Minnesota: Contacts For Further Information

1390 Eckles Avenue
St. Paul, MN 55108-6005

Bruce N. Wilson, Associate Professor
Phone: (612) 625.6770
Fax: (612) 624.3005
Internet: wilson@gaia.bae.umn.edu

Soil, Water and Climate
1991 Upper Buford Circle
St. Paul, MN 55108-6028
Fax: (612) 625.2208

Jim L. Anderson, Professor
Phone: (612) 625.8209
Internet: janderson@mes.umn.edu

David J. Mulla, Professor
Phone: (612) 625.6721
Internet: dmulla@soils.umn.edu

USDA - AGRICULTURAL RESEARCH SERVICE
Soil and Water Management Research Unit
1991 Upper Buford Circle
St. Paul, MN 55108

R. R. Allmaras, Soil Scientist
Phone: (612) 625.1742
Internet: allmaras@soils.umn.edu

R. H. Dowdy, Soil Scientist
Phone: (612) 625.7058
Internet: bdowdy@soils.umn.edu

Back | Forward | Table of Contents
Michigan agricultural producers have many years of experience controlling subsurface drainage to enhance crop production. Much of the highly productive cropland in Michigan has a naturally occurring shallow water table and relatively flat topography. To be productive those soils were artificially drained many years ago. The drain pipes, located approximately three feet below the ground surface, often required a drainage pump to raise the discharge waters to an elevation that would allow the drainage water to be discharged. A few innovative farmers began turning their drainage pumps off after field work was completed in the spring and leaving them off during much of the growing season. They noticed increased crop yields along with savings on their electric bill. A few farmers began experimenting with using their pumps to add water to the subsurface drainage systems during the growing season when a lack of rainfall would normally reduce yields. During dry years, this practice seemed to further increase crop yield.

In the early 1980s, Michigan producers began asking Michigan State University agricultural engineering extension specialists questions about the practice of using subsurface drainage systems for both drainage and irrigation. A multi-disciplinary team of engineers, soil scientists, agronomists, crop modelers, economists, farmers and drainage contractors was assembled and began planning applied research projects that would provide answers to the practical questions being asked by Michigan farmers and others.

The research that resulted was designed to address questions such as:
● does subirrigation work; and what are the conditions for successful subirrigation;

● how should systems that are used for both drainage and irrigation be designed, installed and operated;

● what are the costs and benefits associated with subirrigation; and

● how does subirrigation effect the edge of field surface and subsurface water quality?
Research and field demonstration projects have been coordinated by Michigan State University at several sites located in the south central area of the lower peninsula of Michigan. A first project was installed in 1984 at the East Lansing Campus site to compare subirrigated yield to overhead irrigated yield. The effect of water table depth on plant physiology and nitrate-N and atrazine transport and distribution was also studied.

Field demonstrations to examine the effects of drain pipe spacing on water table management system performance began in 1985 at Bannister on a poorly drained, fairly heavy clay loam, and in 1986 at St. Johns on a sandier and poorly drained soil series. In 1987, the Bannister site system was modified to allow for study of effects of subirrigation on nutrient and pesticide concentrations and loading in discharge water and the soil profile.
A view of the Subirrigation Rainshelter Project showing one of the automated, mobile buildings used to prevent and simulate rainfall on twelve research plots growing a variety of vegetables.

In 1989, a research study was initiated near Unionville to comprehensively compare water table management by subirrigation to both conventional subsurface drainage and to the same soil without subsurface drains.

**Water Quality Results**

At Bannister:

- For 20 months of monitoring beginning in 1987, the total nitrate-N delivered from the field to the outlet ditch by the subsurface drainage system was reduced 64% by subirrigating (see graph).

- For the same period subirrigation had little effect on the dissolved orthophosphate-phosphorus delivered by the drainage system.
At Unionville:

- For the 1990 and 1991 growing seasons (12 months of monitoring), water table management by subirrigation reduced nitrate-N leaving the field by 58% and dissolved orthophosphate-phosphorus by 16% compared to conventional subsurface drainage (see graph at right).

- For the months of May through October, subirrigation reduced the average drainage flow nitrate-N concentration from 41 mg/L to 12 mg/L in 1990 and 18 mg/L to 10 mg/L in 1991.

- The average orthophosphate-phosphorus concentration in subsurface drainage flow was nearly equal for both growing seasons.

- The total drainage volume, surface and subsurface, was 17% greater for subirrigation than for conventional subsurface drainage. However, subirrigation increased the volume of surface drainage by only 7%.

**Yield and Economics Results**

Side by side comparison of subirrigated to conventional subsurface drained crop yields have been made at all of the above research sites plus other Michigan locations.

- The average of 24 measurements for subirrigated corn was 173 bu/acre. Eight subirrigated soybean yield measurements averaged 53 bu/acre and five subirrigated sugar beet measurements averaged 25 t/acre.

- Comparison yields measured from adjacent subsurface drained fields without subirrigation averaged 138 bu/acre for 16 corn yield measurements, 37 bu/acre for two soybean yield measurements and 22 t/acre for five sugar beet yield measurements.

- The yield results suggest that for field crops, at present market value, subirrigation provides a positive return on investment until the capital cost of subirrigation improvement exceeds about $600/acre more than the cost of a conventional subsurface drainage system.

- The cost of water table management by subirrigation is less than other irrigation methods both in terms of capital cost and operation cost for cropland that requires subsurface drainage.

**In General**

For a substantial percentage of Michigan cropland, water table management by subirrigation is feasible and often provides both water quality and economic benefit. Fields that are suitable have:
● I poorly drained soils with slopes that are flat or gently sloping;

● I an irrigation water source that will provide, for the entire growing season, good quality water at a rate that will meet the evapotranspiration needs of the crop plus water that may be lost by seepage;

● I an energy source for pumping irrigation water; and

● I a conservation plan that addresses potential conservation problems.

Water Table Management System Operation

The field studies, coupled with information from farmers with water table management experience, has confirmed that water table management systems must be properly operated to achieve the benefits possible. Water table management systems that are not properly operated result in wasted water, increased discharge of nutrients and pesticides, wasted consumed energy, and reduced yields.

The average yields for plots that are subirrigated (SI) compared to the average yield of plots that are subsurface drained without subirrigation (DO).
Water table management studies, beginning with the Campus site and continuing through research at Unionville, show conclusively that water table management by controlled drainage and subirrigation is a viable method of supplementing natural rainfall to reduce the cost of agricultural production. Just as importantly, the Bannister and Unionville research suggested controlled drainage and subirrigation also reduces the loss of fertilizer nitrogen from the field without increasing the potential for runoff and erosion. However, it became clear that to fully understand these processes and use that knowledge to develop comprehensive water table management system guidelines, a study that allowed for intense, replicated, multi-disciplinary data collection with greater control of climatic variables was needed.

That project was initiated in 1991 on a privately owned field near Saginaw, Michigan. The Michigan Agricultural Experiment Station/USDA Subirrigation Rainshelter Project consists of 32 research plots, each 15 ft by 20 ft, and 3 field scale plots, each 10 acres in size. Rainfall on 24 of the small plots is controlled by two light-weight movable rainshelter buildings. Rainfall control allows the researchers to study dry, normal, and wet season conditions in a single growing season thus accelerating the learning process and transfer of knowledge to agricultural producers. Growing roots are observed and videotaped beneath 16 of the small plots via a reinforced concrete underground access structure adjacent to the sheltered plots. Water tables in each plot can be managed independently and all plots are instrumented to automatically measure depth to water table and subsurface drain flow and to collect water samples.

The project supports research by a multidisciplinary team of Michigan State University scientists from the Departments of Agricultural Engineering, Crop and Soil Sciences, Horticulture and Agricultural Economics. The research is conducted in close cooperation with the USDA Natural Resource
Conservation Service, Cooperative Extension Service and Agricultural Research Service, the Michigan Chapter of the Land Improvement Contractors of America, the Michigan Departments of Agriculture and Environmental Quality and the Michigan Association of Conservation Districts, all of whom participated in the original planning for the project. The soil series at the site is Tappan (fine-loamy, mixed, calcareous, mesic-typic Haplaquolls), one of the most extensive and agriculturally productive soils in the "thumb" of Michigan. Tappan is very suitable for water table management.

Research objectives of the project are to: (1) evaluate the short and long term effect of water table management by subirrigation on the transport of agricultural chemicals, soil properties, surface and subsurface water and sediment movement, biological dynamics of the root zone soil system, economics of production of field crops and vegetables, and above and below ground plant development; (2) develop nutrient, pesticide, tillage, residue and water table management guidelines through field research and simulation modeling; and (3) share the research results with agricultural producers and their advisors.
Today, we can answer many questions farmers have about using their drain pipes to irrigate. But we are a long way from having the knowledge to take full advantage of this important practice. The research effort at Michigan State University is moving from the macro-view toward a more intense and detailed micro-view. Researchers are searching for answers to the basic water table management questions that address soil quality, crop ecology and agricultural sustainability. For example, can the water table be managed to enhance the physical infrastructure resulting from reduced tillage systems; can the water table be managed to improve the habitat for beneficial farm biota; can water table management contribute to managing pests and diseases with minimal environmental impact; can water table management be used to enhance the energy flow in agricultural ecosystems? In other words, can the water table be managed to contribute to holistic farming systems that are sustainable without economic penalty. If so, the importance of water table management to agriculture will continue to grow and broaden.
Agricultural Drainage

Bulletin 871-98

Michigan

Contacts For Further Information

MICHIGAN STATE UNIVERSITY
Agricultural Engineering
Farrall Hall
East Lansing, MI 48824-1323
Fax: (517) 432.2892

Harold W. Belcher,
Visiting Associate Professor
Phone: (517) 353.5270
Internet: belcher@egr.msu.edu

George E. Merva, Professor Emeritus
Phone: (517) 353.0884
Internet: merva@egr.msu.edu

Theodore E. Loudon, Professor
Phone: (517) 353.3741
Internet: loudon@egr.msu.edu

Institute of Water Research
115 Manly Miles Building
East Lansing, MI 48824

**Frank D'Itri, Professor**  
**Associate Director**  
Phone: (517) 353.3744  
Email: ditri@pilot.msu.edu

**Agricultural Experiment Station**  
109 Agricultural Hall  
East Lansing, MI 48824

**J. Ian Gray, Director**  
Phone: (517) 355.0123  
Email: grayians@pilot.msu.edu

**MICHIGAN LAND IMPROVEMENT CONTRACTORS OF AMERICA**  
4372 S. Wright Road  
Fowler, MI 48835

**Mike Cook, Executive Secretary**  
Phone: (517) 355.0123

**MICHIGAN DEPARTMENT OF AGRICULTURE**  
Environmental Stewardship Division  
P.O. Box 30017  
Lansing, MI 48909

**Michael R. Gregg, Manager**  
**Resource Conservation and Pollution Prevention Section**  
Phone: (517) 373.9802  
Email: greggm@state.mi.us

**USDA-NATURAL RESOURCES CONSERVATION SERVICE**  
1405 South Harrison Road  
East Lansing, MI 48823-5243

**Steven S. Davis, State Conservation Engineer**  
Phone: (517) 337.6701 Ext. 1221
Reducing Agrichemical Loss to Drainage Systems

Long-term research projects in Iowa have examined a number of factors related to the transport of sediment and agricultural chemicals to surface and ground water resources. Studies conducted in Iowa have shown a similar relationship between agricultural drainage and water quality found in other areas of the Midwest. A combination of water soluble agricultural chemicals and large amounts of water moving from the soil volume into the drainage system can have significant water quality impacts.
In a five-year monitoring study (1976-1980) in east-central Iowa, measurements of nutrients and herbicide concentrations and losses were made in runoff and drainage water from cropland and in a stream draining an agricultural watershed. Herbicide concentration and losses (alachlor, metribuzin, propachlor, cyanazine, and atrazine) were greatest after spring application with in-stream concentrations reaching about 100 micro-g/L for individual herbicides in individual samples during peak runoff. This concentration exceeds or matches the drinking water standards for these chemicals. With the exception of atrazine, herbicide concentrations between peak runoff events, and over the winter were generally below detection (0.1 micro-g/L). During those periods, atrazine concentrations often ranged between 0.1 and 2.0 micro-g/L. The drinking water standard for atrazine is 3.0 micro-g/L. Annual losses of herbicide applied in the watershed were less than or equal to 2%. In-stream nitrate-N concentrations averaged about 9 mg/L, but exceeded the 10 mg/L drinking water standard much of the time when stream flow was dominated by leaching water in the form of base flow and artificial subsurface drainage (for which nitrate-N averaged 12 mg/L).

To reduce agricultural chemical loss to water resources, research has focused on chemical movement through the root zone into subsurface drainage systems. One particular area of interest has been preferential flow paths. If the surface soil becomes saturated, as it does when runoff begins, some water may move through preferential flow paths, or macropores, and leach deeper or more quickly than would be expected if the water had to flow through the soil matrix. Rainfall simulations and analysis of preferential and matrix flow conducted in Iowa showed that preferential flow facilitated the movement of a water soluble tracer (potassium bromide) and nitrate-N. However, if a chemical adheres well to soil, macro-pores can be beneficial, or used to advantage, because they cause water to bypass the soil volume where the chemical resides.

Research in Iowa has also focused on the use of agricultural drainage wells as outlets for subsurface
Agricultural Drainage, Bulletin 871-98 Iowa: Reducing Agrichemical Loss to Drainage Systems

drainage systems. In north-central Iowa, many closed depressional areas, or "potholes" are drained with surface outlets to subsurface drainage systems. However, these surface intakes may allow concentrated contaminants in pothole drainage water to enter a shallow aquifer. A main concern is elevated levels of nitrate-N found in drinking water wells. Proposed solutions to the problem include improved N management and the elimination of surface flow to agricultural drainage wells.

The Walnut Creek watershed is typical of relatively young geologic development characterized by low relief and depressional areas called potholes. This watershed is the site of a long-term study to evaluate the impact of farming practices on water quality at the watershed scale. The objectives of the study are to: (1) evaluate the loadings of nitrate-N, atrazine, and metolachlor from subsurface drained fields, subwatersheds, and the entire Walnut Creek watershed; and (2) to evaluate the temporal patterns of drainage relative to precipitation and crop water use patterns. Farming practices in Walnut Creek are typical of the Midwest region in terms of loadings onto the soil surface, and agricultural chemical movement through subsurface drains.

Surface water samples are collected weekly throughout the year as part of the Walnut Creek Watershed Project. Monitoring efforts were designed to evaluate the effect of individual field practices, aggregated effects over subwater-sheds, and agrichemical loadings from the entire watershed on surface water quality.

Results from 1992-1995 indicate stream discharge closely mimics subsurface drainage flow patterns. Surface runoff events contribute less than 1 percent of the total discharge from Walnut Creek. This evaluation shows that subsurface drainage is the primary flow path for soluble agricultural chemicals from Walnut Creek. Relative to stream discharge, cumulative loads for nitrate-N reflect the same pattern at the three scales measured: field, subwatershed, and watershed scale (see figure). The highest nitrate-N concentrations observed were at the smaller scales; however, the relative changes among the three locations were not different. Nitrate-N concentrations in drainage water vary slightly from field to subwatershed to watershed scales. The magnitude of the loads is dependent upon the discharge volumes.

Results show nitrate-N concentrations are largest in the spring when evaporation rates are low and the
greatest discharge rates occur. In watersheds that have artificial subsurface drainage, reducing nutrient loads requires more than soil testing as a Best Management Practice. Reducing loads also requires innovative methods of drainage water management, possibly altering the seasonal pattern of drainage discharges and associated nitrate-N, or reducing chemical concentrations at subsurface drains.

Cumulative distributions of nitrate-N loads from the field (22 ac) and subwatershed (904 ac) scales, and the entire Walnut Creek watershed (12,676 ac) for the period from 1992 through 1995 (1 kg equals 2.2 lbs).
Agricultural Drainage

Bulletin 871-98

Iowa

Highlights

Research suggests that wetlands may act as sinks for a variety of agriculturally important chemicals, and there is considerable interest in the potential of wetlands for reducing pollution loads in agricultural drainage water. A model of wetland nitrate-N consumption was combined with estimates of watershed nitrate-N loads to determine the potential for integrating constructed or restored wetlands as part of agricultural drainage systems. The model predicted that a 2.5 acre wetland would remove approximately 60% of the annual nitrate-N load draining from 250 acres of corn. Although wetland inlet concentrations averaged around 18 mg/L nitrate-N, outlet concentrations fell below the drinking water standard of 10 mg/L nitrate-N. The model was also used to predict changes in nitrate-N removal by wetlands with relatively low vegetation densities, representing the first year or two after construction, and higher vegetation densities, representing more mature systems several years after wetland construction. Over a three-year period, the wetland's capacity for nitrate-N removal increased approximately four fold.

Tillage is one management factor that can potentially affect agricultural chemical concentrations and losses by affecting erosion rates and hydrology, as well as the need for and method of chemical application. Studies conducted at Iowa State University's Northeast Research Center in Nashua have shown that tillage practice has little influence on nitrate-N and pesticide losses to the subsurface drainage water in a corn-soybean rotation. However, ridge-till and no-till resulted in larger losses of atrazine than the moldboard plow and chisel-based systems under continuous corn. Simulations of nitrate-N concentrations and losses made with a modified Root Zone Water Quality Model (RZWQM) for the growing season of three years (1990-1992) generally followed the same pattern as the observed data.

Practices that increase infiltration tend to improve water quality, particularly for runoff. However,
increased infiltration can increase chemical leaching. A new fertilizer applicator was designed and tested at Iowa State University for its ability to protect fertilizer from infiltrating water and thus reduce the potential for leaching. The device uses a localized soil surface compaction and doming method directly above the fertilizer band. Nitrate-N applied with the applicator moved approximately 60% as deep as nitrate-N applied by a conventional knife. The method appears to present a simple yet effective strategy to reduce nitrate-N leaching losses and possible impact on drainage and ground-water quality.

Research at farms in Ames and Ankeny examined the effects of water table depth on crop yield and shallow ground-water quality. These studies help in optimizing drainage and irrigation requirements. The results show that corn and soybean yields increased significantly when shallow water table depths were maintained. In one field experiment, average soybean yield obtained for a 0.5 ft water table depth was 42% lower than for a 2.0 ft depth. In another experiment where water table depth was lowered from 0.7 to 3.6 ft, the largest corn yields were obtained at the 3.6 ft depth and the smallest at the 0.7 ft depth. However, the average concentrations of water soluble agricultural chemicals increase with lower water table depths. Results show that significant reductions in nitrate-N, metolachlor, atrazine and alachlor concentrations can be achieved by maintaining shallow water table depths. Nitrate-N and metolachlor concentrations in drainage outflow were 54 and 45% lower for a 0.5 ft water table than for a 2.0 ft depth. A depth of 1 ft was found most suitable for ground-water quality control. Based on these results, researchers at Iowa State University have recommended a water table depth between 2.0 and 3.0 ft as a Best Water Table Management Practice for crop productivity and ground-water quality control.

Nitrogen applied to fields before crop establishment is susceptible to losses by many mechanisms (i.e., denitrification, leaching, runoff, volatilization and immobilization) in the time interval between application and crop uptake. Research results show lower concentrations of nitrate-N in drainage water for reduced-rate split application treatments (an initial treatment at planting followed by applications later in the growing season).

**Iowa Management Systems Evaluation Area**

The Iowa Management Systems Evaluation Area (MSEA) is one of five research programs comprising the President's Initiative. In 1989, the President's Initiative on Enhancing Water Quality was formed to address rising concern over contaminated ground water. MSEAs were also selected in Minnesota, Missouri, Nebraska, and Ohio. As part of this cooperative program, the Iowa project has been quantifying the levels and movement of nitrate and pesticides in soils according to soils, climate, crops, and varying management practices. Research teams are assessing the impact of Iowa's current farming systems on water quality as well as developing and evaluating new farming systems. The implications of this assessment are leading to socioeconomic adaptations of farming systems which are sensitive to the environment. These solutions are arrived at through: (1) extensive monitoring of surface and ground water; (2) comparison of farming systems impacts on water quality; and (3) evaluation of new and improved farming systems for their environmental and economic impact. The Iowa MSEA project involves three primary agencies--USDA-ARS, Iowa State University, and USGS working at four research sites in three different hydrogeologic settings: thin till over bedrock, thick till, and thick loess.
Walnut Creek Nitrogen Initiative

The Walnut Creek Nitrogen Initiative addresses one of the most prevalent environmental issues of the Midwest: nitrate-N contamination of surface waters. The investigation has evolved from an on-going USDA-ARS National Soil Tilth Laboratory water quality assessment study of an extensively subsurface drained agricultural watershed, Walnut Creek, located near Ames, IA. The goal of the project is to determine the potential of a conservation-based N fertilizer program to serve as a management tool for corn production. Endpoints are reduced nitrate-N contamination in surface water and maintenance of economic viability when compared to conventional farming practices at the watershed scale. Project objectives are to: (1) quantify the change in stream flow nitrate-N content as a result of implementing the conservation-based N fertilizer program; (2) develop a N balance for the conservation-based N management system; and (3) determine the economics and farmer-cooperator perspectives of the conservation-based N management system.

Composite samples are analyzed for nitrate content and side-dressed nitrogen fertilizer rates are determined: (a) Sidedressing of nitrogen fertilizer for corn during late spring; (b) Soil samples are 6-12 inches tall from ground level to center of the whorl.
Agricultural Drainage

Bulletin 871-98

Iowa

Contacts For Further Information

IOWA STATE UNIVERSITY
Agricultural and Biosystems Engineering
Davidson Hall
Ames, IA 50011-3120
Fax: (515) 294.2552

James L. Baker, Professor
Phone: (515) 294.4025
Internet: jlbaker@iastate.edu

Rameshwar S. Kanwar, Professor
Phone: (515) 294.4913
Internet: rskanwar@iastate.edu

Botany
Bessey Hall
Ames, IA 50011
Fax: (515) 294.1337

William G. Crumpton, Professor
Phone: (515) 294.4752
Subsurface drainage research in the North Central Region has produced findings that will further agriculture’s quest to meet the national and global demand for abundant, affordable food, as well as clean water and a healthy environment. An increased understanding of the interactions between drainage systems and soil, hydrologic and ecological systems is contributing to the development of modern drainage system technologies.

Research results in the North Central Region clearly show that drainage improves yields for crops grown on poorly drained soils. Average yield increases for long-term studies conducted in Indiana and Ohio report annual increases in corn yields of 14 to 23 bu/acre, and 20 to 30 bu/acre, respectively, for crops grown with subsurface drainage versus without. Even larger increases in yield were obtained where subsurface drainage system function included the capability for water table management. Michigan results show corn yield increased 9% in an above average rainfall growth season, and 58% in a below average rainfall growing season. Soybean and corn yields in Ohio were on average 43% and 30% greater, respectively, for subirrigation/drainage systems compared to conventional subsurface drainage alone.

In addition, research in Ohio and Minnesota shows that subsurface drainage promotes mellower soil conditions and reduces compaction potential. Where soil infiltration is promoted by practices such as subsurface drainage and conservation tillage, significant reductions have been found in total and dissolved phosphorus and sediment concentrations of surface waters. At an Ohio site evaluated over a 14-year period, subsurface drainage reduced the losses of sediment, phosphorus and potash by 40, 50 and 30%, respectively, compared to surface drained cropland.

Improved agricultural stewardship of land and water resources has led to reductions in phosphorus and sediment loadings from agricultural land, however nitrate-N losses to surface waters have continued and
are increasing in some areas, for reasons that are not completely understood. Elevated concentrations of nitrate-N have long been considered a source of drinking water pollution. Recently, N fertilizer has received attention for its contribution to hypoxia in the Gulf of Mexico. Hypoxia is a condition of low dissolved oxygen occurring in vital Gulf of Mexico fisheries. Oxygen depletion occurs when nutrients exported from upstream Mississippi Basin watersheds cause increased algal growth in the nutrient-limited marine ecosystem. The decomposition of dead algal matter by oxygen-using organisms results in depleted oxygen levels that kill animals in the sediment and force shrimp and fish out of preferred habitats.

Although the relative loading of nitrate-N to surface waters from different sources and the mechanisms by which nitrate-N loss occurs remains a matter of debate requiring more scientific research, agricultural production in the North Central Region is probably a key contributor. Certainly, subsurface drainage acts as a conduit for the movement of nitrate-N to surface waters. Research in Illinois showed that nitrate-N concentrations in drainage water from fertilized crop fields was 10 times greater than concentrations measured in drainage from a meadow.

In addition, there is a great potential for nitrate-N loss when available N exceeds plant requirement. Minnesota results reveal that interactions between N management and weather patterns play an important role in loss of nitrate-N to surface water. Nitrate-N losses occur when large rainfall and flow events flush nitrate-N that has yet to be used by plants. In Iowa and Illinois, stream flow and instream N loading have been linked to subsurface drainage flow patterns, indicating nitrate-N loss is highly related to climate and hydrology. Long-term research in Minnesota has demonstrated a strong relationship between precipitation, subsurface drainage volume, and nitrate-N losses. Indiana findings show that nitrate-N is present in drainage water at all times that drainage occurs. Since most drainage flow occurs during the off-season when crops are not growing (November-May), most of the nitrate-N losses occur then. This contrasts with the timing of pesticide loss which typically occurs immediately after application.

These findings indicate innovative methods of drainage water management, possibly altering the seasonal pattern of drainage discharges or eliminating discharge and thus associated nitrate-N, are required in addition to N application management strategies.

Fortunately, innovative water table management technologies are being developed, tested, and increasingly used. These technologies are developed at universities and MSEA sites throughout the region and communicated to producers through educational programs. Research in Ohio and Michigan found that water table management leads to improved ground water and drainage water quality. At several sites in Michigan, subirrigation reduced nitrate-N delivered through subsurface drainage to surface water by 64 and 58%. Research in Iowa and other sites shows corn and soybean yields increase, and nitrate-N concentrations decrease in drainage outflow when shallow water table depths are maintained. Cropland with controlled drainage may provide reduction in nitrate-N losses by raising the water table during the off-season.

Systems that link subsurface drainage with wetlands serve to further reduce soluble pollutant loadings to surface water. Wetlands that intercept agricultural drainage are being evaluated in Illinois as a method to
reduce agrichemical inputs to rivers and reservoirs used as drinking water supplies while maintaining agricultural production. Preliminary results indicate that most of the nitrate-N can be removed by wetlands during spring and summer periods. A great potential exists to reduce pollutant losses and increase agricultural production using Wetland Reservoir Subirrigation Systems. These systems that recycle drainage are being tested and demonstrated at sites in Ohio. The system supplies water to crops, eliminating drought stress; uses the wetland system to reduce sediment and plant nutrients in drainage water; and increases wetland acres, vegetation, and wildlife habitat.

In summary, significant progress has been made through research and educational efforts toward the goals of increasing and maintaining agricultural production in the North Central Region and reducing nonpoint source pollution. Problems remain, but vital and active research and educational programs have already contributed greatly to mitigation of water quality impacts and will continue to balance key food production, economic, and environmental objectives.
Agricultural Drainage

Bulletin 871-98

Drainage and Water Quality Research Needs

- Evaluate ways to minimize preferential flow of soil-applied pesticides during the first several rainstorms after application.

- Evaluate winter cover crops for ease of establishment and ability to trap significant amounts of N during the off-season, thereby decreasing drainage N losses.

- Investigate the full scope of water table management strategies to reduce sediment, nitrate, and pesticide losses to surface waters.

- Investigate riparian system dynamics, determine riparian area degradation, and develop models that incorporate these functions related to drainage management.

- Investigate the full range of application for agricultural stormwater retention/detention basins, and constructed wetlands, to reduce the nutrient content of runoff and drainage before it moves off-site.

- Investigate and model on a watershed scale the seasonal management of water levels in drainage outlets and networks for controlled release. Evaluate the hydrologic, water quality and quantity, environmental, food production, legal, and socioeconomic aspects of such watershed-scale management.
Agricultural Drainage

Bulletin 871-98

Minimizing Nitrate-N Loss

Research has demonstrated a strong linkage between subsurface drainage and nitrate-N losses to surface waters. An obvious, but least economical method to reduce nitrate-N losses is to abandon subsurface drainage systems. The practicality of this method is minimal, however, as crop production would be reduced substantially on millions of acres of productive poorly-drained soils in the Midwest. In addition, sediment and phosphorus concentrations in surface waters would increase. Research conducted in the North Central Region suggests the following strategies would minimize nitrate-N loss to surface waters:

1. Implement wetland restoration areas, denitrifying ponds or managed riparian zones where drainage water could be "treated" to remove excess nitrate-N before discharge into drainage ditches or streams. This may be a cost-effective alternative in portions of the Midwest.

2. Design new subsurface drainage systems or retrofit existing drainage systems to manage soil water and water table levels through controlled drainage or subirrigation, lowering concentrations of nitrate-N in shallow ground water. The cost of retrofitting existing systems for subirrigation can be compared to the benefit of increased yields.

3. The use of alternative cropping systems that contain perennial crops would also likely reduce nitrate-N losses. However, obtaining a market and a satisfactory economic return presents some barriers.

4. The development of improved soil N testing methods to determine the availability of mineralizable N and carryover N from the previous crop would be effective, especially following dry years, legumes, or past manure applications.
5. Fine-tune fertilizer N management. Research shows that applying the correct rate of N at the optimum time would have a substantial effect on reducing nitrate-N losses.

6. Improved management of animal manures would contribute to lower nitrate-N losses in livestock producing areas. Knowing the nutrient content and application rate of the manure, spreading it uniformly, and incorporating it in a timely manner would all lead to better management and confidence in manure N as a nutrient source.
Agricultural Drainage

Water Quality Impacts and Subsurface Drainage Studies in the Midwest

Bulletin 871-98

Editors

Leslie A. Zucker
Extension Associate
Food, Agricultural and Biological Engineering Department
Ohio State University Extension

Larry C. Brown
Associate Professor
Extension Agricultural Engineer
Food, Agricultural and Biological Engineering Department
The Ohio State University

This publication was produced through the Department of Food, Agricultural, and Biological Engineering at The Ohio State University, in cooperation with the USDA-Agricultural Research Service (ARS), Soil Drainage Research Unit, Columbus, Ohio, and various USDA agencies and land grant universities in the North Central Region, including the Midwest Water Quality Initiative’s Management Systems Evaluation Area (MSEA) projects in Iowa, Minnesota, Missouri, Nebraska, and Ohio. Support for this publication was provided by these cooperating agencies and programs, and Ohio State University Extension, Ohio Agricultural Research and Development Center, Overholt Drainage Education and Research Program; and the Ohio MSEA project (USDA CSREES Grant No. 94-EWQI-1-9057).
Contents

- Management Systems Evaluation Areas
- Drainage, Agriculture and the Environment
- Status and Importance of Drainage
- Beneficial and Adverse Water Quality Impacts of Drainage
  - Water Table Management
- Ohio: Research, Engineering, and Science-Based Education
  - Agricultural Drainage Field Studies
  - Highlights
  - Wetland Reservoir Subirrigation Systems
  - Field Demonstrations
  - Subirrigation and Ground-Water Quality
  - Contacts For Further Information
● Indiana: **Drainage and Yield Studies**
  - **Drainage and Chemical Transport**
  - **Highlights**
  - **Contacts For Further Information**

● Illinois: **Drainage Research and Transport of Agrichemicals**
  - **Agricultural Drainage Watershed Studies**
  - **Highlights**
  - **Contacts For Further Information**

● Minnesota: **Hydrologic and Water Quality Impacts of Agricultural Drainage**
  - **Nitrogen Loading to Surface Waters**
  - **Rate and Timing of Nitrogen Application**
  - **Highlights**
  - **Contacts For Further Information**

● Michigan: **Water Table Management to Enhance Water Quality**
and Farm Profit

- Research and Demonstration
- Current Research - Subirrigation Rainshelter Project
- Looking Ahead
- Contacts For Further Information

- Iowa: Reducing Agrichemical Loss to Drainage Systems
  - Highlights
  - Contacts For Further Information

- Summary of Research Findings

- Drainage and Water Quality Research Needs

- Minimizing Nitrate-N Loss

All educational programs conducted by Ohio State University Extension are available to clientele on a nondiscriminatory basis without regard to race, color, creed, religion, sexual orientation, national origin, gender, age, disability or Vietnam-era veteran status.

Keith L. Smith, Associate Vice President for Ag. Adm. and Director, OSU Extension.

TDD No. 800-589-8292 (Ohio only) or 614-292-1868