Drainage Water Management
for the Midwest

Questions and Answers About Drainage Water Management for the Midwest

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Introduction

Subsurface tile drainage is an essential water management practice on many highly productive fields in the Midwest. However, nitrate carried in drainage water can lead to local water quality problems and contribute to hypoxia in the Gulf of Mexico, so strategies are needed to reduce the nitrate loads while maintaining adequate drainage for crop production. Practices that can reduce nitrate loads on tile-drained soils include growing winter forage or cover crops, fine-tuning fertilizer application rates and timing, bioreactors, treatment wetlands, and modifying drainage system design and operation. Drainage water management is one of these practices and is described in this fact sheet. Answers given here apply specifically to Midwest corn and soybean cropping systems, and not to perennial or winter annual crops.

1. What is drainage water management?

Drainage water management is the practice of using a water control structure in a main, submain, or lateral drain to vary the depth of the drainage outlet. The water table must rise above the outlet depth for drainage to occur, as illustrated at right. The outlet depth, as determined by the control structure, is:

- Raised after harvest to limit drainage outflow and reduce the delivery of nitrate to ditches and streams during the off-season. (Figure 1)
- Lowered in early spring and again in the fall so the drain can flow freely before field operations such as planting or harvest. (Figure 2)
- Raised again after planting and spring field operations to create a potential to store water for the crop to use in midsummer. (Figure 3)

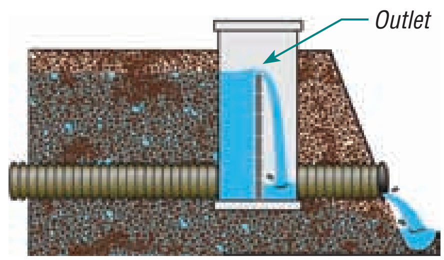

Figure 1. *The outlet is raised after harvest to reduce nitrate delivery.*

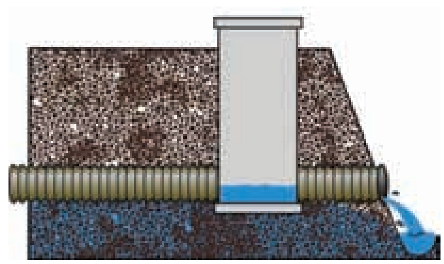

Figure 2. *The outlet is lowered a few weeks before planting and harvest to allow the field to drain more fully.*

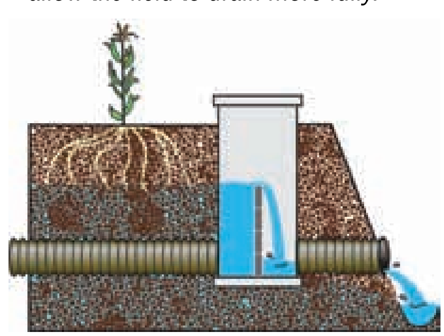

Figure 3. *The outlet is raised after planting to potentially store water for crops.*

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2. Is drainage water management the same as subirrigation?

No. Drainage water management relies on natural rainfall to raise the water table, and the water table will fluctuate below that depth without sufficient rainfall. Subirrigation adds water to the subsurface drainage system to raise the water table close to the outlet depth and to maintain it there. Subirrigation typically requires closer spacing of the tiles than that in a conventional or controlled drainage system. Subirrigation also requires an adequate water supply to meet crop needs throughout the growing season.

3. What fields are most suitable for drainage water management?

The practice is only suitable on fields that need drainage, and is most appropriate where a pattern drainage system (as opposed to a random system) is installed or is feasible. The field should be flat (generally less than 0.5 percent slope) so that one control structure can manage the water table within 1 to 2 feet for as many acres as possible. If drainage laterals are installed on the contour, the practice could be used with greater slopes. The producer must be able to manage the drainage system without affecting adjacent landowners. The practice can be used with any drain spacing; however, narrower drain spacing reduces the risk of yield loss due to excess wetness during the growing season. If a new drainage installation is being planned for a field, drains should be designed for minimum grade (along the contours), so each control structure can control the maximum possible area of the field.

In drainage water management, water control structures are used to vary the depth of the drainage outlet. Flatter fields require fewer structures.

4. How many acres can I manage with one structure?

It depends on field topography and the desired uniformity of water table management. Flatter fields require fewer overall structures and allow each structure to manage a larger area. A field is typically divided into "drainage management zones," each managed by one control structure. The zones are delineated by the desired feet of elevation change within the zone, which corresponds to the desired uniformity of water table management. For example, to maintain control of the water table to within 1 foot of the desired depth, a structure must be placed in a drainage management zone with 1 foot or less of elevation change. One structure can typically control at least 10 or 20 acres, and the larger the area that can be controlled with one structure, the more economical the practice.

5. How much management is required?

The level of management required depends on whether the water control structures will be used to raise the system outlet during the fallow season, the growing season, or both. During the fallow season, the only management required is to raise the outlet after harvest and field operations in the fall, and to lower it about two weeks before the start of field operations in the spring. During the growing season, management may involve temporarily lowering the outlet height to increase the drainage during periods of heavy rain or sustained wet periods. Automated devices are available to aid in management.

6. How do I manage the outlet?

Current recommendations are to place the control structure outlet within 6 inches of the field surface for maximum water quality benefits in the winter months. (Some surface ponding might occur in depressional areas of the field.) Researchers have yet to determine the optimum outlet height during the growing season, but they suggest an outlet depth of 2 or more feet below the field surface. The goal is to provide enough drainage for good aeration and root development but to capture some of the water that would otherwise drain out under conventional systems. It is important to understand that the drainage outlet setting does not ensure that a water table will be present at the desired depth; sufficient rainfall must occur for the water table to rise to the depth of the outlet setting. Caution should be exercised during the growing season, because maintaining water table depths shallower than 2 feet may increase the risk of crop excess water stress during pro-

Management includes raising the outlet after harvest and planting, and lowering the outlet before field operations in the spring and fall.

longed wet periods in spring/summer. Particular attention should be paid to the management of soybean fields, since soybeans are less tolerant of wet roots.

7. Do I need a pump for drainage water management?

Not unless you need a pump for your existing drainage system, such as drainage systems that outlet into pumped sumps where gravity flow outlets are difficult or impossible to establish.

8. When is it possible to retrofit an existing system?

Most drainage systems can be retrofitted with control structures, but sometimes the benefits will not be significant because of the slope and layout of the pipes. The best candidates for retrofitting are pattern drainage systems where the grade of the laterals is 0.2 percent or less.

9. Will I need more drain tile (narrower spacing)?

No. This practice is not like subirrigation, which is only economical with narrower spacing. Drainage water management is more likely to increase yield on fields with pattern drainage, rather than those with random drainage. Narrower drain spacing may reduce the risk of yield loss during times of heavy rainfall, because water is removed faster.

10. What yield impact can I expect?

With proper management of the structures and timely rainfall, the potential exists to improve crop yields beyond the typical crop response to drainage. However, field research on the agronomic benefits of the practice is very limited and inconclusive. Field studies in North Carolina have found average yield increases of about 5 percent, with greater response in some years. For Midwest conditions, computer modeling studies show limited long-term crop yield benefits (up to 5 percent) with controlled drainage, because yield benefits will not accrue in years where rainfall is not sufficient or not at the right time to raise the water table above the tile depth. Potential crop yield increases will be greater in regions where drains typically

With proper management of the structure and timely rainfall, drainage water management may improve crop yields in some years.

flow for long periods after planting, because more water is available to be stored in the root zone. In all regions, increases in crop yields will be much greater in some years than in others. There may be a risk of excessive moisture in some years, but the risk can be minimized with proper management.

11. How much less nitrate flows into ditches and streams?

Studies have found reductions in annual nitrate load in drain flow ranging from about 15 percent to 75 percent, depending on location, climate, soil type, and cropping

Drainage water management reduces the nitrate that flows to ditches and streams from tile drains compared to unmanaged drainage (shown above).

practice. Nitrate load is reduced by about the same percentage as drain flow is reduced, since most studies have found that drainage water management does not change the nitrate concentration in the drain flow. In regions where much of the drainage takes place during the winter (such as Illinois, Indiana, and Ohio), the reduction is likely to be greater than where most of the drainage takes place in April or later, such as in parts of Iowa and Minnesota.

12 Can I use less nitrogen fertilizer?

No. Reducing the annual drain flow does not imply that all of that unreleased water with its soluble nitrate is still in the field. Most of this water and nitrate leave the field by some other route. That flow path is longer and slower, giving more opportunity for denitrification or assimilation of the nitrate into organic nitrogen forms, and any nitrate that remains in the root zone will be lost when water is released before planting.

13. Where does the rest of the nitrate go?

Nitrate reductions from drainage management systems result from three factors: (1) reduced volume of drainage water exported from the system, (2) denitrification within the soil profile, and (3) deep seepage. The decrease in drainage water has been measured in several locations and is a major factor in reducing nitrate flow to ditches and streams. Some of the water that is not drained becomes surface runoff instead, but nitrate concentrations are considerably lower in the surface runoff. Denitrification converts some of the nitrate to harmless nitrogen gas (N_2) as well as a small amount of nitrous oxide (N_2O), a potent greenhouse gas, but the extent of denitrification is not known. The amount of deep seepage has not been quantified, nor has the extent to which the nitrate will be denitrified as it travels through these pathways.

14. How does drainage water management affect soil quality?

This question has not been studied under field conditions, so the answer is based on knowledge from related studies. A small increase in soil organic matter content is likely with drainage water management, and this would be a positive effect on soil quality. Drainage water management will cause prolonged wetness during the non-growing season, and this may promote the breakdown of aggregates. But normal drying of the soil is likely during the growing season, and this process contributes to aggregate formation and stability. Field operations carried out when the soil is wet add to soil compaction, but proper drainage water management would allow drainage for a sufficient amount of time before field operations so that soil wetness would be comparable to that in fields with conventional drainage.

15. Will earthworms be affected?

Maybe. Worms in general do not like soil that is too wet, but scientists are not sure how wet is “too wet” for earthworms. The effect of drainage water management is likely to vary for different species of worms. Some evidence suggests that nightcrawlers may be most sensitive to excessive wetness, although more studies are needed. Worm populations are also highly variable. Some fields or portions of fields have high populations, and other areas have low populations. To understand whether the higher water table has affected worms at specific sites, researchers must count

Earthworms may be impacted by drainage water management, but more research is needed.

worms before drainage water management is initiated and then again several years later. These studies are just beginning.

16. Will the practice cause blowouts?

Not with most commercially available control structures installed on shallow gravity flow drainage systems. Excessive pressure heads within a drainage pipe cause blowouts. Most commercial control structures do not close tile outlets, but simply raise the elevation or height of the outlet. Water is free to flow over the top of the control structure, keeping pressure heads within the field drainage system only marginally greater than that at the top of the control structure. Some control structure designs use pressure-sensitive valves that, again, will not allow excessive buildup of pressure heads within the drainpipe. However, if the drains are closed using valves, excessive pressure heads are possible and these need to be monitored carefully. Finally, if the downstream drainage mains are not sized correctly, the large discharge volumes that can result from lowering the water table in the spring, especially if several fields are lowered at once, could cause blowouts below the farmer's field.

17. Will drainage water management cause tile plugging?

Probably not. Raising the water table can cause water to move more slowly or stagnate in the tile drains, allowing any sediment to settle out. However, the high flow rates that result from setting the control structures to lower the water table in the spring will probably flush any accumulated sediment from the tile system, especially systems that are installed on a self-cleaning grade.

18. Will tile freeze?

Soils rarely freeze as deep as the tile, and they are less likely to do so when the water table has been raised with the control structure. Freezing of the control structure itself could be an issue, as cold air can settle in the structure housing. A frozen control structure could make it impossible to lower the outlet depth in the spring to lower the water table. However, there have been no reports of control structures being frozen in the spring at the recommended time for lowering the water table.

19. Will my neighbors be affected?

Maybe. Site selection certainly needs to include consideration of potential impacts on neighbors. Upstream neighbors on the same drainage main could be affected,

Freezing is unlikely to be a concern, as soils rarely freeze as deep as the tile.

so managing the outlet of a shared main is not a good idea unless the upstream field is at least 2 to 4 feet higher in elevation than the outlet being managed. There are no anticipated impacts on downstream neighbors on the same drain system, unless mains are not sized correctly (see answer to Q16). Other potential problems include raising the water table near home septic fields. Septic leach fields need several feet of unsaturated soil below them for adequate treatment.

20. Will surface runoff, erosion, and the loss of other chemicals be increased?

Maybe. Wetter soils are likely to have more runoff and erosion. Since some contaminants such as phosphorus and pesticides are lost through surface runoff and erosion, this is an important consideration. If there is a pathway for runoff to leave the field, drainage water management may increase runoff and associated contaminants during the time that the water level is raised. However, most pesticides are applied just before planting, when the water controlled over the winter would have already been released. Also, land that is most suitable for drainage water management is very flat, and is therefore less likely to be susceptible to water erosion. A wetter soil profile due to drainage water management could potentially reduce wind erosion on selected soils and landscapes.

21. Will manure application be affected?

Possibly. Spring application of manure is generally not compatible with drainage water management, while summer and fall application can be. When the water table is near the soil surface, as it would be in spring with drainage water management, manure cannot be applied because of trafficability and soil compaction problems. Lowering the outlet even earlier in the spring to allow for spring application would negate much of the nitrate reduction benefit of drainage water management. When the soil is dry, however, such as in summer or early fall, raising the subsurface drain outlets can prevent the entry into surface water of liquid manure that has leaked directly into drainage pipes through macropores caused by roots, earthworms, or cracks. In fact, raising subsurface drain outlets before liquid manure application is a recommended practice in some states (e.g., Michigan and Ohio). In most years in the fall, there is an adequate time window for manure application between when the outlets are raised and sufficient rainfall occurs to raise the water table to near the surface. Because of an increased potential for surface runoff after the water table has risen, manure should be injected or incorporated into the soil.

22. How much does drainage water management cost?

Costs include purchase of the water control structure, installation of the structure, and management time. Structure costs range from $500 to $2,000, depending on height, size of tile, structure design, manufacturer, and whether it is automated. Some contractors and farmers fabricate their own structures. Installation costs may be about $200 for a basic structure in a new drainage system installation, but may increase depending on the size of the structure, level of automation of the structure, and for retrofit situations. Assuming grades are flat enough for one structure to control 20 acres, initial costs would be in the range of $20 to $110 per acre. A producer should also consider the cost of the time spent on management of the structure.

23. What is the life of a water control structure?

The practice of drainage water management is still fairly new, so there is not a large body of experience on which to base estimates of structure life. Materials used in control structures may include plastics, metal, rubber (gaskets), and electronic components (for automated structures), each with varying durability and longevity of use. One manufacturer's structures have been used for water management in wetlands and are still working well after 20 or 25 years.

24. What crop varieties work best?

No research has considered this question. The best varieties may vary by location. High-yield varieties with good early vigor and disease resistance should perform well in a managed drainage system.

25. How is the application of other conservation practices affected?

Drainage water management should be one of a suite of practices in an overall conservation plan. Drainage water may need to be managed differently, depending on other practices in a plan. For example, drainage water management may not work well with cover crops unless the water is not raised as high in the winter and is let out earlier in the spring. No-till soils tend to be colder and wetter, and water may need to be released earlier to allow for longer warm-up. Drainage water management can work well in conjunction with riparian buffers to remove nitrate not otherwise treated by the buffer.

The cost of drainage water management includes installation, as well as purchase and management of the structure.

26. Who will help pay for the practice?

The USDA National Resource Conservation Service (NRCS) has approved conservation practice standards that support drainage water management in some states. The standards are 554, "Drainage Water Management," and 587, "Structure for Water Control." Farm Bill programs, including the Environmental Quality Incentives Program (EQIP) and the Conservation Security Program (CSP), may provide some of the cost of structure installation and/or a management incentive for a number of years in some states. The Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP) may provide funding for the installation of structures in riparian buffers in some states. For more information, talk with your local District Conservationist.

27. Where can I get more information?

The Agricultural Drainage Management Systems Task Force is a national effort to improve drainage practices to reduce adverse impacts while enhancing crop production and conserving water. <extension.osu.edu/~usdasdru/ADMS/ADMSindex.htm>

More information about USDA cost-share programs is at www.nrcs.usda.gov/programs/.

The following Extension publications, NRCS standards and handbook chapters, and books provide information on what is known about drainage water management.

- NRCS Conservation Practice Standard 554, "Drainage Water Management," and 587, "Structure for Water Control." State and local standards are in Section IV of the Electronic Field Office Technical Guide (eFOTG) at www.nrcs.usda.gov/technical/efotg/.
- "Operating Controlled Drainage and Subirrigation Systems" by R. Evans and R.W. Skaggs. North Carolina Cooperative Extension Service, Publication Number AG 356, 1996. <www.bae.ncsu.edu/programs/extension/evans/ag356.html>
- "Agricultural Water Management for Coastal Plain Soils" by R. Evans, J.W. Gilliam, and R.W. Skaggs. North Carolina Cooperative Extension Service, Publication Number AG 443, 1996. <www.bae.ncsu.edu/programs/extension/evans/ag443.html>
- American Society of Agricultural and Biological Engineers Standard ASAE EP479 "Design, Installation and Operation of Water Table Management Systems for Subirrigation/Controlled Drainage in Humid Regions" March 1990.
- Agricultural Drainage, by R.W. Skaggs and J. van Schilfgaarde (eds), ASA, CSSA, SSSA: Madison, Wis., 1999. Chapters 20, 21, and 22 consider controlled drainage.
- USDA NRCS National Engineering Handbook Part 624, Chapter 10, "Water Table Control," is a guide for the evaluation of potential sites and the design, installation, and management of water table control in humid areas. <ftp://ftp.wcc.nrcs.usda.gov/water_mgt/EFH&NEH_Drainage_Chapters/neh624_10.pdf>
- Subirrigation and Controlled Drainage. Edited by H.W. Belcher and Frank M. D'Itri. 1995. Lewis Publishers, an imprint of CRC Press Inc., Boca Raton, Fla. 482 pages.

Drainage water management can work well in conjunction with riparian buffers to remove nitrate not treated by the buffer.

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DEMONSTRATING INTEGRATED WATER MANAGEMENT SYSTEMS FOR IMPROVED MANAGED DRAINAGE FOR IMPROVED WATER QUALITY

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Agricultural drainage is not a new concept; however, utilizing drainage as part of an integrated water management system (IWMS) is a relatively new concept that has been shown to improve water quality by reducing nitrate-N load up to 75% (Frankenberger et al. 2006) and sustain agricultural viability (Belcher and D'ltri 1995). Currently, Missouri is not a major subsurface drainage state. However, designing systems for IWMS or managed drainage is necessary for improved water quality. This demonstration site would provide stakeholders with the necessary information to design and install systems that minimize environmental impacts and avoid retrofitting systems that may marginally work. No-till corn production has had limited adoption in this region due to cool, wet soils in the spring. Subsurface drainage systems have been utilized to lower water levels in fields with seasonally high water levels during planting and harvest. Agricultural drainage water has been perceived to be a substantial source of nonpoint source nitrate-nitrogen (nitrate-N) pollution. Numerous studies have quantified the impact of subsurface agricultural drainage water on water quality. Reviews have reported that improved subsurface drainage reduced peak runoff, peak outflow rates, and sediment loss (Fausey et al. 1995). Surface water runoff has been the major contributor of phosphorus, pesticide, and sediment loss when compared with subsurface drainage. In Missouri, claypan soils are known to have slow infiltration due to the impermeable claypan and a high runoff potential which encourages surface water runoff (Smith et al. 1999).

Nitrate loss from soils has contributed to the contamination of drainage waters and has become an economic and environmental concern regarding hypoxia in the Northern Gulf of Mexico. The Mississippi-Atchafalaya River basin is one of the largest river systems in the world. Drainage systems may deliver water with increased nitrate-N levels; however, research has reported that water-level management using an IWMS reduced nonpoint source dissolved nitrate-N from 25 – 64% (Drury et al. 1996; Fausey et al. 1995), while more recently, up to 75% reduction has been reported (Frankenberger et al. 2006). An IWMS using water-level management in the soil profile is a technological advancement in soil and water management systems using water-level management of drinking water. Drainage water management (NRCS Practice 554) conservation practice standard has been outlined by Natural Resources Conservation Service (NRCS) as a means to improve water quality and the soil environment, reduce oxidation of soil organic matter, reduce wind erosion, and enable seasonal shallow flooding (NRCS 2002). Subsurface drainage water from agricultural lands contributes to the quantity and quality of water in receiving streams, when properly implemented water management systems are adopted.

Increased water infiltration in the soil and less surface water runoff are two of the water quality benefits of subsurface drainage. Runoff water carries sediment and attached nutrients to surface waters. Sediment loss can be reduced up to 65% and phosphorus loss up to 45% on cropland with subsurface drainage. An adverse effect of subsurface drainage is that water soluble chemicals and plant nutrients such as nitrate-N can move from the soil to surface waters via the drainage systems. Nitrogen is continuously cycled within the soil-plant-air systems and availability is weather-dependent which makes it difficult to predict nitrate losses. Nitrate-N removed through subsurface drainage (88-95%) generally occurs when there is no crop in the field (Kladivko et al. 1991; Drury et al. 1996). The lowest nitrate-N concentrations have been found under shallow water table management using an IWMS (Kalita and Kanwar 1993). This is similar to the arrangement in the University's demonstration site. Fogiel and Belcher (1991) had more nitrate-N loss through the surface drainage in treatments without subsurface drainage than from an IWMS. Although an IWMS may increase the amount of nitrate loss through surface water runoff when compared to free-flowing drainage, this loss was minor compared to losses through free-flowing tile drainage (Drury et al. 1996). Additional management methods to reduce nitrate-N loss include managing rates and timing of application and improved management of the drainage water through an IWMS. Skaggs et al. (1994) reviewed the effects of agricultural drainage on water quality. Improved drainage and agriculture production usually increases peak runoff rates, sediment losses, and pollutant loads on surface water resources; however, land that was converted to agricultural production with subsurface drainage had reduced surface water runoff, peak outflow rates, and sediment losses. Similarly, Baker and Johnson (1977) reviewed several studies in the Midwest and reported nitrate in subsurface drainage water was greater than in surface water runoff, and sediment loss was substantially greater in surface water runoff than in subsurface water based on drained compared to non-drained agricultural lands.

Intensive management of the water level in the soil using an IWMS is a practice of controlling drainage water flow and the soil water level using a subsurface drainage or subirrigation system. A control structure manages the release of drainage water and keeps the soil below the root zone wet for a longer period of time. Wet soil is a favorable condition for the conversion of left-over nitrate into the gaseous form of nitrogen by soil microbes through denitrification. Nitrate at deep soil depths has limited value to the plant and can be susceptible to leaching. However, the slow permeability of the claypan limits deep leaching which is unique to this soil type. If someone would look at the fate of nitrogen (N) in an agroecosystem, an IWMS should increase harvest output (grain N removal) and immobilization by the plant, increase denitrification during the winter months, and reduce N levels in drainage outflow and N stored in soil layers that may be unavailable to the plant.

Pesticides generally degrade at a faster rate than nitrate and are held tighter by the soil; therefore, they are less available for transport later in the year. In Canada, atrazine dissipation occurred in a sandy soil at the root zone depths and shallow subirrigation reduced residues in the soil by maintaining higher water content in this zone when compared to free-flowing drainage (Jebellie and Prasher 1999). Similarly, metribuzin (Sencor) degradation was faster in a soil with subirrigation (Jebellie and Prasher 1998). Simulation studies have shown that free drainage had the greatest aldicarb (Temik) losses while managed drainage resulted in the lowest amount of loss through drainage outflow (Munster et al. 1996). This further reinforces the benefits of an IWMS.

Missouri researchers have been evaluating enhanced efficiency fertilizers and the interaction with water management systems (Nelson et al. 2009). The IWMS increased N uptake and grain yield when compared to non-drained control. A greater amount of N was utilized by the plant which would limit the amount of N available for loss mechanisms. In years with low rainfall or other factors limiting crop growth, residual N from an application to corn many remain in the soil profile (Nelson et al. 2009) and be susceptible to loss (Blevins et al. 1996). This demonstration site should complement previous results and demonstrate reduced nitrate loss from drain tiles, reduced sediment loss, and reduced phosphorus loss. The objectives of this project were to 1) demonstrate the effect of subsurface drainage on surface water runoff, sediment and phosphorus loss; and 2) demonstrate the effects of managed drainage on reduced nitrate-N loss.

Work Element #1 – Demonstrate the effect of subsurface drainage on surface water runoff

An IWMS manages the water-level during strategic times of the year to conserve water, improve crop production, and reduce negative impacts to our water resources. The primary water quality concerns are two-fold. First, subsurface drainage may reduce surface water runoff and subsequently reduce TSS and phosphorus loss compared with no drainage. Free-flowing drainage may increase NO_3-N loss, but an IWMS should reduce NO_3-N loading of surface waters.

A plastic barrier was installed approximately two feet deep using a trencher to open a trench around each designated field area to prevent lateral water flow from adjacent field areas. The plastic border was installed into the claypan part of the soil profile. The claypan has very slow permeability; therefore, deep leaching should be limited. Water from rainfall either ran off of the soil surface of the field area, was removed through the subsurface drainage system, or evaporate from the soil surface. Approximately one foot of plastic extended above the soil surface and a levee plow used for building levees for rice production was used to create a ridge around the demonstration site areas. Again, this will prevent the transfer of water from adjacent areas from running across the demonstration site.

A flume was installed in the corner of each demonstration site area with a water sampler and flow meter to determine the amount of surface water runoff from 6 sites. Flumes were installed in each of the demonstration site field areas including: 1) drainage only planted to corn in 2010 and soybean in 2011, 2) drainage only planted to soybean in 2010 and corn in 2011, 3) drainage plus subirrigation (IWMS) planted to corn in 2010 and soybean in 2011, 4) drainage plus subirrigation (IWMS) planted to soybean in 2010 and corn in 2011, 5) non-drained control planted to corn in 2010 and soybean in 2011, and 6) non-drained control planted to soybean in 2010 and corn in 2011. A flow meter was installed in the subsurface drainage line at 4 sites from the water level control structure to the main drainage line in field areas #3 and 4 listed above as well as in the submain in field areas #5 and 6 listed above. These devices quantified the amount of surface water runoff and subsurface water removal for a subsurface drainage system in a claypan soil. This site demonstrated the amount of surface water runoff that occurred with an IWMS during the winter months when there is regulated water flow. Continuous flow measurement allowed us to quantify total flow from surface water runoff and subsurface water flow and which was used to directly calculate nitrate (NO_3-N), total nitrogen (TN), phosphorus (ortho-P and TP) and total suspended solids (TSS) loading in Work Element #2.

Work Element #2 – Demonstrate the effects of managed drainage on reduced NO_3-N loss

Nitrate (NO_3) loss from soils has contributed to the contamination of drainage waters and has become an economic and environmental concern with a large emphasis on hypoxia in the Gulf of Mexico. Systems that minimize NO_3-N loss and increase nitrogen (N) uptake by the crop need to be implemented to remediate these impacts. Missouri can implement such BMPs from the beginning and avoid retrofitting drainage systems that were designed for drainage only and may not be as effective at reducing NO_3-N loss. It has been shown that the non-cropping season may contribute more than 90% of the NO_3-N removed with subsurface drainage water (Fausey et al. 1995). An IWMS is a technological advancement for fine soils as it reduces NO_3-N contamination of drainage water, increases nitrogen use efficiency, and provides water during the dry months of the summer (Drury et al. 1996). Since subsurface drainage reduces surface water runoff, TSS and ortho-P loss should also decrease. As a result, an IWMS should reduce the loss of TSS, TP, ortho-P, TN, and NO_3-N. This portion of the project utilized NO_3-N, TSS, and ortho-P measurements to demonstrate the benefits of an IWMS on water quality. Water flow rates were determined to quantify load at the outlet.

This work element utilized water samples and surface runoff calculations from Work Element #1 to determine total nitrogen (TN), NO_3-N, total suspended solids (TSS), total phosphorus (TP), and ortho-P concentrations and demonstrate the benefits of an IWMS on water quality. Automated sample collection was utilized throughout the growing season, while grab samples were collected during the winter months when freezing conditions could cause damage to the auto samplers. The individual flow meters in Work Element #1 were utilized to activate the individual samplers when programmed conditions occur which signaled the sampler to collect a sample. In addition, a grab sample from the pond was utilized to demonstrate the effect of discharge water on impoundment water quality. A duplicate sample was taken approximately 6 to 8 feet from the shore with a water depth of approximately 3 to 4 feet, and processed through the MU Soil and Plant Analysis Laboratory similar to previous samples. Clint Meinhardt and Patrick Nash were responsible for collecting samples while Dr. Ranjith Udawatta performed the analysis of the rest of the samples. Dr. Udawatta provided technical assistance as needed.

The expected outcomes for water quality data in this project were to estimate NO_3-N , TSS, TN, TP, and ortho-P load reductions in the presence and absence of an integrated water management system (IWMS). These data allowed the performance of an IWMS to be evaluated based on direct estimation of N, P, and TSS loss via surface or subsurface water flow. Because ortho-P and TSS transport is greatest during high surface drainage water flow events and NO_3-N transport is greatest during high subsurface drainage flow events, accurate estimations require that both flow rate and concentrations of NO_3-N, ortho-P and TSS be known. To achieve loading estimates for the sampling period of this work, continuous flow measurement and flow proportionate sampling analysis schemes were utilized to provide NO_3-N, TN, ortho-P, TP, and TSS concentration data from samples selected to minimize uncertainty in load estimations.

Results

Water quality monitoring was initiated in April and was completed in December 2011. Our goal was to evaluate pollutant loss into the spring since a majority of the nitrate-N load reduction with an IWMS occurs during the winter months while the system is in managed drainage mode (Drury, 1996; Zucker and Brown, 1998), but we were limited on the sampling time during the first year for this demonstration site due to a September 2, 2010 approval of the QAPP. Sampling should occur prior to the nitrogen fertilizer application (180 lbs N/acre on May 27, 2010 and April 12, 2011) and continue until the following nitrogen fertilizer application for corn. This provides an opportunity to evaluate residual nutrient loss from soybean in the subsequent year. Data from the demonstration site are summarized in Table 1.

In soybean, surface water runoff from the non-drained area had 0.2 lbs nitrate-N/acre, 1.8 lbs total N/acre, 0.7 lbs ortho-P/acre, 1.1 lbs total P, and 129 lbs total suspended solids/acre (Table 1). There were limited differences in nitrate-N, total N, ortho-P, and total P loss among management systems. Grain yields were summarized in Figure 1 below. This demonstrated that the yield increase with drainage water management removed 0 to 81 more lbs of N/acre and 0 to 19 lbs more lbs of P_2O_5/acre than the non-drained control in soybean.

In corn, surface water runoff from the non-drained area carried 3.6 lbs nitrate-N/acre, 13.3 lbs total N/acre, 7.2 lbs ortho-P/acre, 9 lbs total P/acre, and 786 lbs total suspended solids/acre (Table 1). Surface water runoff from the area with subsurface drainage reduced nitrate-N (0.6 lbs/acre) compared to the non-drained control, but loss through the drain tile increased total nitrate-N loss to 22.6 lbs/acre. Total N in surface water runoff was reduced 8.4 lbs/acre for subsurface drainage compared to the non-drained control, but total loss (surface + subsurface) increased 16.4 lbs/acre and management of N loss is needed. The system was placed into subirrigation mode on July 5, 2011. This is typically later than normal, but spring conditions were extremely wet and we have learned to delay changing the system into drainage mode due to a risk of crop injury (Nelson and Meinhardt, 2011; Nelson et al., 2009, 2011, 2012). Drainage only reduced ortho-P loss 5.9 lbs/acre and total P 6.8 lbs/acre compared to the non-drained control. Total suspended solids were reduced 586 lbs/acre compared to the non-drained control. However, there were limited benefits in nitrate-N, total N, ortho-P loss, and total suspended solids between the IWMS and drainage only for the period evaluated (April to December, 2011). Corn grain yields are summarized in Figure 2 below. This demonstrates that the yield increase with drainage water management removed 47 to 57 more lbs of N/acre and 23 to 28 more lbs of P_2O_5/acre than a non-drained control in corn. Gaseous nitrogen loss as nitrous oxide in poorly drained claypan soils is common (Nash et al., 2012)

Daily rainfall, cumulative surface water runoff, and cumulative subsurface tile drainage from April to December 2011 were collected (data not presented). There was a rainfall event that occurred in mid- to late-December when the system was in managed drainage mode and flow through the subsurface drainage system did not increase, while water flow increased with the subsurface tile drainage system. A reduction in flow reduces loading of pollutants into surface waters.

Load Reduction Calculations and Summaries

Direct measurements were used to calculate loads (Table 1) as: Water drained (Liters/ha) x water sample nutrient concentration (mg/L) x (1 kg/1000000 mg) = kg nutrient loss/ha. The flow weighted mean was calculated as: kg nutrient loss/ha divided by the total water drained/ha.

Table 1. Nitrate-N, total N, ortho-P, total P, and total suspended solid (TSS) loading for non-drained surface water runoff, drainage only (surface and subsurface drainage water), and integrated water management system (surface and subsurface drainage water) from April to December, 2011.

Pollutant		Lbs./acre†	Load Reduction (lbs/acre)	Method Used
Nitrate-N				
Corn	Non-drained	3.6		DC‡
	Drainage only§			
	Surface drainage	3.0	0.6	DC
	Subsurface tile drainage	23.2		DC
	Total¶	26.2	-22.6	
	IWMS£			
	Surface drainage	6.7	-3.7	DC
	Subsurface tile drainage	20.3	2.9	DC
	Total¶	27.0	-0.8	
Soybean	Non-drained	0.2		DC
	Drainage only			
	Surface drainage	0.9	-0.7	DC
	Subsurface tile drainage	1.2		DC
	Total	2.1	-1.9	
	IWMS			
	Surface drainage	0.9	0	DC
	Subsurface tile drainage	0.4	0.8	DC
	Total	1.3	0.8	
Total N				
Corn	Non-drained	13.3		DC
	Drainage only			
	Surface drainage	4.9	8.4	DC
	Subsurface tile drainage	24.8		DC
	Total	29.7	-16.4	
	IWMS			
	Surface drainage	14.8	-9.9	DC
	Subsurface tile drainage	20.9	3.9	DC
	Total	35.7	-6.0	
Soybean	Non-drained	1.8		DC
	Drainage only			
	Surface drainage	4.9	-3.1	DC
	Subsurface tile drainage	1.8		DC
	Total	6.7	-4.9	
	IWMS			
	Surface drainage	9.1	-4.2	DC
	Subsurface tile drainage	0.9	0.9	DC
	Total	10.0	-3.3	
Ortho-P				
Corn	Non-drained	7.2		DC
	Drainage only			
	Surface drainage	0.7	6.5	DC
	Subsurface tile drainage	0.6		DC
	Total	1.3	5.9	
	IWMS			
	Surface drainage	3.7	-3.0	DC
	Subsurface tile drainage	0.3	0.3	DC
	Total	4.0	-2.7	
Soybean	Non-drained	0.7		DC
	Drainage only			
	Surface drainage	1.5	-0.8	DC
	Subsurface tile drainage	0.1		DC
	Total	1.6	-0.9	
	IWMS			
	Surface drainage	1.9	-0.4	DC
	Subsurface tile drainage	0.2	-0.1	DC
	Total	2.1	-0.5	

Table 1. continued

Total P				
Corn	Non-drained	9.0		DC
	Drainage only			
	Surface drainage	1.2	7.8	DC
	Subsurface tile drainage	1.0		DC
	Total	2.2	6.8	
	IWMS			
	Surface drainage	6.8	-5.6	DC
	Subsurface tile drainage	0.4	0.6	DC
	Total	7.2	-5.0	
Soybean	Non-drained	1.1		DC
	Drainage only			
	Surface drainage	2.8	-1.7	DC
	Subsurface tile drainage	0.2		DC
	Total	3.0	-1.9	
	IWMS			
	Surface drainage	3.9	-1.1	DC
	Subsurface tile drainage	0.2	0	DC
	Total	4.1	-1.1	
TSS				
Corn	Non-drained	786		DC
	Drainage only			
	Surface drainage	200	586	DC
	Subsurface tile drainage	36		DC
	Total	236	550	
	IWMS			
	Surface drainage	923	-723	DC
	Subsurface tile drainage	33	3	DC
	Total	956	-720	
Soybean	Non-drained	129		DC
	Drainage only			
	Surface drainage	239	-110	DC
	Subsurface tile drainage	27		DC
	Total	266	-137	
	IWMS			
	Surface drainage	233	6	DC
	Subsurface tile drainage	8	19	DC
	Total	241	25	

†Total water drained and nutrient loss was calculated over the period of April 25, 2011 through December 31, 2011.
‡ Abbreviations: DC, direct calculation; IWMS, integrated water management system; TSS, total suspended solids.
§Load reduction was calculated as the difference between the non-drained control and drainage only or IWMS treatments. A positive value represented a load reduction and a negative value indicated a load increase.
¶Calculated as the sum of the surface and subsurface tile drainage water pollutant loads.
£Load reduction was calculated as the difference between drainage only and the IWMS.

Other Environmental Field Activities Conducted

Soybean (Figure 1) and corn (Figure 2) yields were affected by drainage and an IWMS, which would indicate increased fertilizer use efficiency with drainage water management and less fertilizer losses in the environment. Corn removes nearly 0.9 lbs N/bushel and 0.45 lbs of P_2O_5/bushel of grain produced while soybean removes 3.5 lbs N/bushel and 0.84 lbs of P_2O_5/bushel of grain produced. This demonstrates that the yield increase with drainage water management removed 47 to 57 more lbs of N/acre and 23 to 28 more lbs of P_2O_5/acre than a non-drained control in corn, and 0 to 81 more lbs of N/acre and 0 to 19 lbs more lbs of P_2O_5/acre than the non-drained control in soybean. Similarly, a greater amount of N was utilized by the corn plant using an IWMS in other years (Nelson et al., 2009). Similar grain yield responses have been observed in other research at this location (Nelson et al., 2009; Nelson and Meinhardt, 2011; Nelson et al., 2011, 2012).

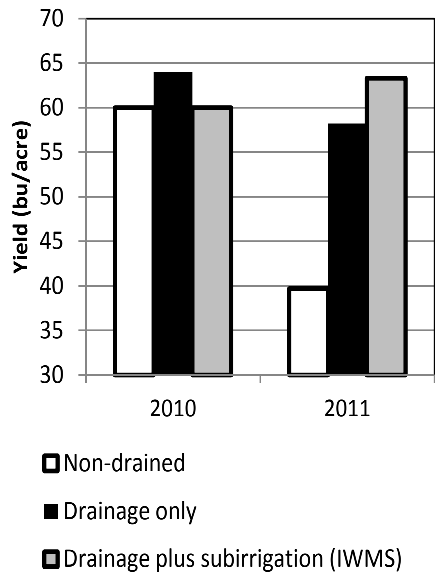

Figure 1. Soybean yield response to non-drained, drainage only, and drainage plus subirrigation (IWMS) in 2010 and 2011. Soybean yield increased 4 bu/acre with drainage only in 2010, but no difference was observed with an IWMS due to the extremely wet conditions (Nelson and Meinhardt, 2011). In 2011, grain yields increased 17 bu/acre with drainage only and 23 bu/acre with an IWMS.

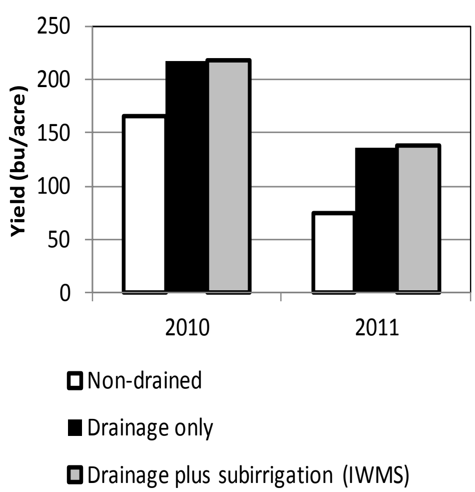

Figure 2. Corn yield response to non-drained, drainage only, and drainage plus subirrigation (IWMS) in 2010 and 2011. In 2010, corn grain yield increased 52 bu/acre with drainage only or an IWMS compared to the non-drained control. Grain yield increased 61 to 63 bu/acre with drainage water management compared to the non-drained control in 2011.

Grab samples from the lake receiving water from the demonstration site were monitored for nitrate-N, phosphate-P, and total suspended solids through the University of Missouri Soil and Plant Testing Lab (Figure 3). Nitrate-N and phosphate-P concentrations were less than 2.2 and 0.5 ppm, respectively, from 2009 to 2011. Total suspended solids were up to 187 ppm in 2010.

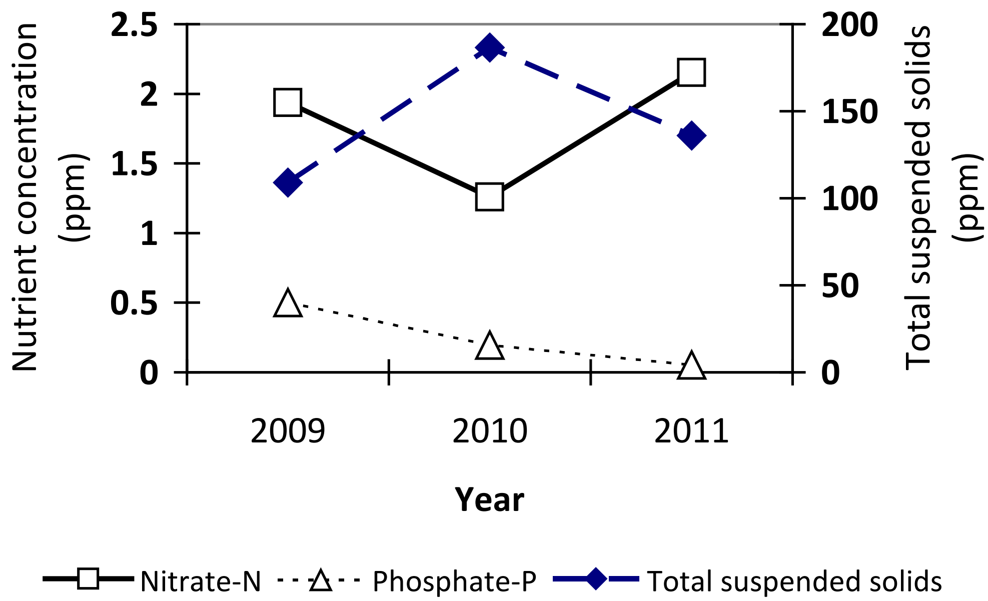

Figure 3. Nitrate-N, phosphate-P, and total suspended solid concentration in the lake where drainage water was collected and used to subirrigate through the integrated water management system (IWMS).

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Replicated research was initiated in 2010 at two sites in Northeast Missouri to evaluate the utilization of polymer-coated urea fertilizer and managed subsurface drainage systems to improve N management and corn yields.

UTILIZATION OF POLYMER-COATED UREA FERTILIZER AND MANAGED SUBSURFACE DRAINAGE SYSTEMS TO IMPROVE N MANAGEMENT AND CORN YIELDS

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Agronomic production on poorly drained soils in humid regions, such as the Central Claypan Region (MLRA), can exhibit low crop production in moderate to wet growing seasons. Extended periods of saturated soil conditions during a growing season may severely lower crop production by inhibiting plant growth, increasing the chance of disease, and providing conditions ideal for nutrient loss. Trafficability issues are often overlooked but can have a significant impact on crop production due to potential delays in fertilizer, herbicide, and pesticide applications, planting, and harvesting. Installation of a subsurface tile drainage system can effectively minimize issues with saturated soil conditions near the soil surface and the plant root zone. In NE Missouri, subsurface tile drainage has been found to improve corn and soybean yields by 20% compared to non-tile drained soil (Nelson et al., 2010). However, since nitrate-N is soluble and has little affinity for adsorption onto soil particles there is a considerable amount of fertilizer N that can be lost in subsurface drainage water from agricultural soils (Cambardella et al., 1999).

Recent advances in subsurface drainage technology now allow for the management of the tile outlet height with the addition of a water level control structure, thereby effectively regulating the water table height and drainage outflow (Brown et al., 1997). Corn production in dry growing seasons may improve with managed subsurface drainage systems (MD) compared to conventional subsurface drainage systems (CD) due to the ability to increase retention of crop-available water and nutrients in the root zone. Although little agronomic research has been conducted on managed drainage, a recent two year research study evaluating corn and soybean yield production differences between managed and conventional subsurface drainage systems reported significantly higher yields in both seasons with managed drainage systems (Drury et al., 2009). Additionally, reducing tile drain outflow during the non-cropping season can significantly reduce the annual N loss in water draining out of tile drains. A study by Drury (1996) reported 88 to 95% of the total nitrate-N transported through the tile drains occurred during the non-cropping period (i.e., fall, winter, spring). Research evaluating managed subsurface drainage has reported up to a 75% reduction in annual nitrate-N loss compared to conventional subsurface drainage systems (Fausey et al., 1995; Drury et al., 1996; Frankenberger et al., 2006; Drury et al., 2009).

Polymer-coated urea (PCU) is designed to have a slower release rate than traditional dry urea fertilizers (NCU) (Wilson et al., 2009), which in wet growing conditions can potentially reduce N loss, resulting in increased corn production. Evidence for this decreased N loss using PCU compared to NCU can be found in a recent corn study conducted in this region which found that in low-lying areas, PCU increased N recovery efficiency (NRE) by 116 and 17% compared to NCU in 2005 and 2006, respectively (Noellsch, 2009). Surface applications of PCU also have been found to reduce ammonia volatilization loss by 60% compared with NCU (Rochette et al., 2009). A study conducted in a claypan soil found reduced nitrate-N concentration in water located in the soil profile early in the growing season with PCU compared to NCU fertilizer (Nelson et al., 2009), which indicates PCU's potential to minimize nitrate-N leaching. In regards to corn grain yield, pre-plant application of PCU has been reported to increase yields by 6.4 to 11.2 bu/acre compared to NCU (Blaylock et al., 2004, 2005; Nelson et al., 2008). These results are presumably a function of a slower release of urea throughout the growing season resulting in greater plant uptake of N and reduced N loss.

Based on past studies, literature, and conditions in NE Missouri in which a majority of rainfall typically occurs in the first two months of the growing season, combining PCU with MD could create a synergistic relationship that would further maximize crop production, as well as possibly reduce nitrate loss in tile drains. However, no studies at this time have evaluated the impact of combining both of these best management practices. Therefore, the objective of this study is to determine the effects of MD and PCU fertilizer on corn grain yields and the fate of applied N.

This is a four year study was initiated in the fall of 2010 at the University of Missouri's Greenley Memorial Research Center (40° 1' 17" N 92° 11' 24.9" W) near Novelty, MO (Fig. 1) in a Putnam silt loam (fine, smectitic, mesic, Vertic Albaqualfs). Depth to the claypan at this research station ranges from 18 to 24-in (data not presented). Sub-surface tile drainage systems, including control structures were installed in Aug., 2009. The sub-surface tile drains run 200 to 300 ft long with 20-ft spacing, and at a depth of 2 ft.

The experiment field site was in continuous corn (*Zea mays L.*) production under conventional tillage. There were two replications of treatments consisting of the N fertilizer source [i.e., NCU and PCU (ESN, Agrium Advanced Technology, Denver, CO)] at 180 lbs-N /acre in combination with a sub-surface drainage system [i.e., CD, MD, and non-subsurface drained (ND)]. Each plot was 30 ft wide, 200 to 300 ft long, and separated by plastic lining in the soil (i.e., 2.3 ft depth) and berms on the surface to impede any potential movement of fertilizer N across treatments (Figure 1). Within each replication there was a 20 ft wide, non-drained, non-treated control.

Extremely wet conditions occurred in the spring of both the 2010 and 2011 growing seasons which likely impacted corn production and minimized the grain yield response to subsurface drainage. Because of the large amount of rainfall in the spring, planting and N fertilizer application was delayed until July in 2010, while corn plant population was very low across the field trial, N deficiency was observed, and it was the second year of continuous corn in 2011 (Figure 1). Fall tillage will be utilized to help breakdown corn residue in the future. In 2010, the addition of a CD or MD in combination with N fertilizer sources had no significant ($P < 0.10$) increase in grain yield over the ND treatment (Figure 2). In 2011, minimal yield benefits with CD or MD compared to ND was also observed, however; on average yield with PCU fertilizer increased by 37 bu/acre ($P < 0.10$) compared to NCU when there was no subsurface drainage system. These results mirror a previous study conducted at the University of Missouri, Greenley Research Center which found PCU increased corn yield over NCU in poorly drained areas (Noellsch et al., 2009).

Field measurements of plant N content and ammonia volatilization loss taken during the 2010 and 2011 growing season provide additional information on how subsurface drainage systems and N fertilizer source impacted the fate of applied N. In 2010, ear leaf N content was significantly ($P < 0.10$) greater with NCU (0.97 %) compared to PCU (0.87%) when averaged over the subsurface drainage treatments (Figure 3). Polymer-coated urea had a 70% reduction in ammonia volatilization lost compared to NCU which lost 18.5 lbs-N/acre (Figure 4). In 2011, plant uptake of N was approximately 84 lbs-N/acre, but no impact on N uptake was found due to subsurface drainage or N fertilizer source (Figure 4). Ammonia volatilization loss with PCU (4.2 lbs-N/acre) was similar to that lost in 2010, while loss with NCU (4.9 lbs-N/acre) was 73% less. Differences in ammonia volatilization loss with NCU among the growing seasons may be due to the later application date and the timing of rainfall after N application in 2010.

The largest amount of annual N loss typically occurred through the water that drained out of the subsurface drainage systems. Conventional subsurface drainage on average drained approximately 50% of the rainfall received, which was approximately 200% greater ($P < 0.05$) than the amount of water drained with MD in 2010 (7-6-10 to 12-31-10) and 2011 (Figure 5). With CD there was 24 and 32 lbs nitrate-N lost per acre in 2010 and 2011, respectively (Figure 6). Managed subsurface drainage significantly ($P < 0.05$) reduced nitrate-N/loss by 51 and 68% compared to CD in 2010 and 2011, respectively.

Modest yield production and limited yield benefit with subsurface drainage over non-subsurface drained treatments observed in 2010 was presumably due to a delay in planting and N fertilizer application until July. In 2011, a combination of reduced plant populations across the field trial, N deficiency (visual observation), and the second year of continuous corn with spring tillage for residue management likely resulted in low yield production which minimized any potential yield benefits of subsurface drainage. During wet growing seasons, application of PCU instead of NCU for corn production on poorly drained soils without subsurface drainage may produce significantly greater grain yields due to a slower release of plant available N over time. Lastly, since both 2010 and 2011 were wet growing seasons we would not expect to find yield benefits with MD compared to CD systems, but MD was able to reduce nitrate-N loss entering surface waters by at least 50% without lowering grain yields production.

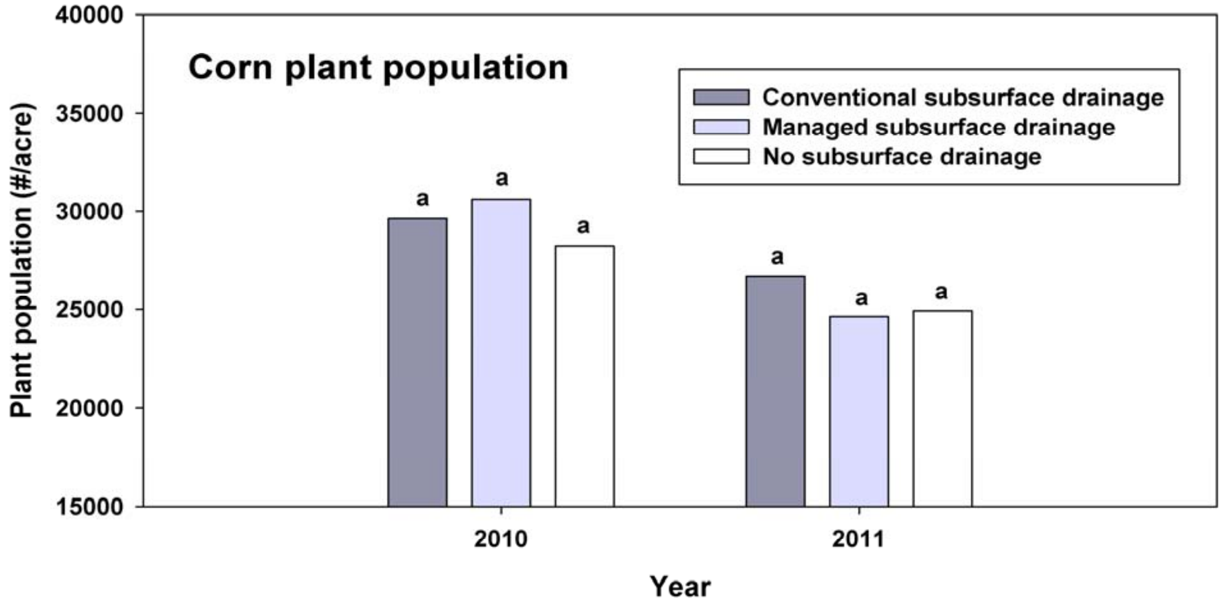

Figure 1. Corn plant population due to the subsurface drainage system in the 2010 and 2011 growing seasons. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD (*P* < 0.10).

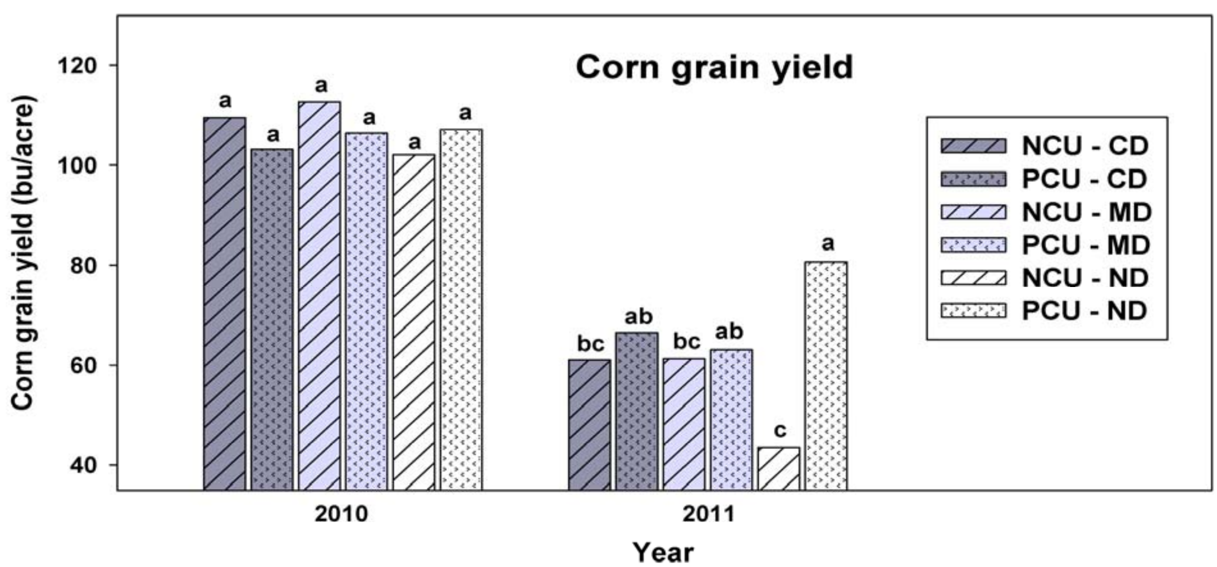

Figure 2. Corn grain yield due to the interaction of N fertilizer source [non-coated urea (NCU), polymer-coated urea (PCU) and a subsurface drainage system [conventional (CD), managed (MD), non-subsurface drained (ND)] in the 2010 and 2011 growing seasons. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD (*P* < 0.10).

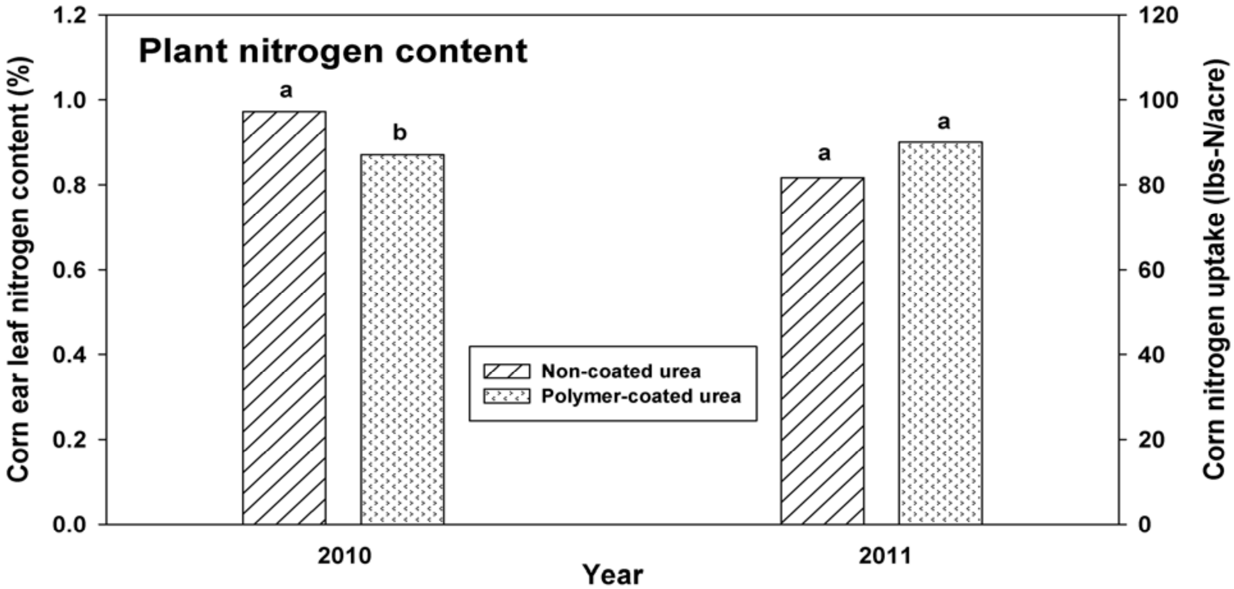

Figure 3. Corn ear leaf N content and uptake due to N fertilizer source in the 2010 and 2011 growing seasons, respectively. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD ($P < 0.10$).

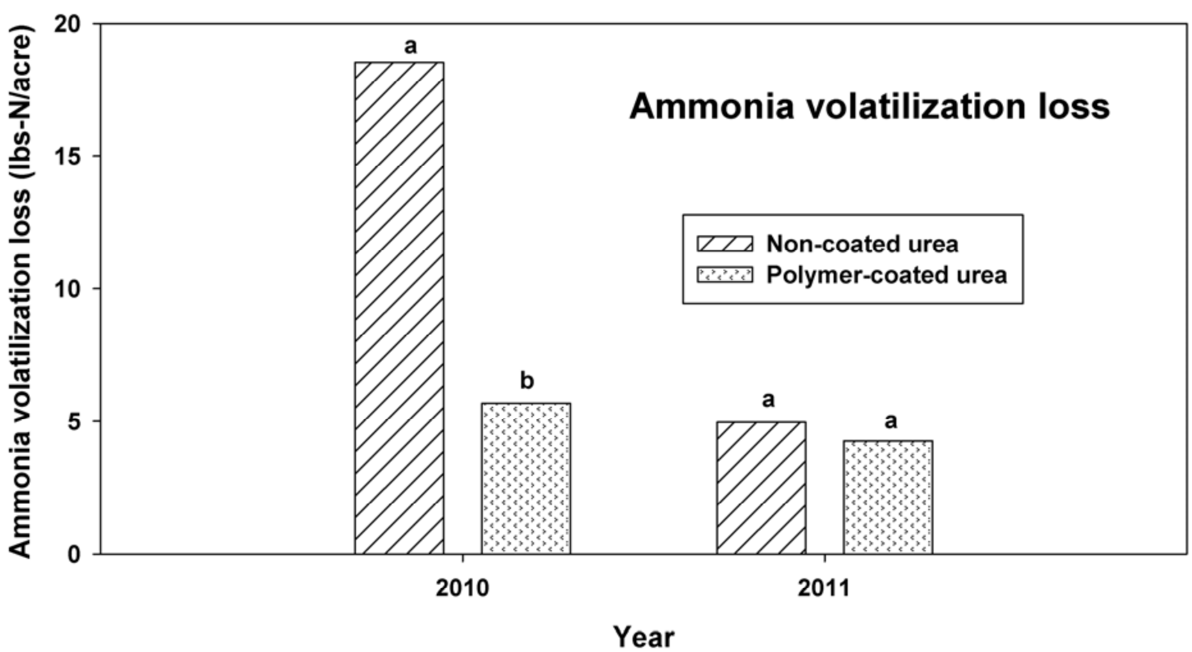

Figure 4. Ammonia volatilization loss in the 2010 and 2011 growing seasons due to N fertilizer source. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD ($P < 0.05$).

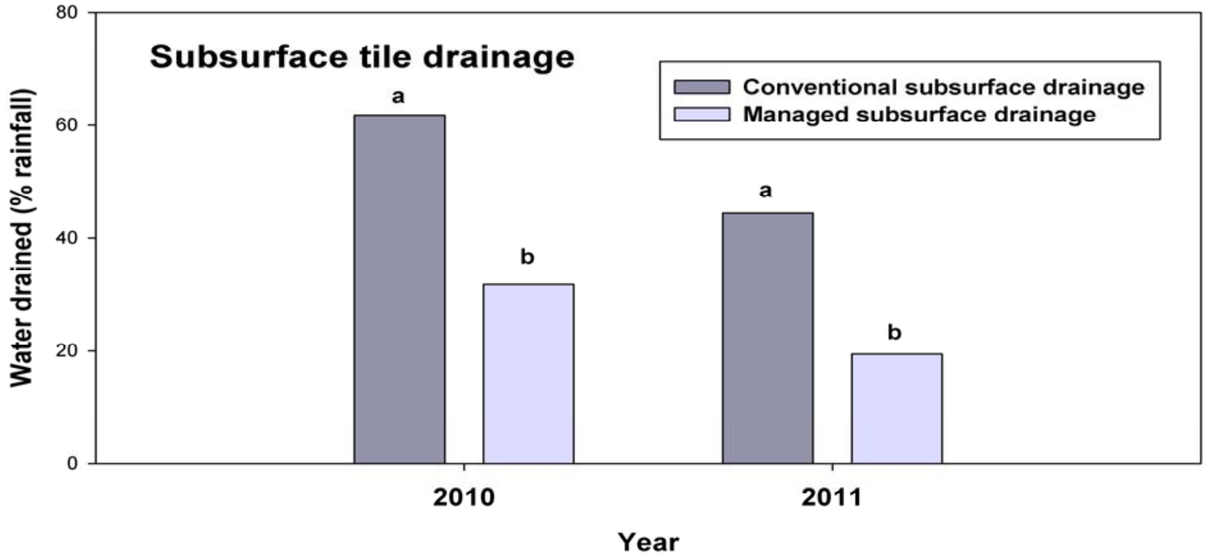

Figure 5. Total water drained with subsurface drainage due to the drainage system and expressed in the percent of rainfall received. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD ($P < 0.05$).

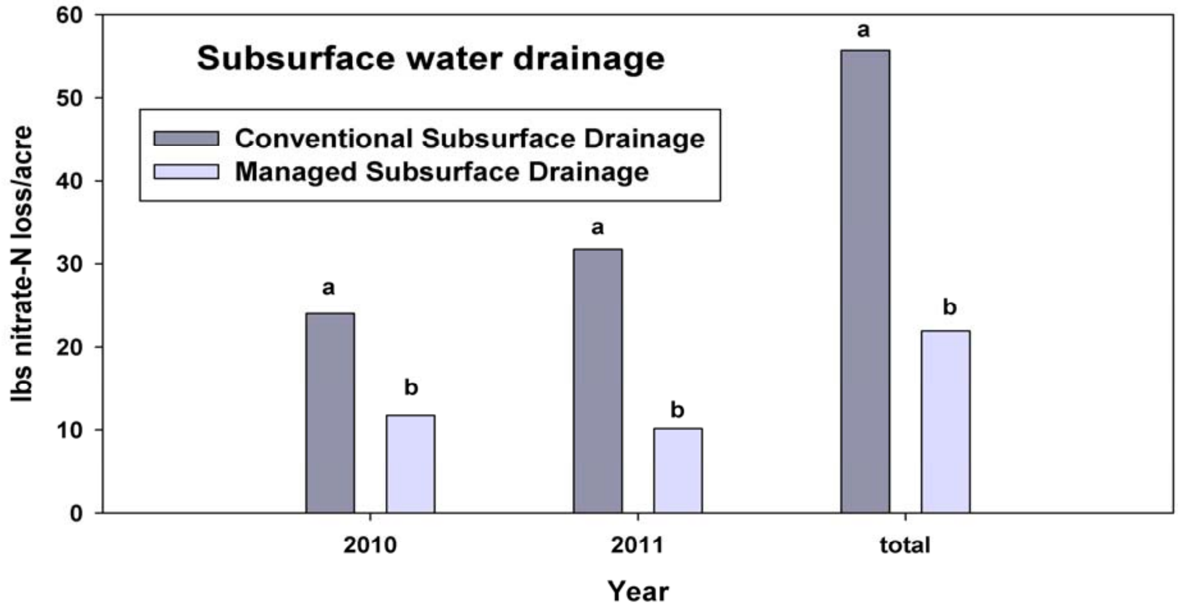

Figure 6. Annual nitrate-N loss in subsurface drainage water due to the drainage systems in 2010 (7-6-10 through 12-31-10) and 2011. Letters over bars indicate differences among treatments within a given year using Fisher's Protected LSD ($P < 0.05$).

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Food, Agricultural and Biological Engineering

590 Woody Hayes Dr., Columbus, Ohio 43210

Nitrogen and the Hydrologic Cycle

AEX-463-96

Larry C. Brown
Jay W. Johnson

Water is an abundant natural resource in Ohio. Ohioans use an estimated 14 billion gallons of water per day (BGD) for various beneficial purposes. This large amount of water fulfills public, rural (domestic and livestock), industrial, and crop and turf irrigation needs. Another much used resource is nitrogen. Nitrogen (chemical symbol N) is important as a plant nutrient for food and fiber production, and for lawn and turf management. Nitrogen is abundant in its atmospheric form, N^2 (nitrogen gas), which makes up 78 percent of our atmosphere. Most plants cannot use nitrogen in this form, but N^2 can be transformed into several other compounds that plants can use. The form and movement of nitrogen are greatly influenced by components of the hydrologic cycle, which is particularly important for agriculture and the environment.

Considering the abundance and importance of both nitrogen and water, Ohioans should understand how the forms and movement of nitrogen may be affected by contact with water. Of particular public concern is the occurrence of nitrate in drinking water supplies. The purpose of this publication is to provide the reader with an overview of the nitrogen cycle and how it relates to the hydrologic cycle, and to help increase the reader's awareness of human activities that impact the quality and quantity of Ohio's water resources. Water resources terminology used in this publication is defined in *Ground- and Surface-Water Terminology*, AEX 460, which provides a listing of generally accepted water resource definitions (available through your Ohio county office of Ohio State University Extension).

The Hydrologic Cycle

The Earth holds more than 300 million cubic miles of water beneath the surface, on the surface and in the atmosphere. This vast amount of water is in constant motion in a complex cycle known as the hydrologic cycle. The hydrologic cycle describes the pathways that water travels as it circulates throughout the world by various processes. Visible components of this cycle are precipitation and runoff. However, other components, such as evaporation, infiltration, transpiration, percolation, ground-water recharge, interflow and ground-water discharge are equally important. An in-depth discussion of the hydrologic cycle is beyond the scope of this publication. However, the reader should have an understanding of the components (refer to *Ohio's Hydrologic Cycle*, AEX 461).

The Nitrogen Cycle

Just as water moves through the environment, so does nitrogen, in various forms. The nitrogen cycle is a representation of the various forms of N and how they relate to one another through many complex interactions. Figure 1, a simplified nitrogen cycle, illustrates many of the complex interactions of various forms of nitrogen, including: atmospheric nitrogen (N^2), ammonia (NH_3), ammonium ion (NH_4^+), nitrite ion (NO_2^-), and nitrate ion (NO_3^-). Each nitrogen form has characteristics that relate to plant utilization and possible impacts on water resources.

Nitrogen Availability to Plants

For nitrogen, non-leguminous plants, such as lawn and turf grasses, corn and most fruit and vegetable crops, must rely on either bacteria that live in the soil to "fix" the nitrogen (N^2) into a usable form or nitrogen from decomposing organic matter, or fertilizers. The forms of nitrogen that most plants can use are ammonium ion (NH_4^+) and nitrate ion (NO_3^-), as shown in Figure 1. Of these, the ammonium and nitrate ions are the most common forms taken in through plant roots. Ammonium is converted to the nitrite and nitrate forms rather quickly by nitrifying bacteria, such as *Nitrosomonas .sp* and *Nitrobacter .sp*, which add oxygen to the ammonium ion and convert it to nitrate. However, the legumes, for example, alfalfa, clover, soybeans and peanuts, have nodules on their roots that contain bacteria. The plants benefit by having the bacteria that fix atmospheric nitrogen into a usable form for the plant, while the bacteria benefit from the energy obtained in the chemical conversion. **Note: The ammonia and nitrite forms of nitrogen are highly toxic to humans!**

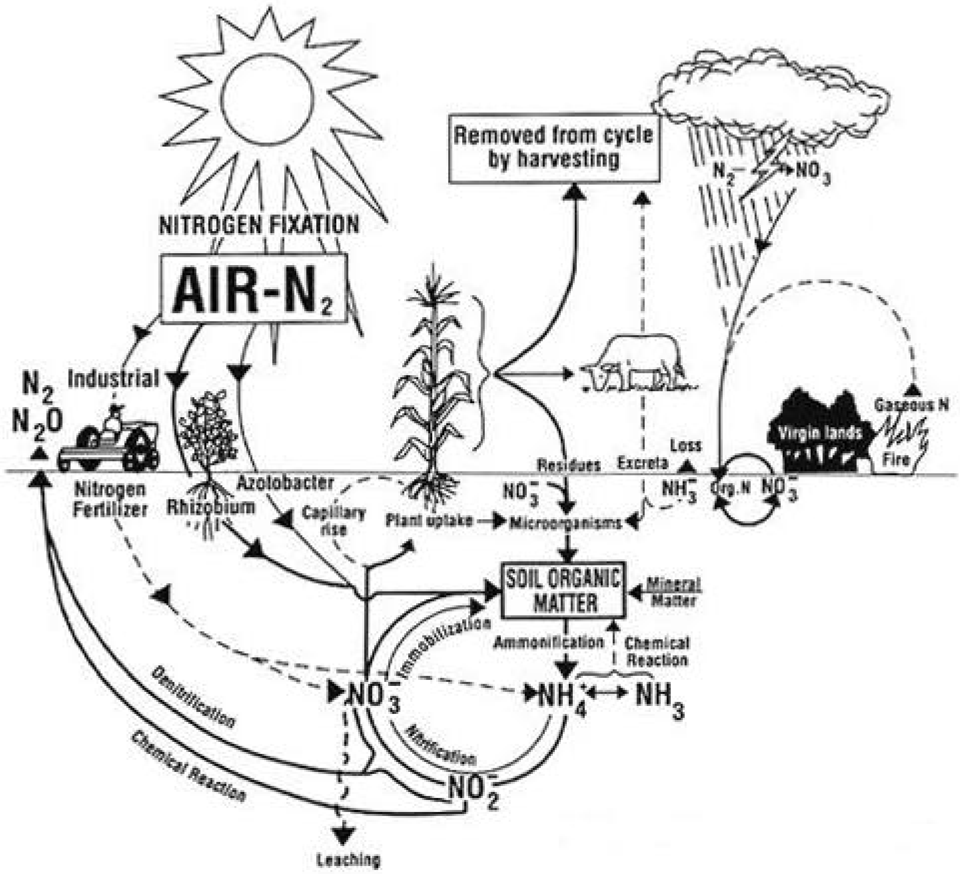

Figure 1. The nitrogen cycle in soil.

Nitrogen Loss from Availability to Plants

Nitrogen can become unavailable to plants primarily in three ways, which are illustrated in Figure 1. First, most nitrogen is lost through denitrification, which is a problem in wet or compact soils. Since these soils contain little oxygen, denitrifying bacteria remove the oxygen from nitrite (NO_2^-) and nitrate (NO_3^-) ions for their own use, releasing N^2 and/or N^2O back to the atmosphere. The second means of nitrogen loss is by nitrate leaching, which is a particular concern with the nitrate ion (NO_3^-). Leaching occurs when the water-soluble nitrate ion moves through the soil as water percolates downward beyond the reach of plant roots. Surface volatilization (conversion to the gaseous phase) is the third method of nitrogen loss. This loss occurs when ammonia (NH_3), usually in the form of urea, volatilizes and is lost to the atmosphere. Surface volatilization is usually a problem in areas with high temperatures, and with soils that have a high pH value. Soils that have been compacted by field operations and other human activities also are a problem because it may not be possible to properly mix the urea with the compacted soil. Another pathway for nitrogen loss from plant availability is the loss of the nitrogen through the process of soil erosion by water (discussed in a later section).

Nitrogen Cycle-Hydrologic Cycle: Interactions

Since nitrogen and water are so vital for all organisms, it is inevitable that components of the nitrogen and hydrologic cycles are closely related. These relations have particular importance for agriculture, and lawn and turf management. By understanding these interactions, we can better understand the effects of human activities on water resource quality.

Atmospheric Production

Nitrogen, mostly in the form of ammonium and nitrate, reaches the Earth's surface as a result of atmospheric lightning, precipitation and industrial pollution. Research in northern Ohio showed that the average annual nitrate concentration in rainfall, over a six-year period, was about 2 parts per million (ppm). This concentration translates to an average application of 17 pounds per acre per year (lb/ac-yr) for an average annual rainfall of 37 inches during the six-year study period.

Denitrification

Nitrifying organisms can only function when free oxygen (O_2) is present. In saturated soils, free oxygen is very low, suppressing the growth of the nitrifying organisms, often causing nitrogen deficiencies in excessively wet soils. This condition is enhanced by denitrifying bacteria since they thrive in an oxygen-free environment, like a saturated soil, and therefore consume nitrate at a rapid rate. Excessive rainfall promotes nitrogen loss not only by promoting nitrate leaching from the plant root zone, but also by creating wet soil conditions that favor denitrification. Evaporation works in the opposite way to remove water from the upper soil layers. Space then becomes available for oxygen, thereby making the environment suitable for the growth of nitrifying bacteria.

Surface Volatilization

In agricultural situations, surface volatilization (vaporization of urea to ammonia gas) may occur when urea is applied on crop residues, and not in good contact with soil particles. To limit volatilization of the urea, producers usually incorporate it into the soil by tillage to bring the urea into contact with the soil. Limited rainfall also helps with proper incorporation of the urea in the upper portion of the soil profile. When water and urea combine, the result is the ammonium ion (NH_4^+), which has a positive charge and attaches to negatively charged soil particles. Both tillage and rainfall can help make nitrogen available for plant use. Unfortunately, the interaction between tillage and excessive rainfall increases the potential for soil erosion. After tillage, the soil is more susceptible to being carried away by water during heavy rainfall.

Nitrogen Movement Through Soil

The nitrate ion (NO_3^-) is the most water-soluble form of nitrogen as well as the form least attracted to soil particles. Therefore, its interaction with the hydrologic cycle is very important since it moves where water moves. Precipitation, evaporation and transpiration may affect the movement of nitrate in the near-surface soil profile. Rainfall that infiltrates the soil surface may cause nitrate ions to move down through the soil profile by percolation. The more rain that infiltrates, the further down in the profile nitrate ions move. Nitrate movement below the plant root zone is called nitrate leaching. Soil texture, structure and permeability, along with other soil properties, affect nitrate leaching. Deep percolation of water through the soil profile potentially allows the movement of nitrate out of the root zone and downward, where it may pollute the underlying aquifer. In contrast to the nitrate ion, the ammonium ion has a strong attraction for soil, and therefore is considered to be immobile in most soils. However, in soils with very high sand and low organic matter contents, the ammonium ion will move in the direction of water movement.

Surface evaporation and transpiration may help nitrate move toward the soil surface within the root zone as a result of capillary movement as the plant withdraws water from the soil profile. Upward movement of nitrate occurs mainly in the summer when evaporation and transpiration exceed rainfall.

Nitrogen Movement to Surface Waters

Runoff contributes to the movement of several forms of nitrogen to surface water. Runoff results when the rainfall rate exceeds the infiltration rate at the soil surface. Runoff from agricultural and suburban watersheds carries sediment, as well as nutrients like nitrate and ammonium. Ammonium ions attach to sediments very readily, which means they move with soil, but generally do not leach. Therefore, ammonium may contribute to surface-water problems, but generally does not impact ground water.

Subsurface drainage improvements may contribute to the movement of the nitrate form of nitrogen to surface waters. Many agricultural soils with poor internal drainage require installation of drainage systems to promote a healthy environment for crop root development, and to improve nitrogen efficiency. Where nitrate is present in wet agricultural soils without proper drainage improvement, there is a great potential for nitrogen loss by denitrification if soil conditions (i.e., organic matter and temperature) are favorable. Ohio has approximately 12.5 million acres of existing cropland, of which about 50 percent has received drainage improvements. Research shows that not only can crop yields and economic stability be improved with drainage improvements on wet agricultural soils, but also that runoff and erosion rates can be reduced. In addition, rapid removal of excess water from the plant root zone decreases the potential for denitrification.

With subsurface drainage, some of the rainfall that infiltrates the soil surface is intercepted by the subsurface drainage system, and subsequently discharged to a ditch or stream. If nitrate ions are present in the soil profile, they will move with the percolating water. Subsurface drainage systems actually intercept the nitrate after it has been leached from the plant root zone, and before it has the opportunity to move by deep percolation to an underlying aquifer. Unfortunately, these systems may discharge nitrate in surface waters instead.

Subsurface drainage water generally will have a higher concentration of nitrate than runoff water, but considering the greater potential for movement of sediment, nitrate, ammonium and phosphorous in runoff, subsurface drainage water is generally of better quality. The loss of nitrate in subsurface drainage water is not a simple matter to resolve since it is related to rainfall timing and amount, soil profile characteristics, subsurface water flow rate (soil-dependent), nitrogen application rate and timing, and the extent of plant uptake of the nitrate available in the soil profile.

Nitrogen from Organic Materials

Another source of nitrogen that has potential for water resource pollution is organic materials, such as animal manure, municipal sludge, septic system sludge and plant materials (leaves, stalks, etc.). When incorporated into the soil, these materials are broken down by microbiological decomposition, which produces a number of benefits for the soil. One product is the ammonia form of nitrogen. Ammonia can be transformed easily into the ammonium or nitrate ion, both of which can be used by the plant. However, if organic materials enter a water resource, such as animal wastes from a feedlot being washed into a nearby stream during rainfall, the potential for two problems exists. First, ammonia, which is produced by bacterial decomposition of the organic material, is highly toxic to fish depending on the pH and temperature of the water. Second, as the microorganisms break down the organic materials in the water, they consume much oxygen during the process. The resulting oxygen depletion can cause a fish kill.

Ground- and Surface-Water Interactions

In many parts of Ohio, ground and surface waters are physically connected. Therefore, the potential exists for water-mobile nitrate to move from surface waters, such as lakes and streams, to aquifers through the process of ground-water recharge. Nitrate movement through ground-water recharge has a greater potential in areas of the state underlain by sand and gravel aquifers. Likewise, nitrate may move from ground water to surface-water bodies through the process of ground-water discharge, although the potential for this mode of nitrate movement is lower than for ground-water recharge.

Nitrate in Drinking Water Supplies

Nitrate has been detected in ground- and surface-water supplies in various parts of the state. Low levels of nitrate can be found in most of the surface waters of the state throughout the year. In a recent statewide survey of water wells, a small percentage contained excessive nitrate concentrations. In cases where the concentration of nitrate-nitrogen exceeds the maximum contaminant level of 10 mg/L, as set forth by the U.S. Environmental Protection Agency, water suppliers are required to issue a nitrate alert to users. The health of infants, the elderly and others, and certain livestock may be affected by the ingestion of high levels of nitrate. It is beyond the scope of this publication to fully address this important water resource issue. For more information on nitrate in drinking water, refer to *Nitrate in Drinking Water* (Bulletin 744).

Summary

Water and nitrogen are important resources in Ohio. Both are necessary for human existence, plant growth and food production. The components of the nitrogen and hydrologic cycles interact in numerous ways to affect Ohio's water supply. Many human activities (urban, rural, industrial and agricultural) have an influence on these interactions, and thus the quantity and quality of our water resources (refer to *Nonpoint*

Source Pollution: Water Primer, AEX 465). To make wise decisions about the proper use and protection of these resources, we must be aware of how the various components of these complex cycles affect one another. This publication presents an overview of the nitrogen cycle and how it relates to the hydrologic cycle. The main intent of this publication is to help increase the reader's awareness of human activities that impact the quality and quantity of Ohio's water resources.

For more information on this or other water resources topics, refer to the publications listed below, or contact your Ohio county office of Ohio State University Extension.

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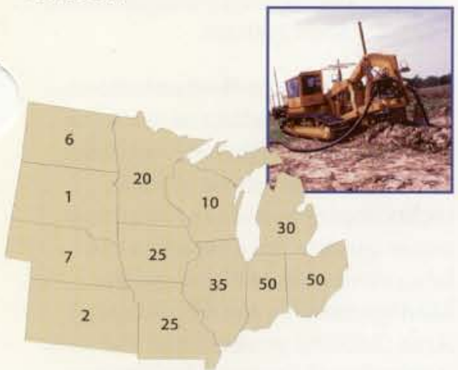
Agricultural Drainage and Nitrate

MSEA • Management Systems Evaluation Areas

Agricultural drainage: status and importance... Agricultural drainage is a method for lowering the water table to prevent flood damage of crops and enhance access to fields for planting and harvesting. Drainage is required for food production on a large portion of the tillable soils in the Midwest. According to a 1982 survey completed by the USDA Natural Resources Conservation Service, there are over 233 million acres of wet soils on private, rural land in the U.S. Of this total, 45 percent was cropped and 30 percent forested.



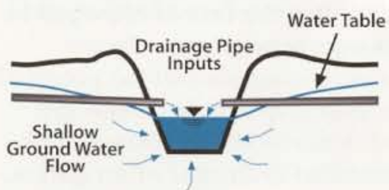
Percent of all cropland that is drained in each North Central state (1985 USDA data).

How subsurface drainage works... Conventional drainage methods involve installing underground (subsurface) drainage pipes that outlet into a ditch or stream. The water table is lowered to the depth of the drainage pipe by the force of gravity.

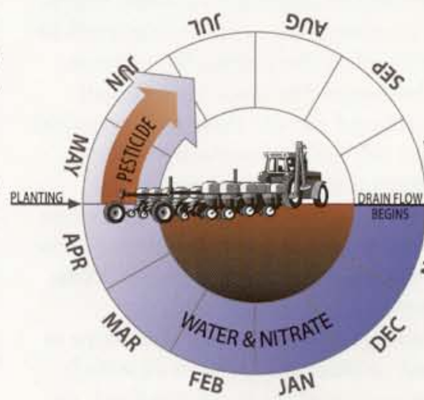
Subsurface Drained Cropland

Surface water quality impacts of subsurface drainage... A water quality benefit of subsurface drainage is that more water infiltrates the soil and there is less runoff. Runoff carries sediment and attached nutrients to surface waters. Sediment loss is reduced by up to 65% and phosphorus loss by up to 45% on cropland with subsurface drainage. An adverse effect of subsurface drainage is that water soluble chemicals and plant nutrients (such as nitrate-nitrogen) in shallow ground water can move from the soil to surface waters by means of the drainage system.

Nitrate-nitrogen concentrations greater than 10 mg/L in drinking water supplies (U.S. EPA maximum contaminant level for drinking water) may impact human health. Nitrate can also contribute to the condition of hypoxia, or low dissolved oxygen levels in freshwater and marine systems. Agriculture is not the only source of nitrate. Sources of nitrogen include crop and lawn fertilizers, crop residues, animal manures, organic soils, septic tank effluent, municipal sewage wastes, industrial wastes, and industrial atmospheric by-products.



Understanding how and when, nitrate loss occurs... Nitrogen is continuously cycled within the soil-plant-air system, and its availability is weather-dependent. These natural processes make it difficult to predict exact nitrate losses ahead of time. Nitrate can be present in drainage water at all times of the year that drainage occurs. Most drainage flow and nitrate loss occurs from November to May when crops are not growing. This contrasts with the timing of pesticide loss which mostly occurs soon after application in the spring.

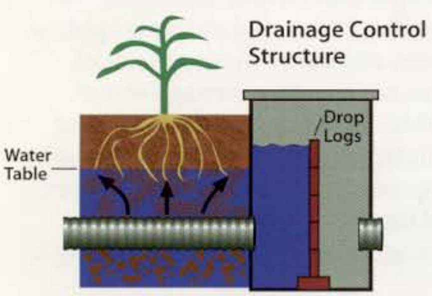


Pesticides generally degrade faster than nitrate and are held more tightly by the soil. Thus, they are less available for transport later in the year. Nitrogen is more likely to remain available in the soil after plant growth requirements have been met. Methods to minimize nitrate loss include managing the rate and timing of nitrogen application, and better management of drainage waters through water table management. Both of these strategies prevent the build-up of excess nitrate in soils during times of the year when plants are not growing and drainage flow is high.

Reducing nitrate loss by changing the rate and timing of nitrogen application... When nitrogen application is more closely matched to the needs of the crop, nitrate leaching can be reduced substantially. Applying nitrogen at the optimal rate and time of year for plant uptake reduces the amount of unused nitrogen in the soil and the potential for leaching. However, a change in application regime is not always practical for farmers.

Further research will investigate the practicality of different cropping, tillage, and fertilization systems, and provide specific nitrogen recommendations for the Midwest's different climate zones.

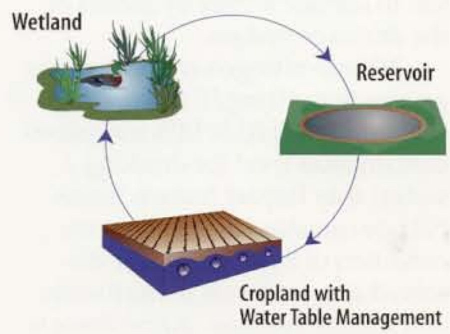
Reducing nitrate loss using innovative methods of drainage water management... Another way to reduce the amount of nitrate leaving fields is to more intensively manage the movement of shallow ground water. Conventional subsurface drainage systems work by lowering the water table level to the level of the subsurface drains. Subsurface drainage waters and associated nitrate flow uncontrolled from the field to surface waters. Water table management is the practice of controlling the drainage flow and water table level using the subsurface drainage system. With controlled drainage and/or subirrigation, a control structure is used to manage the rate at which drainage water leaves the field, or to pump water back into the drainage system. A crop production benefit is that water tables can be raised during dry weather to irrigate the crops from beneath the soil surface (subirrigation). Drainage during wet weather is maintained to prevent the flooding of crops.



This controlled release of drainage water keeps soil below the root zone wet for a longer period of time. Wet soil is a favorable condition for conversion of left-over nitrate to the gaseous form of nitrogen by soil microorganisms (denitrification). Nitrate at deeper soil depths has little value to plant growth and is susceptible to leaching. During the non-growing season when plants do not require nitrogen, water table levels can be raised higher to create seasonal wetland-like conditions.

Linking drainage water and wetlands to reduce nitrate loss... In addition to promoting denitrification, some water table management systems link subsurface drainage systems with wetlands and/or riparian areas that capture, treat, and recycle drainage water.

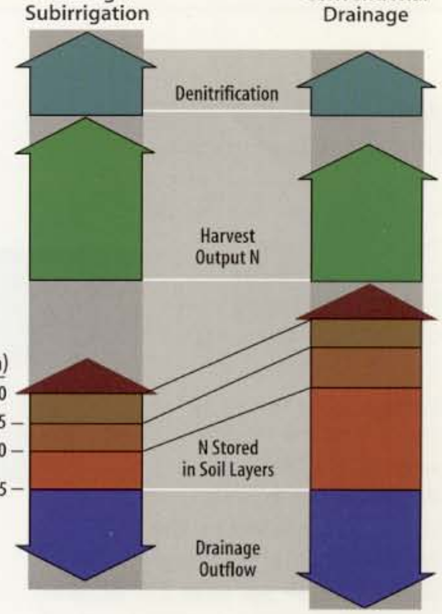
Field-scale demonstration of agricultural drainage systems linked to wetland and/or riparian systems are being studied under real-world farming conditions to learn the full range of costs and benefits for landowners and the environment.



The projected benefits of new drainage water management techniques include improved crop yields, improved water quality, and increased riparian and wetland areas.

Changing the fate of nitrogen in the agroecosystem... Recent research suggests that the potential for both crop uptake of nitrogen and denitrification increases with controlled drainage/subirrigation, and the loss of nitrogen to drainage waters decreased when compared to conventionally drained cropping systems. Further research will investigate the cycling of nitrogen and water in agroecosystems.

Fate of Nitrogen in the Agroecosystem



The arrows indicate how much nitrogen goes into air, plant matter, soil and drainage components of the agroecosystem with managed versus conventional systems.

Collaborating to find solutions... Better understanding of nitrogen cycling in agricultural ecosystems, and the development of new technologies to manage drainage water quality are a result of collaborative research such as the Management System Evaluation Area (MSEA) projects and the new Agricultural Systems for Environmental Quality (ASEQ) projects. These comprehensive research and educational efforts provide solutions that meet environmental, economic and food production objectives.

An extensive bulletin on agricultural subsurface drainage and water quality in the Midwest is available through MSEA Project offices in Ohio, Minnesota, and Iowa. Contact: Ohio MSEA at (614) 292.3826 or brown.59@osu.edu.

THE OHIO STATE UNIVERSITY EXTENSION

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