MANAGED DRAINAGE FOR IMPROVED WATER QUALITY

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Agriculture 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 (NO_3-N) load up to 75% (Frankenberger et al., 2006) and sustaining agricultural viability (Belcher and D'Itri, 1995). Designing systems for IWMS or managed drainage is a step toward improved water quality. A demonstration site was established at the University of Missouri, Ross Jones Farm in 2010 to provide stakeholders with the necessary information to visualize an IWMS that minimizes environmental impacts.

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 NO_3-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 (Fausey et al. 1995). 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 (NO_3) 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 NO_3-N levels; however, research has reported that water-level management using an IWMS reduced nonpoint source dissolved NO_3-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 soil-water level management is a technological advancement in soil and water management systems. Drainage water management (NRCS Practice 554) conservation practice standard has been outlined by the 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. We will be using RUSLEII to model soil loss and total suspended solids (TSS) to quantify the improved water quality. An adverse effect of subsurface drainage is that water soluble chemicals and plant nutrients such as NO_3-N can move from the soil to surface waters via the drainage system. Nitrogen is continuously cycled within the soil-plant-air systems and availability is weather-dependent which makes it difficult to predict NO_3 losses. Nitrate-N removed through subsurface drainage (88-95%) generally occurs when there is no crop in the field (Kladivko et al. 1999; Drury et al. 1996). The lowest NO_3-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 MU Drainage and Subirrigation (MUDS) demonstration site. Fogiel and Belcher (1991) had more NO_3-N loss through the surface drainage in treatments without subsurface drainage than from an IWMS. Although an IWMS may increase the amount of NO_3 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 NO_3-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 NO_3-N 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 (Figure 1). 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 NO_3-N 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. 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 NO_3 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. An IWMS could be utilized as part of a voluntary nutrient trading program when state and/or federal cost-share programs are used to provide financial assistance in the installation and implementation of this technology.

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 may remain in the soil profile (Nelson et al. 2009) and be susceptible to loss (Blevins et al. 1996). Drainage water management is an accepted NRCS conservation practice standard (practice 554) and has been implemented by other states as part of an Environmental Quality Incentive Program (NRCS, 2002). The crop production benefits of drainage and drainage plus subirrigation have been demonstrated (Nelson et al. 2007; Nelson et al. 2009; Nelson and Meinhardt 2011; Nelson et al. 2011); however, the water quality benefits for reducing sediment loss and preventing NO_3-N loss have not been demonstrated. The MUDS demonstration site should complement previous results and demonstrate reduced NO_3 loss from drain tiles, reduced sediment loss, and reduced phosphorus loss.

The project area encompasses the major land resource area referred to as the Central Claypan. Over 10 million acres of claypan soils are found in the Midwestern U.S. with over 5 million acres in Missouri. This site is representative of other watersheds on the 303(d) List of impaired waters with similar soil characteristics. The particular demonstration site has subsurface drainage tile installed with water-level control devices as part of an integrated agricultural water management system (IWMS). This site was established to demonstrate the implementation of an IWMS to manage drainage water for reduced total suspended solids (TSS), ortho-P, TP, TN, and NO_3-N loss. This practice could apply to surrounding 303(d) Listed watersheds such as: Blackbird Creek in Putnam County (10.5 miles, sediment, M priority); E. Fork Medicine Creek in Mercer and Grundy Counties (36 miles, sediment, M priority); Edina Reservior in Knox County (51 acres, atrazine & cyanazine, H priority); Honey Creek in Grundy and Livingston Counties (23 miles, sediment, M priority); L. Medicine Creek in Putnam and Grundy Counties (40 miles, sediment, M priority); LaBelle #2 Lake in Lewis County (112 acres, atrazine & cyanazine, H priority); Lewistown Reservior (27 acres, atrazine & cyanazine, H priority); M. Fork Grand River in Gentry and Worth Counties (25 miles, sediment, M priority); M. Fork Salt River in Monroe and Macon Counties (49 miles, sediment, M priority); Monroe City Rt. J Lake (94 acres, atrazine & cyanazine, H priority); Mussel Fork from Sullivan to Macon County (29 miles, sediment, M priority); N. Fabius River from Schuyler to Marion County (82 miles, sediment, L priority); S. Wyaconda River from Scotland to Clark County (9 miles, sediment, M priority); and Troublesome Creek in Marion County (3.5 miles, sediment, M priority).

The goals of the project are to: 1) demonstrate the effect of subsurface drainage on surface water runoff, total suspended solids (TSS) and phosphorus [ortho-P and total phosphorus (TP)] loss; 2) demonstrate the effects of managed drainage on reduced NO_3-N and total nitrogen (TN) loss, and 3) initiate educational programs and demonstration field days of IWMS best management practices (BMPs). The following work elements describe the goals 1 and 2 in more detail.

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 will run off of the soil surface of the field area, be 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. This prevents 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 (Figure 2). 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 are able to quantify the amount of surface water runoff and subsurface water removal for a subsurface drainage system in a claypan soil. This demonstrates the amount of surface water runoff that occurs with an IWMS during the winter months when there is regulated water flow. Continuous flow measurements allow us to quantify total flow from surface water runoff and subsurface water flow and will be utilized to calculate nitrate (NO_3-N), total nitrogen (TN), phosphorus (ortho-P and TP) and total suspended solids (TSS) loading in Work Element #2. The RUSLEII model will be used to estimate sediment runoff reductions from the field sites under the implemented management systems.

In 2011, anhydrous ammonia was spring applied for the corn plots (Figure 2) at 180 lbs N/acre. 'DKC63-42' was no-till planted at 30,000 seeds/acre on April 14. Soybean, 'Asgrow 3803', was no-till planted at 180,000 seeds/acre in 15 inch rows on May 11. Standard crop protection programs were used for both crops to control weeds. The water level control structures in plots 303 and 304 were shifted to subirrigation mode on July 5, 2011. One of the plots, corn with drainage only (# 311), was used to demonstrate surface water runoff flow rates and subsurface water flow rates through the drainage tiles (Figure 3). Surface water runoff flow rates were generally higher than subsurface drainage flow rates and corresponded well with rainfall events at this location. Further analysis of the data will be completed on individual plots.

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 will utilize NO_3-N, TSS, and ortho-P measurements to demonstrate the benefits of an IWMS on water quality. Water flow rates will be determined to quantify load at the outlet.

This work element utilizes water samples and surface runoff calculations from Work Element #1 to determine total nitrogen (TN) NO_3-N, TSS, total phosphorus (TP), and ortho-P concentrations and demonstrate the benefits of an IWMS on water quality. Automated water quality monitoring sample collection will be utilized throughout the growing season, while grab samples will be 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 occurred which signaled the sampler to collect water samples. In addition, a grab sample from the pond used as a subirrigation water source and catchment for subsurface drainage water will be taken to demonstrate the effect of subsurface drainage water discharge on impoundment water quality. Modeling using RUSLEII will be utilized to quantify soil loss compared to expected loss with conventional tillage to quantify potential sediment loss. Measured TSS loss will help validate expected soil loss using RUSLEII. The expected outcomes for water quality data in this project are to estimate NO_3-N , TSS, TN, TP, and ortho-P load reductions in the presence and absence of an IWMS. These data will allow the performance of an IWMS to be evaluated based on direct estimation of N, P, and TSS loss via surface or subsurface water flow.

In plot #311, the NO_3-N concentration in the subsurface water samples collected from June 17 to 18 varied over time and ranged from over 80 mg/L (initial flow) to 5 mg/L (high flow rate) (Figure 4). Similarly, surface water NO_3-N concentrations from May 25 to May 26 ranged from 7 mg/L to 35 mg/L (Figure 5). This indicates that there was nitrate loss from the site through surface water runoff and subsurface drainage flow. This data will be used to estimate load reductions in the presence and absence of an IWMS. The system was shifted to subirrigation mode on July 5 and data collection is ongoing.

This project was initiated in 2010 and current demonstrations are underway. Environmental Protection Agency Region 7 through the Missouri Department of Natural Resources has provided partial funding for this project under Section 319 of the Clean Water Act. MoDNR Subgrant G10-NPS-02.

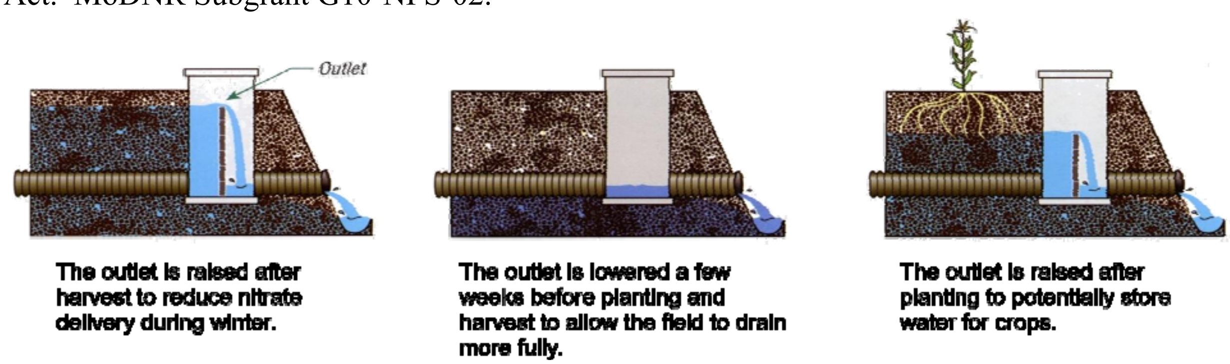

Figure 1. An integrated water management system uses controlled drainage to vary the depth of the drainage outlet.

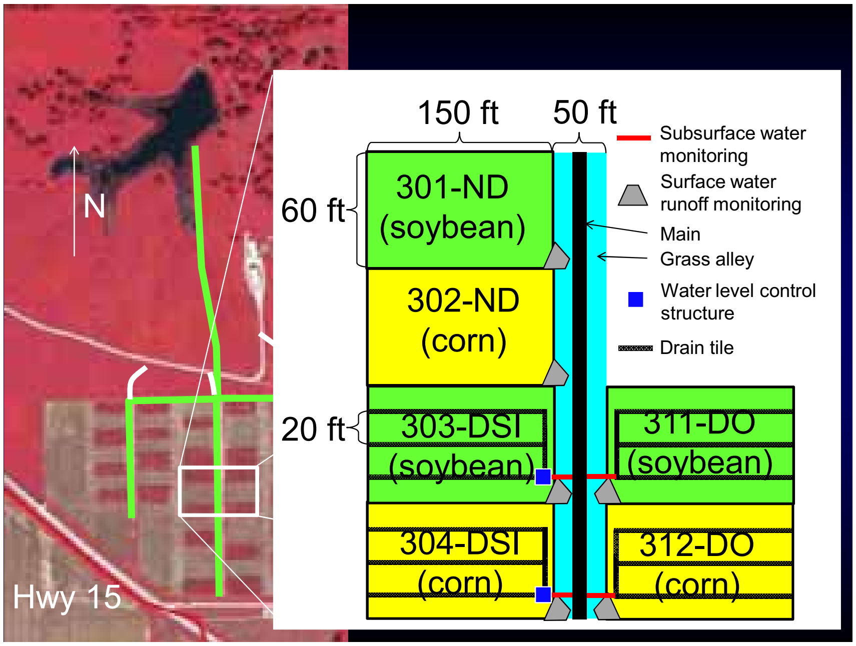

Figure 2. Overhead infrared site map with an outline of individual water management systems. Sampling points for surface and subsurface water monitoring for the non-drained (ND), drainage/subirrigation (DSI), and drainage only (DO) areas in corn (yellow in 2010) and soybean (green in 2010). The corn and soybean will rotate in 2011. A plastic border will be trenched around each 60 by 150 ft area to prevent lateral water flow. A levee plow was used to create a border around each area to contain water within each delineated area. The water supply lake is located near the top of the site map.

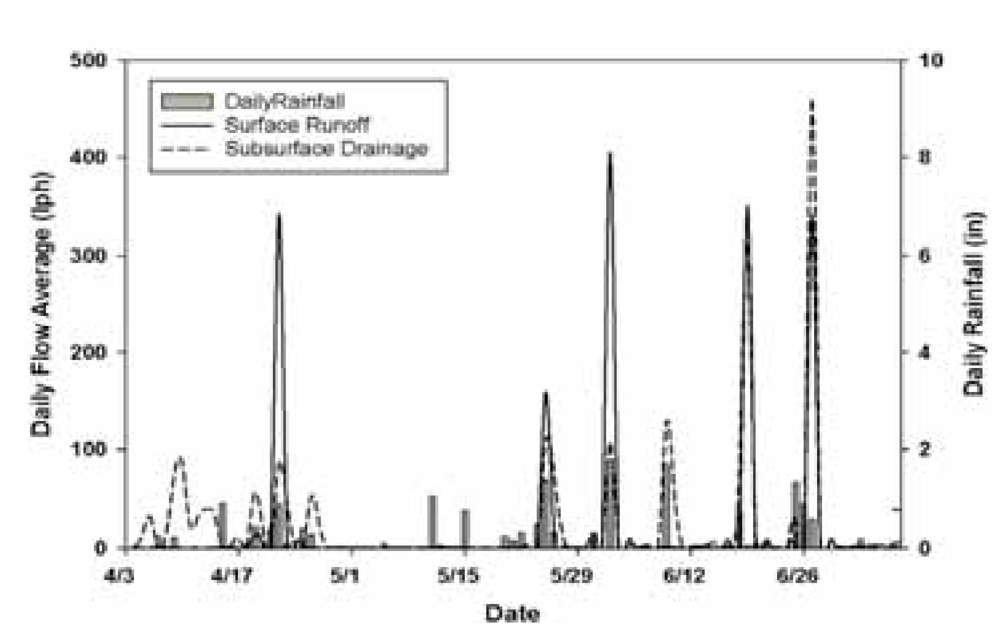

Figure 3. Surface and subsurface water flow rates from April until June in plot #311. This area was planted to corn in 2011.

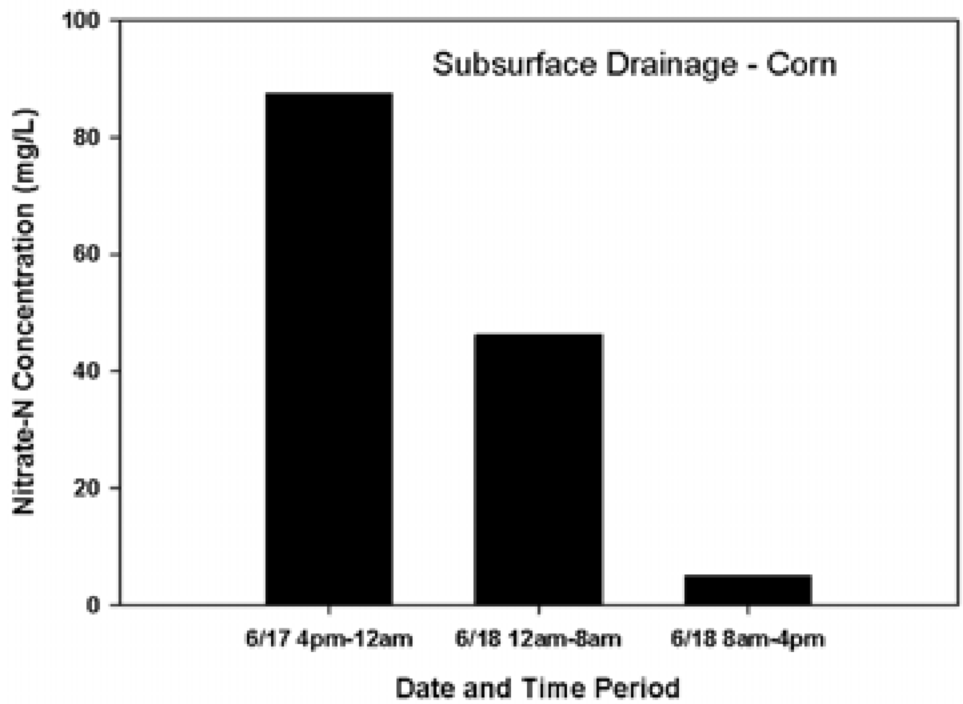

Figure 4. Subsurface drainage water nitrate-N concentration during a mid-June rainfall event in plot #311 in 2011.

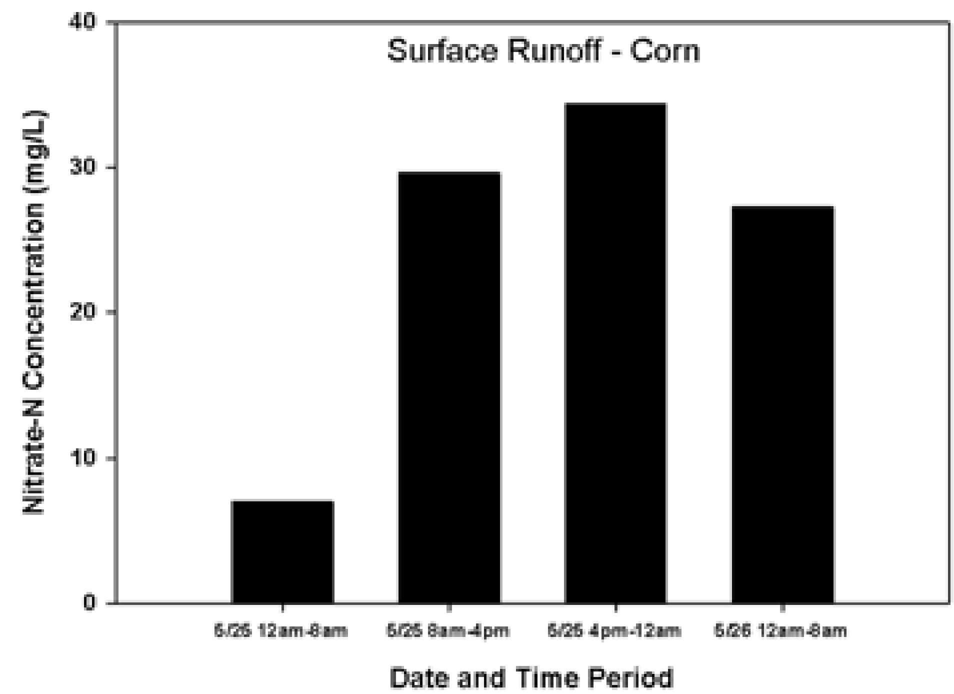

Figure 5. Surface water nitrate-N concentration during a mid-June rainfall event in plot #311 in 2011.

References

Baker, J.L., and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10:519–522.

Belcher, H.W. and F.M. D'Itri (Eds.). 1995. Subirrigation and controlled drainage. Lewis Publishers, Boca Raton, FL. pp. 482.Blevins, D.W., D.H. Wilkinson, B.P. Kelly, and S.R. Silva. 1996. Movement of nitrate fertilizer to glacial till and runoff from a claypan soil. J. Environ. Qual. 25:584-593.

Drury, C.F, C.S. Tan, J.D. Gaynor, T.O. Oloya, and T.W. Welacky. 1996. Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. J. Environ. Qual. 25:317-324.

Fausey, N.R., L.C. Brown, H.W. Belcher, and R.S. Kanwar. 1995. Drainage and water quality in Great Lakes and cornbelt states. J. Irrigation and Drainage Engineering 121:283-288.

Fogiel, A., and H.W. Belcher. 1991. Research literature review of water table management impacts on water quality. Agricultural Engineering Dept., Michigan State Univ., East Lansing, MI.

Frankenberger, J., E. Kladivko, G. Sands, D. Jaynes, N. Fausey, M. Helmers, R. Cooke, J. Strock, K. Nelson, and L. Brown. 2006. Drainage water management for the Midwest: Questions and answers about drainage water management for the Midwest. Purdue University Coop. Ext. WQ-44. pp. 8.

Jebellie, S.J., and S.O. Prasher. 1998. Role of water table management in reducing metribuzin pollution. Trans. ASAE 41:1051-1060.

Jebellie, S.J., and S.O. Prasher. 1999. Effect of subirrigation on the mobility of atrazine. Trans. ASAE 42:391-402.

Kladivko, E.J., J. Grochulska, R.F. Turco, G.E. Van Scoyoc, and J.E. Eigel. 1999. Pesticide and nitrate transport into subsurface tile drains of different spacings. J. Environ. Qual. 28:997–1004.

Kalita, P.K., and R.S. Kanwar. 1993. Effect of water-table management practices on the transport of nitrate-N to shallow groundwater. Trans. ASAE 36:413-422.

Liao, N., and S. Marten, 2000. Determination of total phosphorus by flow injection analysis colorimetry (Acid perusulfate digestion method; 10-115-01-1-F). Zellweger Analytics, Lachat Instruments, 6645 West Mill Road, Milwaukee, WI 53218-1239. pp. 26.

Munster, C.L., R.W. Skaggs, and V.R. Pemmireddy. 1996. Effect of water table management on the fate of the pesticide aldicarb. 39:55-66.

Nelson, K.A., and C.G. Meinhardt. 2011. Soybean yield response to pyraclostrobin and drainage water management. Agron. J. 103: 1359-1366.

Nelson, K.A., S.M. Paniagua, and P.P. Motavalli. 2009. Effect of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. Agron. J. 101:681-687.

Nelson, K. and R. Smoot. 2007. MU drainage and subirrigation (MUDS) update. Greenley Research Center Field Day Report. pp. 19-28.

Nelson, K.A., R.L. Smoot, and C.G. Meinhardt. 2011. Soybean response to drainage and subirrigation on a claypan soil in Northeast Missouri. Agron. J. 103:1216-1222.

NRCS. 2002. Drainage water management (DWM). NRCS Conservation Practice Standard Code 554. NRCS, IL. pp. 4.

NRCS. 1983. Engineering field manual notice MO-14. USDA, SCS. pp. 19.

Skaggs, R.W., M.A. Breve, J.W. Gilliam. 1994. Hydrologic and water quality impacts of agricultural drainage. Critcal Rev. in Environ. Sci. and Technol. 24:1-32.
Smith, M., P. Blanchard, W. Smith, and G. Smith. 1999. Atrazine management and water quality. MU Extension, University of Missouri-Columbia. Missouri Manual 167. pp. 16.

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