DRAINAGE WATER MANAGEMENT: A PRACTICE FOR REDUCING NITRATE LOADS FROM SUBSURFACE DRAINAGE SYSTEMS

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Introduction

Drainage water management (DWM) is a practice in which the outlet from a conventional drainage system is intercepted by a water control structure that effectively functions as an in-line dam, allowing the drainage outlet to be artificially set at levels ranging from the soil surface to the bottom of the drains as shown in Figure 1.

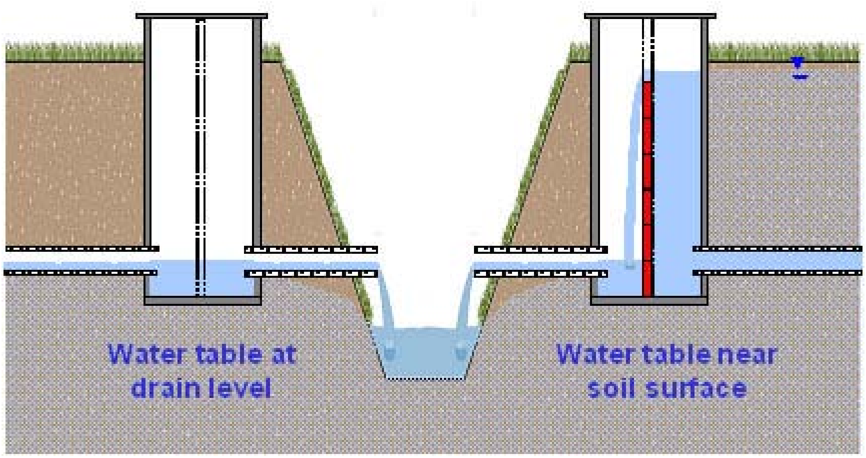

Figure 1. Using control structures to manipulate water table levels.

Two types of structures in common usage are shown in Figure 2. Water table level is controlled with these structures by adding or removing “stop logs” or using float mechanisms to regulate the opening/closing of a flow valve. There are many variations in the shapes and sizes of structures. Gate structures may either be manually operated or automated to adjust the water table level on fixed dates or in response to rainfall patterns.

Drainage water management practices can target agronomic goals, environmental (water quality) goals, or both. The drainage outlet can be set at or close to the soil surface between growing seasons to recharge the water table, thereby temporarily retaining contaminated water in the soil profile where it will be subjected to attenuating and nitrate transforming processes. In addition, it is possible to raise the outlet after planting to help increase water availability to then shallow plant roots, and to raise or lower it throughout the growing season in response to weather conditions. In some soils, water may even be added during very dry periods to reduce crop loss from drought, and this practice is termed subirrigation. However, the drain spacing for subirrigation has to be half the recommended value for drainage in order for the addition of water to be very effective.

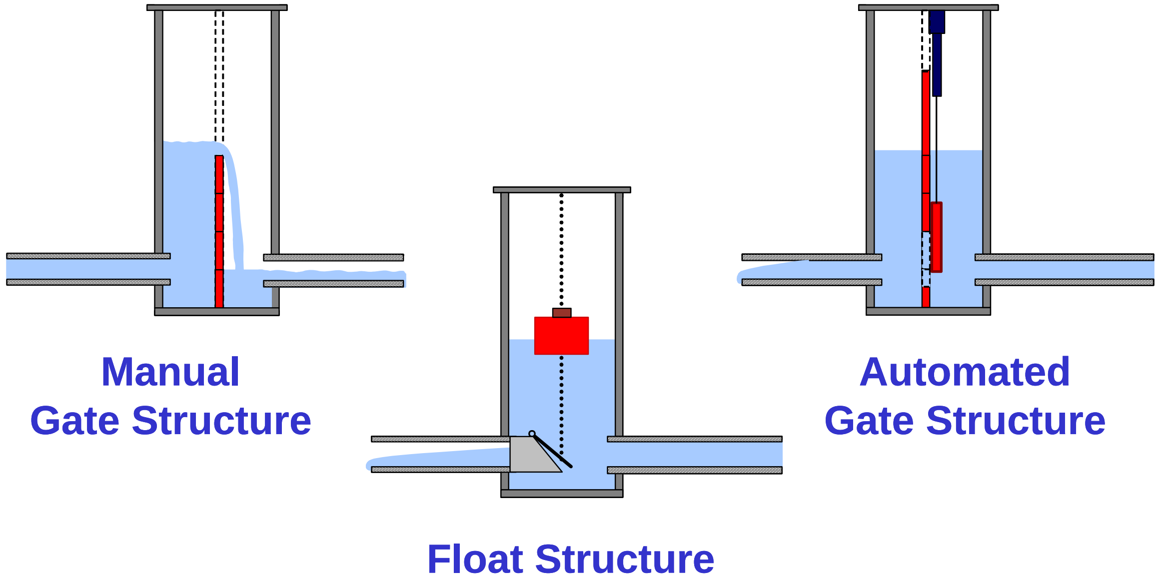

Figure 2. Types of water table control structures

In recent studies, no significant differences in nitrate concentrations have been measured in paired fields with conventional and drainage water management systems. The general consensus is that the dominant process leading to reductions in nitrate loads is a reduction in drain outflow. There is less water leaving the field through the drain pipe, and therefore, less nitrate flowing out of the drain, even if there is no change in nitrate concentration. There may be instances, however, where the implementation of drainage water management leads to increased denitrification.

The installation of drainage water management control structures is guided by National Handbook of Conservation Practices (NHCP), Practice Standard 554, Drainage Water Management (NRCS 2005). Several states have developed local variations of this standard.

Potential

Various researchers have found that drainage water management leads to reductions in chemical transport from agricultural fields. Munster et al. (1995) reported a decrease in aldicarb concentrations when drainage water management was implemented on cultivated fields in North Carolina. In a three-year experiment in Iowa, Kalita and Kanwar (1993) examined the effect of outlet level on crop yield and nitrogen concentration in a drainage water management system. They observed a reduction in nitrate concentration for all outlet levels, and an increase in crop yield for most. They also found, however, that it was possible to obtain reduced yields by holding the water table too close to the soil surface during the growing season. Drury et al. (1996) reported a 25% decrease in mean nitrate concentration, and a 49% decrease in the total annual nitrate load when drainage water management was implemented on clay loam soil in Southwestern Ontario. They did not report the effect on crop yield. Lalonde et al. (1996), working with two-year corn/soybean rotation on a silt loam soil in Quebec, measured nitrate concentration reductions of 76% and 69%, compared to conventional drainage, for two outlet levels in drainage water management systems. Cooper et al. (1991) reported increased yields ranging from 23 to 58% over three years from establishing a controlled drainage system in Ohio. In their experiment, the control plots were not drained and water was added to maintain a constant water table level. Thus, their results are not necessarily representative of the advantages of moving from conventional drainage to drainage water management. Taken together, however, all these results indicate that drainage water management appears to benefit the environment without adversely affecting yields, if properly managed.

A conservative estimate by consensus of drainage researchers is that drainage water management can lead to a 30% reduction in average annual nitrate loads in regions where appreciable drainage occurs in late fall and winter. This figure is based on results from North Carolina where the practice has been implemented for close to two decades, and preliminary research results in the Midwest. Measured average annual nitrate-N concentrations from drained fields in Illinois range from 8 to 19 mg/L depending on cropping practice and the timing of fertilizer application, while average annual nitrate losses ranged from 79 to 115 kg/ha (Algoazany et al., 2005). Based on the 30 % estimate, the practice would lead to loading reductions of 24 to 35 kg/ha.

Currently, there are no good estimates of the extent in the Midwest to which drainage water management systems have been adopted. With the exception of several research and demonstration sites, this practice is a fairly recent introduction to the region, with the majority of systems being installed in the last five years. However, the practice is catching on, partly because of the potential benefits to the environment, and partly because of perceived yield benefits.

Important factors

Drainage water management is best suited for flat, uniform fields with soils that require artificial subsurface drainage. The practice is generally recommended for fields with slopes of 1% or less, but it may be considered for fields with slopes up to 2%. As a control structure is recommended for each 30- to 45-cm change in field elevation, the cost of a system increases with increasing slope because more structures are required. The practice is also not recommended in instances where elevating the water table would have an adverse effect on adjacent fields.

Under prolonged dry conditions, there may not be enough water (from rainfall) to maintain an elevated water table, and drainage water management systems will not offer an advantage over conventional drainage systems (for yield or water quality). Under these conditions the transport of nutrients through drainage systems is not a significant problem. Under prolonged wet conditions, the proportion of water retained by elevating the water table will be insignificant and consequently, drainage water management systems may not be effective.

Limitations

According to 1985 estimates there are close to 13 million hectares in the Midwest (Iowa, Illinois, Indiana, Ohio, Michigan Minnesota, Missouri, and Wisconsin) that have some degree of subsurface drainage. Figure 3 shows the areas that have the potential to benefit from subsurface drainage based on drainage class (poorly, or very poorly drained), hydrologic soil groups (hydrologic soil groups C and D) and slope (less than two percent). Theoretically, drainage water management could be implemented on all of these areas. However, there are practical limitations on a portion of these areas, such as the fact that many existing drainage systems were not designed for drainage water management making retrofitting expensive, and that the practice is economically challenging on some slopes greater than 1%.

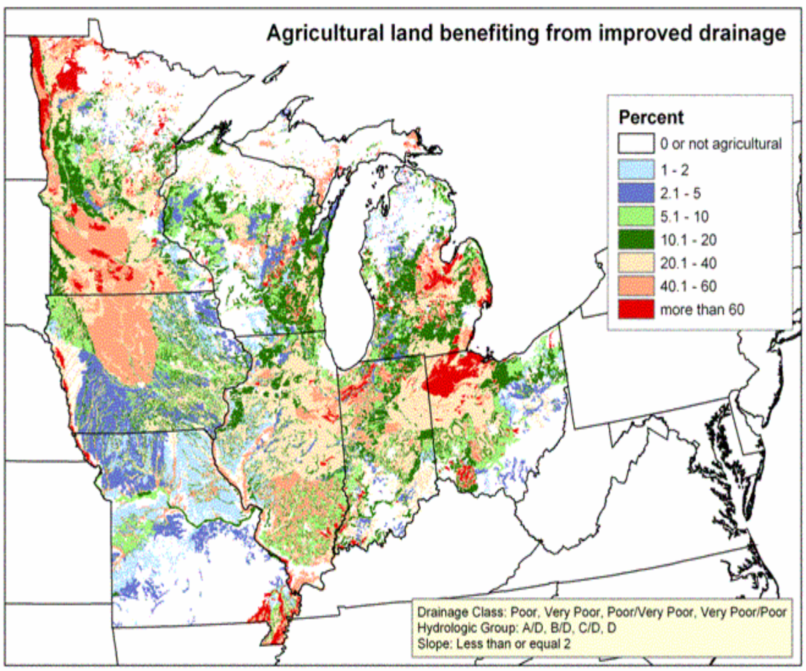

Figure 3. Agricultural land in the Midwest with the potential to benefit from Drainage Water Management

Existing drainage systems can be retrofitted for drainage water management by installing control structures at a cost of $50 to $100 per hectare. For new systems additional costs are incurred by designing the drainage systems to optimize the benefits of drainage water management. Typically, drainage systems are designed to minimize the cost of installation. However, such designs do not necessarily maximize the benefits of drainage water management. Shown in Figure 4 are two possible drainage systems that could be installed on the same field. In all likelihood the lower cost system would be the one selected for installation. Based on an analysis of several fields in Illinois the average difference in cost, based on average installation costs, is $120 per hectare. Thus the cost of implementing drainage water management ranges from $50 to $220 per hectare. The lower cost would be applicable to a retrofitted system on a flat field, while the higher figure would apply to a new system on complex topography. If these numbers are combined with the figures for a 30% nitrate load reduction, the annualized cost for nitrate amelioration with drainage water management systems range from $1.45 - $2.05 per kilogram for retrofitted systems on flat fields, to $6.30 - $9.20 per kilogram for new systems on complex topography. Some of this cost may be offset by potential yield increases.

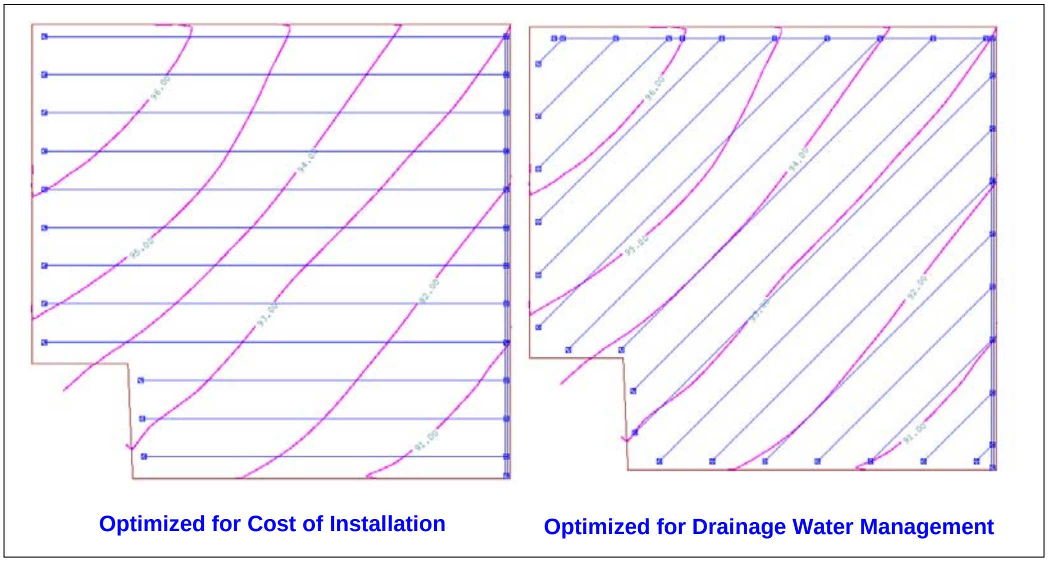

Figure 4. Effect of design objective on drainage system layout.

Because drainage water management systems are normally managed during the fallow period when there are no crops on the field, there is but little potential for yield loss. However, the systems can be used to store water in the soil during the growing season (Figure 5), provided there is adequate rainfall. This water is potentially available for crop consumption and could lead to increase yields. In these instances, if the systems are not managed properly during the growing season, and the water table is allowed to rise into the root zone for extended periods, there is a risk of reduced yield in very wet years.

Long term computer simulations indicate that the average annual yield increase is less than 5%, but it could be substantial in some years. Year to year variability depends primarily on annual precipitation variability and other regional climatic characteristics as well.

One limitation to determining the efficacy of drainage water management stems from the difficulty in characterizing all the pathways by which water, and the dissolved nitrate by extension leaves a field when the water table is elevated. Some of the water may seep laterally or vertically. It is known in some cases that the seepage water gets denitrified, but not known in others. There is also the possibility of increased surface runoff which might result in increased sediment and phosphorus transport from the field.

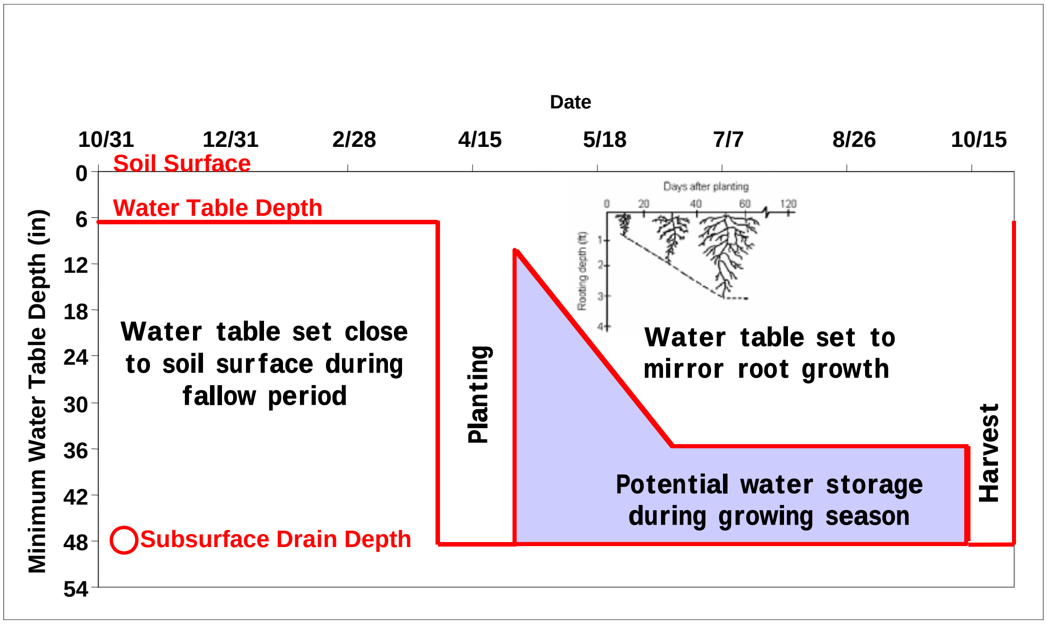

Figure 5. Drainage water management system operated for both water quality and yield benefits.

Summary

The Agricultural Drainage Management Systems Task Force was formed in 2003 in recognition of the potential for DWM to have an impact on the transport of nitrates from drainage systems. This group consists of representatives from universities, USDA-ARS, and USDA-NRCS whose main goal is to "develop a national effort to implement improved drainage water management practices and systems that will enhance crop production, conserve water, and reduce adverse off–site water quality and quantity impacts" ADMSTF (2005). There is also a companion group made up of industry representatives known as the Agricultural Drainage Management Coalition that has a similar goal. The formation of these two groups has resulted in a greater public awareness of the potential for drainage water management to reduce nitrate transport from subsurface drainage systems.

Since its formation in 2003, the members of the Agricultural Drainage Management Systems Task Force have been working to educate producers, drainage contractors, and conservation professionals about the benefits of drainage water management and to address popular concerns and misconceptions about the practice. The foremost misconception is that when the practice is applied, the drainage outlet is completely closed and no water can flow out of the system. In actual fact while the water table is regulated, water in excess of what is required to elevate the water table to the set level, can flow out of the soil profile (Figure 1). Other concerns, such as those relating to the drowning of earthworms, the destruction of soil structure, or excessive pressure on and freezing of subsurface drains, are also being addressed through research or educational activities.

The practice is also being used to benefit wildlife by allowing the water table in some fields to rise above of the soil surface during the fallow period. This mode of operation creates mini-wetlands that provide suitable habitats for migrating birds.

As mentioned above, drainage water management systems can be managed to store water in the soil profile and enhance yields. In the 2004 crop year, farmers in Illinois reported yield increases of 0.3 to 0.6 metric tons/hectare for corn, and 0.2 to 0.4 metric tons/hectare for soybean due to the implementation of drainage water management. However, these are but anecdotal reports; research on the yield benefits of this practice is in the early stages.

Research is being conducted in several Midwestern states to resolve many questions relating to the practice of drainage water management. In order to assess the benefits of this practice, more information is needed on the yield benefits of the practice, and how best to manage the systems in the growing season to maximize yields. There is also a need to obtain more information on the water-related properties of many of the soils on which the practice can potentially be implemented. In addition, economic and environmental research is needed to identify and quantify the societal costs of nitrogen enrichment of inland and coastal surface waters. In Illinois for example, detailed soil water characteristics are only available for 20 of the 244 soils that require drainage. Finally, as with any best management practice, incentives and cost-sharing opportunities for producers must continue to be cultivated to ensure significant adoption of the practice.

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