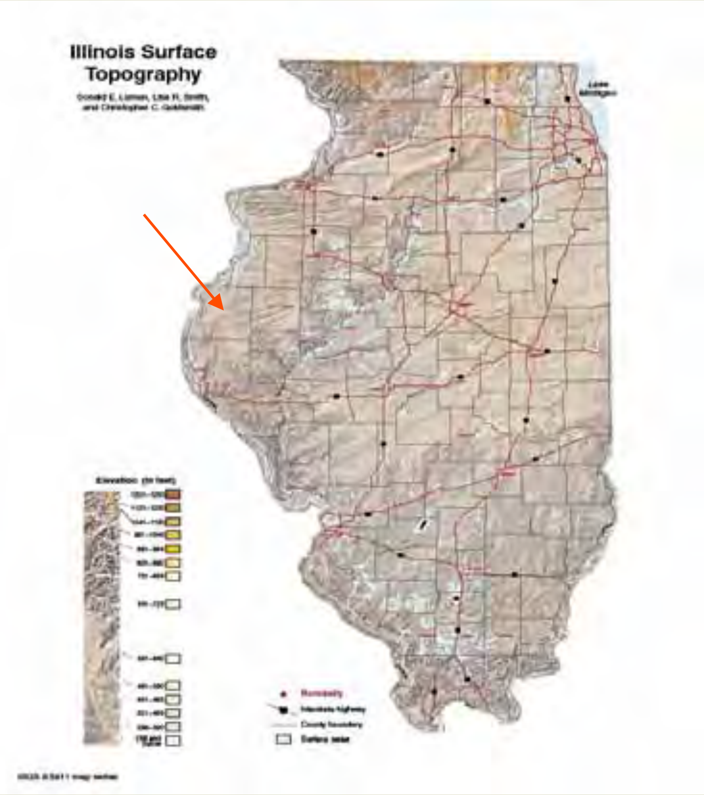
Subsurface Drainage in the Midwest

Mark Hitz
Fall 2008

Background

- From Carthage, IL



Background

Background

- Education
  - Attended Western Illinois University
    - Bachelor of Science in Agriculture in Fall 2000
  - Started Masters of Science in Agronomy Distance Education Program in Fall of 2002
- Work Experience
  - Intern for Farm Optimization (Monsanto) *1999*
  - Intern for Monsanto *2000*
  - Sales Representative for Pioneer Hi-Bred *2001-2004*
  - Resource Conservationist for Hancock County SWCD *2004-2005*
  - USDA NRCS *2005-Current*

Background

- District Conservationist in Cass County, IL

Why Subsurface Drainage?

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Subsurface Drainage in the Midwest

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Introduction

Throughout the nation water quantity and water quality is a concern for commercial crop production. While some regions may have less than adequate rainfall to effectively produce crops other areas may be inundated with excess rainfall also making it difficult to produce crops. Subsurface drainage, or tile drainage as it is more commonly referred to in the agricultural community, is a tool that producers of the Midwest can use to remove excess water from their fields. Subsurface drainage lowers the natural water table of the soil making the soil environment more conducive for plant growth and field operations.

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Introduction

Objectives:

- To define the purpose and uses of subsurface drains in the Midwest.
- To review the history of subsurface drainage in the Midwest.
- To describe field conditions where subsurface drainage may be needed.
- To identify some of the materials that are used in subsurface drainage systems.
- To identify some of the equipment that is used to install subsurface drains.
- To explain design considerations of a subsurface drainage system.
- To identify some management alternatives of a subsurface drainage system.

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Purpose

Within agriculture, subsurface drainage is primarily know for improving soil conditions for plant growth; however, there are several other uses for the practice. Illinois Natural Resources Conservation Service (NRCS) Conservation Practice "Subsurface Drain" defines subsurface drainage as, "a conduit such as corrugated plastic tubing, tile, or pipe, installed beneath the ground surface to collect and/or convey drainage water" (NRCS, 2004). The Subsurface Drain Conservation Practice Standard states a subsurface drain's purpose is to, "improve the soil environment for vegetative growth, reduce erosion, and improve water quality by: regulating water table and ground water flow, intercepting and preventing water movement into a wet area, relieving artesian pressures, removing surface runoff, leaching of saline and sodic soils, serving as an outlet for other subsurface drains, and regulating subirrigated areas or waste disposal areas" (NRCS, 2004). The Subsurface Drain Conservation Practice Standard provides other purposes for subsurface drainage such as: "collecting ground water for beneficial use, removing water from heavy use areas, such as around buildings, roads, and play areas; and accomplishing other physical improvements related to water removal, and regulating water to control health hazards caused by pests such as flukes, flies, or mosquitoes" (NRCS, 2004).

History

The practice of draining the land has been around for a long time. Some of the oldest uses of subsurface drainage include the use of bamboo pipes in ancient China and drainage systems that date back to Mesopotamia some 9000 years ago (Ritzema et al., 2006). Subsurface drainage was first used in the United States near Geneva, New York in 1835 when a farmer named John Johnston used hand made clay tiles to drain his land (Urban, 2005).

History

In an effort to relieve public pressure concerning the release of federal swamp and wetlands for private development, congress passed the Swamp Land Acts of 1849 and 1850 (Zucker and Brown, 1998). These key pieces of legislation transferred large amounts of land from the federal government to individual states (Urban, 2005). Once in the hands of individual states these areas could be turned over to county organizations and/or drainage districts (Zucker and Brown, 1998). More than 53 million acres out of 956 million acres of farmland in the United States had received some sort of drainage by 1920 (Zucker and Brown, 1998). A survey conducted in 1982 by the United States Department of Agriculture (USDA) NRCS indicated 233 million acres of rural land not federally owned in the United States has wet soils with 45% being cropland and 30% forested land (Zucker and Brown, 1998).

Field Conditions

Annual rainfall, topography, the soil, and crop growth requirements are all considerations when evaluating the need for a subsurface drainage system. The natural drainage, or permeability, of the soil, is the most common indicator of need for a subsurface drainage system. Soil permeability is a measurement of how water moves downward through the soil profile and is expressed in inches per unit of time or typically inches per hour (Dravlos and Melvin, 1991). Soil permeability rates will vary based on soil texture and structure. Soils with moderately slow permeability range from 0.2 to 0.6 inches per hour, soils with moderate permeability range from 0.6 to 2 inches per hour, and soils with moderately rapid permeability range from 2 to 6 inches per hour (Soil Survey, 2007).

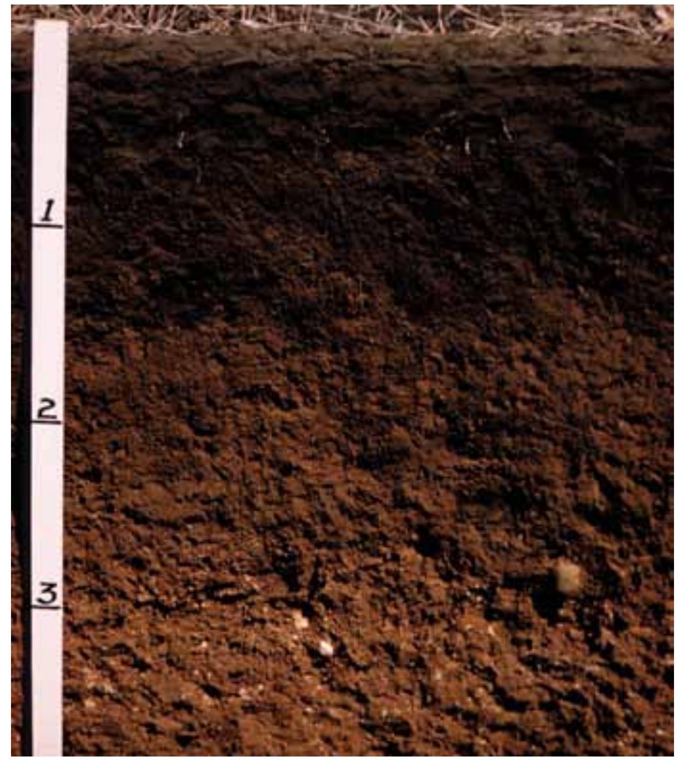


Photo courtesy of USDA NRCS

Field Conditions

The USDA NRCS classifies soils as being: **excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained** (Soil Survey, 2007). Published local county soil surveys or internet sources such as http://websoilsurvey.nrcs.usda.gov can provide much of the needed information for evaluating the soil.

Field containing somewhat poorly drained and poorly drained soils.

Materials

Materials used in subsurface drainage systems will depend on the availability of materials, contractors, cost, and/or landowner preference. In the United States early subsurface drainage systems utilized clay and concrete, simply because they were the most suitable materials at the time. Corrugated plastic tubing has since replaced clay and concrete as the preferred material for drainage systems. Even though it is no longer the most preferred material today, many fields in the Midwest still have functioning drainage systems that were constructed using clay tile. In fact, many landowners and operators are unaware of where these systems are located in crop fields, as drainage records were rarely kept and many times lost during change of land ownership. However, despite their age some of these older clay drainage systems function normally without the landowner even knowing of their existence.

Clay tile dug from a crop field.

Materials

Half of a clay tile that is shaped like a brick. Two halves would have been laid facing each other to form the circular center.

Clay tile stacked along a field edge.

Materials

The most commonly used material in the United States is polyethylene (PE) or otherwise known as plastic tubing. Polyethylene is not affected by chemicals and acids in the soil (Dravlos and Moe, 1984). It is, however, sensitive to sunlight and temperature. When exposed to sunlight and heat plastic tubing will lose some of its rigidness. When exposed to cold temperatures plastic tubing will become hard and brittle. Compared to clay and concrete corrugated plastic tubing is easier to transport because it weighs significantly less. It is also easier to install than clay and concrete because it is a long continuous piece of flexible material.

Corrugated polyethylene tile waiting to be installed.

Materials

Corrugated polyethylene tile being unrolled for installation.

The American Society for Testing and Materials (ASTM) F-405-05 contains the Standard Specifications for Corrugated Polyethylene (PE) Pipe and Fittings. This standard specification covers the requirements and test methods used in manufacturing the product; such as, pipe stiffness, brittleness, and perforations (ASTM F-405-05). It covers corrugated polyethylene pipe and fittings in nominal sizes of 3 in. (76 mm) to 6 in. (152 mm) (ASTM F-405-05). ASTM F-667-06 is the Standard and Specifications for Large Diameter Corrugated Polyethylene Pipe and Fittings. This standard specification covers nominal sizes 8 in. (203 mm), 10 in. (254 mm), 12 in. (305 mm), 15 in. (381 mm), 18 in. (457 mm), and 24 in. (610 mm) (ASTM F-667-06). Using drainage tile and fittings that meet these standards helps guarantee the quality of the material.

Equipment

The first use of trenching and excavating equipment to install subsurface drainage systems came in 1890 (Ritzema et al., 2006). The first tile machines were called trencher tile machines due to their method of excavation and installation. A trencher tile machine digs a trench to a desired depth and grade while simultaneously laying the drainage tile. These machines come in various sizes and capacities. Some machines utilize a chain with "teeth" to dig the trench while others utilize a wheel with a series of "scoops" or "buckets" to dig the trench.

Trencher type tile machine. This machine uses a chain with "teeth" to excavate the trench.

Equipment

Trencher type tiling machine. This machine uses a wheel with a series of "scoops" or "buckets" to dig the trench. It is often referred to as a "wheel digger".

Close up of the digging mechanism of a trencher tiling machine that utilizes a wheel with a series of "scoops" or "buckets" to dig the trench.

Equipment

Close up of corrugated plastic tubing being installed by a trencher type tile machine.

Corrugated plastic tubing being installed by a trencher type tile machine.

Equipment

During the installation of drainage tile with a trencher type tile machine, a small portion of the excavated material is placed on top of and around the drainage tile to hold it in place until the trench can be backfilled. The remaining excavated material can be backfilled into the trench using a variety of machinery. This can be done with a tractor and blade, a bulldozer, backhoe, or a machine that is specifically for backfilling trenches.

Small bulldozer backfilling a tile trench.

Machine designed for backfilling. It uses a auger to move the excavated material.

Equipment

Field with drainage tile installed using a trenchless tile machine.

Machines referred to as trenchless tile machines were introduced in the late 1960's (Ritzema et al., 2006). Trenchless tile machines do not excavate a tile trench like trencher tile machines. Instead, trenchless tile machines act as a plow or a ripper temporarily lifting the soil to allow the drainage tile to be installed at the rear of the plow. Unlike a trencher type tile machine these machines do not redistribute the soil profile. Some trenchless tile machines are not machines at all but rather attachments that can be pulled by tractors or construction equipment. Trenchless tile machines can lay drainage tile at a higher speed than trencher tile machines and do not require any backfilling since there is no excavation. However, they can be more restrictive than trencher tile machines when it comes to depth and size of drainage tile due to capacity limitations.

Equipment

Pull type trenchless tile machine. This piece of equipment is commonly referred to as a "tile plow". It attaches to the 3pt hitch of this tractor.

Close up of the plow blade/point on a pull type tile plow.

Equipment

Trenchless type tile machine.

Close up of the plow and boot.

Design Considerations

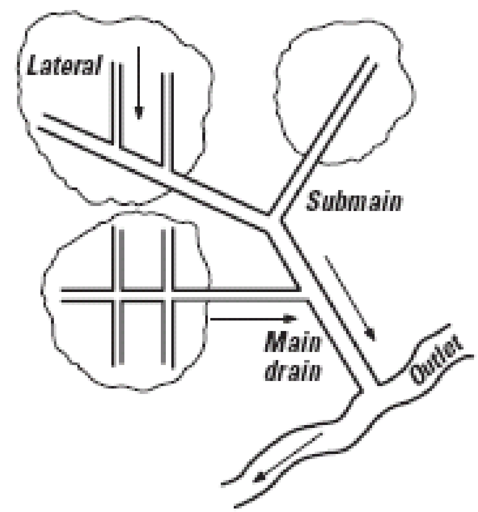
Because all fields are not created equal, different tile patterns may be needed to provide adequate drainage to the desired area. Topography, available outlets, and field boundaries will dictate what drainage pattern will be the most effective. There are a variety of drainage patterns that can be used when planning a subsurface drainage system; however, there are four patterns that are considered to be common. These include:

- random drainage pattern
- parallel drainage pattern
- herringbone drainage pattern
- double main drainage pattern

(Dravlos and Melvin, 1991).

Design Considerations

A random drainage pattern uses an unsystematic series of laterals and mains throughout the field to provide the needed drainage. This drainage pattern is commonly used on ground that has an irregular landscape or is hilly. It can be used to drain isolated wet areas in a field or to drain hillside seeps. A random drainage pattern is also commonly used when erosion control practices are placed throughout the field.

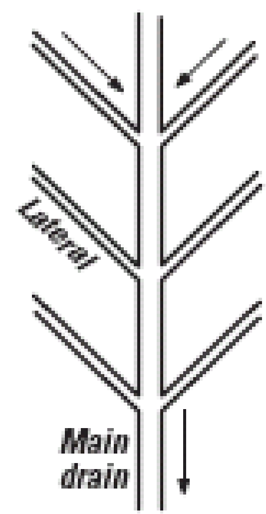


Random Pattern

Source: Dravlos and Melvin, 1991

Design Considerations

A herringbone drainage pattern has multiple laterals draining into one main. The laterals enter the main at an angle from one side or both sides. This drainage pattern can be used for large low lying or depression areas. Areas with long gradual slopes are typical for this drainage pattern. Field boundaries or other obstructions may not allow laterals to enter the main on both sides and drain the entire depression area. In such an instance a modification of this pattern may be used to drain only the area desired.

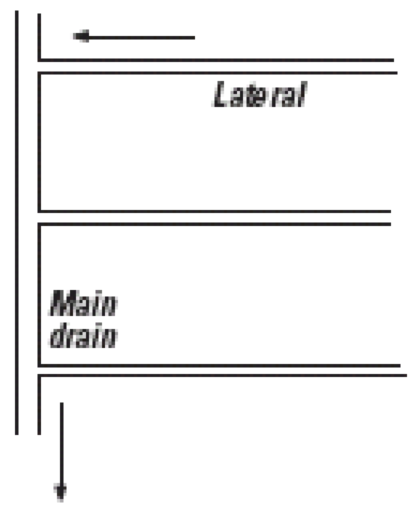


Herringbone Pattern

Source: Dravlos and Melvin, 1991

Design Considerations

A parallel drainage pattern consists of a systematic series of laterals that run parallel to each other and enter a main, usually at 90 degrees. This drainage pattern is commonly used to drain areas that are considered to be flat. It is easier to implement water table management strategies with a parallel drainage pattern than some of the other drainage patterns.



Parallel Pattern

Source: Dravlos and Melvin, 1991

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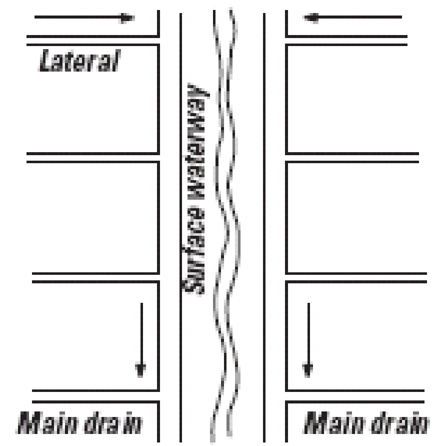
Design Considerations

A double main drainage pattern is similar to a parallel drainage pattern except there is more than one main used to drain the area. Like the parallel drainage pattern the double main consists of a systematic series of parallel laterals that enter a main. With a double main drainage pattern the depression or low lying area is dissected by a water channel or grass waterway. This type of interruption in the landscape makes it infeasible to effectively drain the desired area and use one main for the outlet. A main is placed on each side of the channel or grass waterway and provides an outlet for the laterals entering it.



Double Main Pattern

Source: Dravlos and Melvin, 1991

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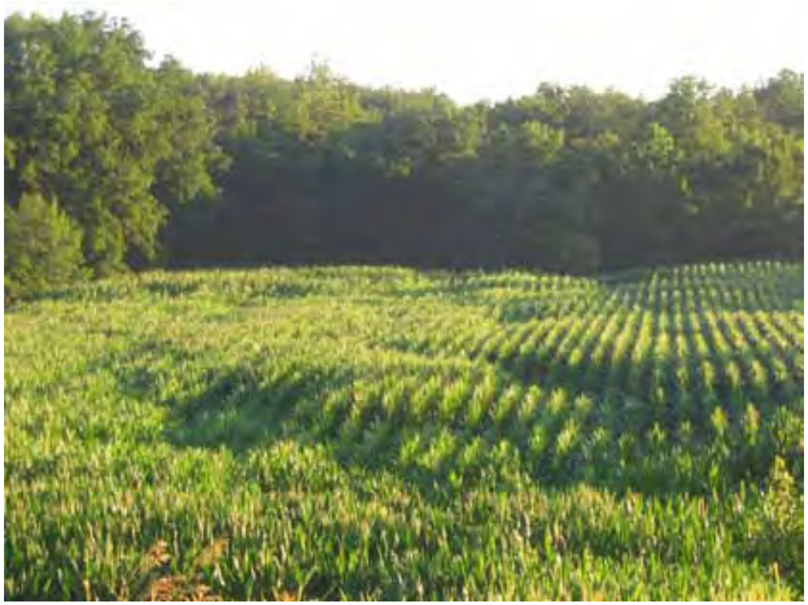
Design Considerations

Drainage tile should be sized to lower the water table in a manner that is conducive to crop production. The first step in sizing a drainage tile is selecting a drainage coefficient. A drainage coefficient is the desired amount of drainage that will occur in inches over a 24 hour period (Dravlos and Moe, 1984). A typical drainage coefficient for most field crops with a **mineral soil** is 3/8 of an inch to 1/2 of an inch while an **organic soil** is 1/2 to 3/4 of an inch (Dravlos and Moe, 1984). Most drainage systems are designed with a drainage coefficient of 3/8 of an inch; however, some landowners choose to bear the increased cost of installing larger tile so that they may use a larger drainage coefficient.

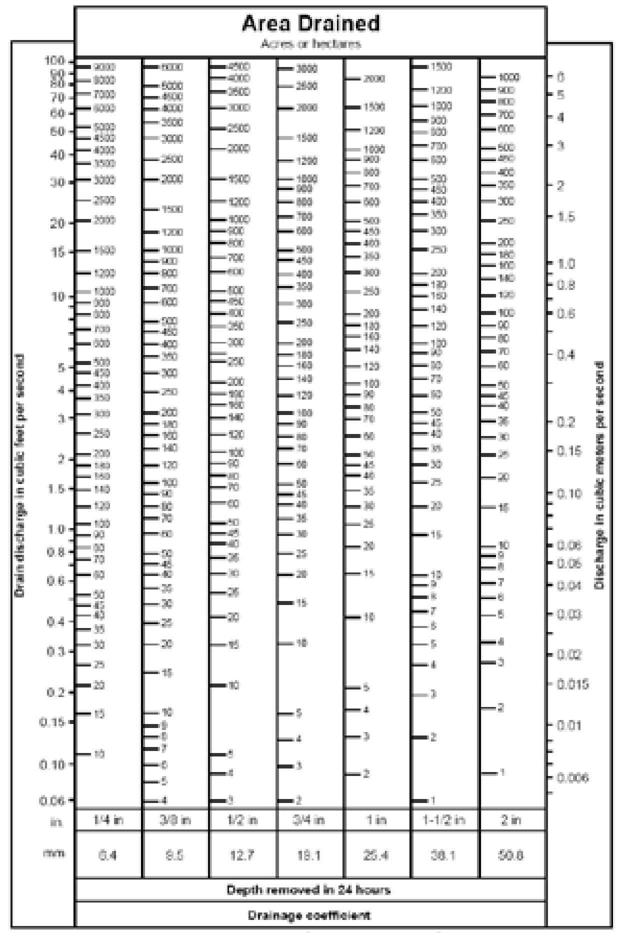


Inconsistency in corn height due to poor drainage during early plant development.

Design Considerations

This chart may be used to determine the cubic feet per second of water for a pre-determined drainage coefficient and the desired amount of acres to be drained. To use this chart find the desired amount of acres to be drained within the desired drainage coefficient column. Next match the selected acres from your pre-determined drainage coefficient column with the column on the left to determine the cubic feet per second (cfs) of water.

Source: NRCS, 2001

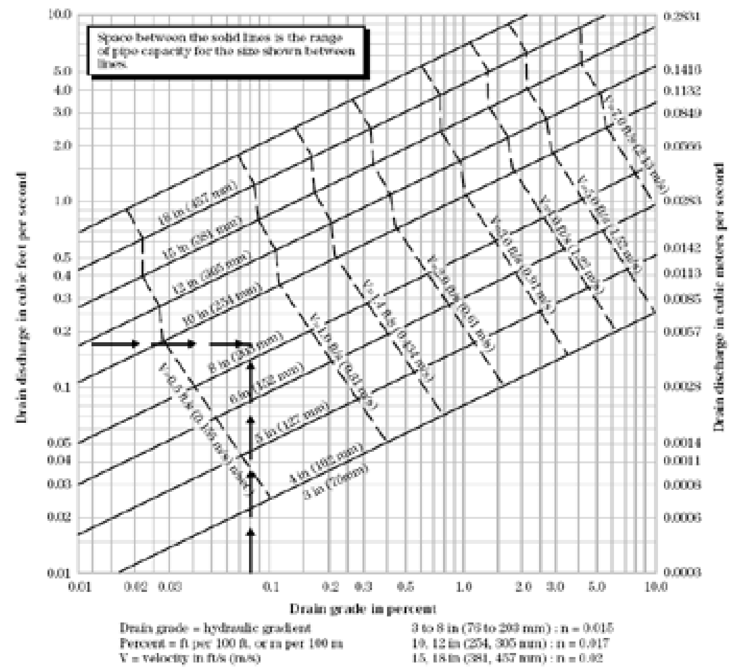


Note: Use acres with ft^3/s and hectares with m^3/s

Design Considerations

After figuring the cubic feet per second of water this chart will determine what size tubing is required per a given grade. It will also provide the velocity of the water within the tile. To use this chart find the cubic feet per second of water on the left and follow it across until it meets with the vertical line from the selected grade based on the percent slope of the drainage area. Where the two line intersect will provide an adequate tile size.

Source: NRCS, 2001



Design Considerations

The depth of the drainage tile should be deep enough to prevent frost heaving and avoid contact with deep tillage operations. The topography of the installation area and available outlets will also dictate the grade of the drainage tile. The grade should be great enough to prevent silt from collecting within the tile and carry the required amount of cubic feet per second of water. The grade should also be flat enough that it does not exceed the maximum velocity; otherwise, erosion could occur around the drainage tile.

Maximum allowable velocity for tile per soil texture

Soil Texture	**Velocity, ft/sec**
Sand and sandy loam	3.5
Silt and silt loam	5.0
Silty clay loam	6.0
Clay and clay loam	7.0
Coarse sand or gravel	9.0

This table provides the maximum allowable velocity within the tile in feet per second for a given soil texture.
Adapted from Dravlos and Moe, 1984.

Design Considerations

The spacing of drainage tile should be close enough to provide adequate drainage for crop growth and field operations. Typical drainage tile spacing ranges from as close as 20 feet to as far as 80 feet and is installed at a depth of 30 to 40 inches (Zucker and Brown, 1998). A properly designed and installed drainage system should lower the water table to at least 12 inches below the surface in 24 hours and approximately 21 inches in 48 hours after a rain event (Dravlos and Moe, 1984). State university publications can be good sources of information for drainage spacing; however, local contractors and landowners can be the best sources of information because of their knowledge of the region.

Design Considerations

Good drainage outlets are necessary in maintaining the functionality of a subsurface drainage system. It should be installed on design grade and sized large enough to handle all of the flow coming from all the laterals in the drainage area. Outlets should be constructed of a rigid section of UV resistant pipe that will protect the system against any erosion and/or undermining that may occur at the outlet site.

Four subsurface drainage outlets partially submerged in a road ditch. Notice the animal guard located just inside the white PVC pipe. This is used to keep animals from crawling up the pipe and becoming lodged during dry periods and potentially plugging the system.

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Design Considerations

Subsurface drainage systems may also be incorporated with erosion control practices such as terraces or water and sediment control basins. These practices temporarily impound water at the surface and slowly release it through subsurface drains and surface inlets. In some instances the subsurface drains are not adequately sized to handle the additional discharge rate of water from these structures.

Photo courtesy of USDA NRCS.

Course Map

Design Considerations

To maintain the integrity of the drainage system, it may be necessary to install a relief well to relieve the additional pressure put on the system and prevent it from blowing out. A blow out can occur when the discharge of water is so great that the pressure pushes the water out of the perforations of the drainage tile and up through the soil profile to the surface. This can lead to the soil covering the drainage tile being removed and exposing the drainage tile, creating what is commonly referred to as a tile hole.

Relief well. The seven outlets on the right are draining cropland and water and sediment control basins. The single drain on the left is the main outlet for all of the drains draining into this relief well.

Agriculture and Environmental Effects

Recent advances in technology have given producers the opportunity to closely monitor their cropping practices. Yield monitors and global positioning systems have paved the way for a monitoring system that ties yield to a specified area in the field. With these tools, producers have seen improved crop growth in areas that are adequately drained and yield declines in areas that are not adequately drained, or where tiles are not functioning properly (Kladiviko et al., 2005).

Photo courtesy of USDA NRCS

Agriculture and Environmental Effects

A subsurface drainage system creates a favorable soil environment for crop growth and allows for timelier field operations. Subsurface drainage increases oxygen to plant roots and increases the soil temperature, which allows for earlier planting, earlier plant emergence, and a longer growing season (Oquist et al., 2007). Long-term studies in Indiana report average annual increases in corn yields of 14 to 23 bu/acre while long-term studies in Ohio report average annual increases in corn yields of 20 to 30 bu/acre for corn grown with subsurface drainage systems versus no drainage systems (Zucker and Brown, 1998).

Excessive rainfall coupled with poor drainage and rushed planting conditions can have long term effects on crop development as seen here in the this uneven corn stand.

Agriculture and Environmental Effects

Research conducted in Minnesota and Ohio report that subsurface drainage can reduce compaction and improve soil tilth (Zucker and Brown, 1998). In addition to creating a favorable soil environment for plant growth, subsurface drainage can also provide some benefits to the environment when incorporated with conservation practices by reducing runoff. Subsurface drainage can reduce the sediment and dissolved phosphorus concentrations that enter surface waters when the system is incorporated with conservation tillage (Zucker and Brown, 1998). Soil that is not saturated is less likely to detach, be transported in runoff water, and deposited in surface waters.

Sediment laden runoff from a crop field.
Photo courtesy of USDA NRCS

Agriculture and Environmental Effects

While subsurface drainage provides several benefits to crop production some researchers have shown it might have a negative effect on surface waters (Algoazany et al., 2007). Production agriculture has been identified as point and non-point sources that negatively affect water quality (Borin et al., 2001). Watersheds within the Mississippi River Basin have been indentified as contributors of nutrients that create hypoxia conditions within the Gulf of Mexico (Tomer et al., 2003).

Tile drainage water from cropland.

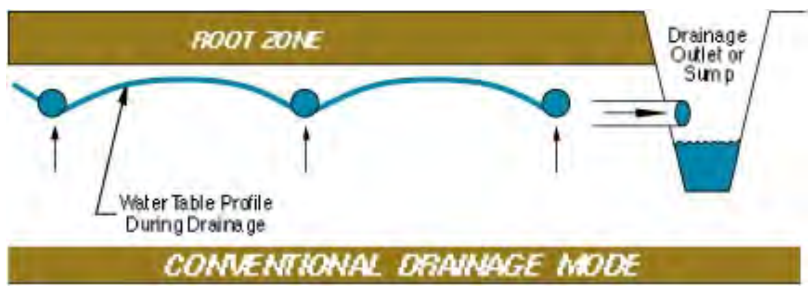
Management Alternatives

Subsurface drainage systems can be installed or manipulated in a manner that allows producers to control how much water is leaving and/or entering their field. These methods of managing drainage water or manipulating the water table can be termed "water table management". Water table management consists of three different groups; which are, conventional drainage systems, controlled drainage systems, and subirrigation drainage systems (Zucker and Brown, 1998). These management systems are discussed further in the next few pages.

Water control structure placed at the end of a drainage system.

Management Alternatives

Conventional Drainage System
A conventional drainage system is typical for many crop production fields in the Midwest. This drainage system consists of a series of laterals and mains that empty into an open channel or body of water unrestricted. The water table is lowered to the depth of the drainage tile by gravity.

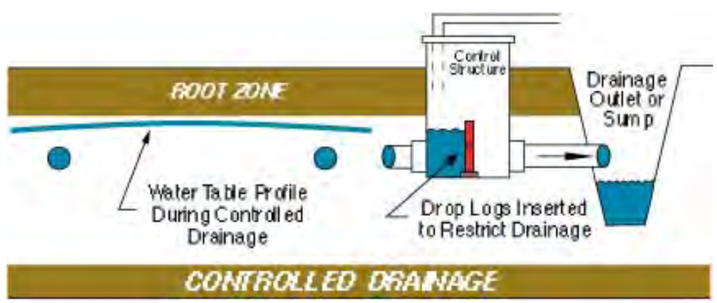


Conventional Drainage System.
Source: Ohio State University Extension Bulletin 871-98, Water Table Management

Management Alternatives

Controlled Drainage System

A controlled drainage system is similar to a conventional drainage system. This system consists of a systematic series of laterals and mains that are intercepted at a certain elevation by a water control structure. A water control structure controls the amount of drainage water leaving the field by manipulating the water table. This is done by adding or removing stop logs within the structure. Placement of these structures within a drainage system will depend on the slope of the land and desired size of the management area. Some existing conventional drainage systems may be modified to a controlled drainage system by the addition of one or more water control structures.

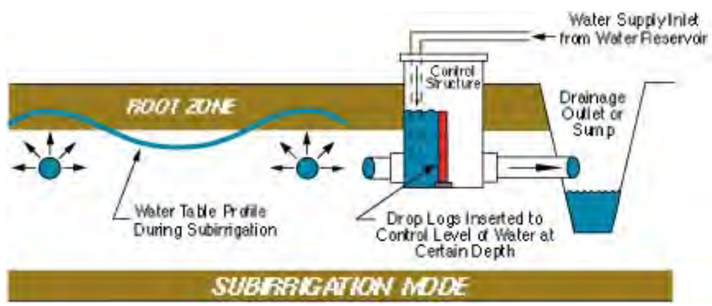


Controlled drainage system.
Source: Ohio State University Extension Bulletin 871-98, Water Table Management

Management Alternatives

Subirrigation System

A subirrigation system acts as a controlled drainage system but is also capable of serving as a subsurface irrigation system. Just like a controlled drainage system the water table is manipulated by the addition or removal of stop logs within a water control structure. However, during periods of dry weather water may be pumped into the system to raise the water table to a level that would not be obtainable through controlled drainage methods.



Subirrigation drainage system.
Source: Ohio State University Extension Bulletin 871-98, Water Table Management

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Management Alternatives

Use of water table management practices such as controlled drainage systems and subirrigation systems has the potential to offset some of the negative effects associated with subsurface drainage, particularly nitrate nitrogen finding its way into surface waters. In Ohio and Michigan research found that use of water table management improves drainage water quality (Zucker and Brown, 1998). Several sites in Michigan showed nitrate nitrogen delivered through subsurface drainage systems to surface waters was reduced by 64% and 58% by using subirrigation (Zucker and Brown, 1998).

Photo courtesy of USDA NRCS

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Summary

Subsurface drainage systems in the Midwest have given producers the ability to improve the drainage of their land. Improved drainage creates a more conducive environment for crop growth and field operations, which ultimately leads to increased yields. By utilizing a subsurface drainage system to its fullest and incorporating water table management practices producers of the Midwest have an opportunity to potentially increase yields and reduce the amount of nutrients that are finding their way into the nation's surface water.

Photo courtesy of USDA NRCS.

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Questions?