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Factors When Considering an Agricultural Drainage System

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Drainage of excess soil water is essential to sustainable agronomic production on many soils in the Mid-Atlantic region. Drainage can improve crop yields, reduce year-to-year yield variability, and provide trafficable conditions for field operations at critical times of planting or harvest. Drainage system design and management can impact crop production and have environmental consequences. This fact sheet presents the benefits and potential consequences of artificially draining agricultural land, the steps to follow when considering a drainage system, and some aspects of proper drainage system operation and management.

Improving drainage of agricultural fields can be achieved by three primary means: (1) installing subsurface, artificial "tile" (perforated pipe) drains at some depth below the soil surface; (2) surface ditching; and/or (3) land shaping (usually used with either ditching or subsurface drainage). Both the subsurface tile drainage and ditch-type systems function to lower the water table in the soil below the crop's root zone, while land shaping prevents water ponding on soils with very low infiltration capacity by building a crown or convex surface to direct surface flow from the field. These practices are usually used in combination; tile lines and/or surface-shaped fields need to drain to a ditch. Selection of a drainage system depends in part on the drainage problem that exists and the particular soil characteristics causing the problem (table 1).

Table 1. Common drainage problems, the soil characteristics associated with the problem, and the potential drainage solution.

Problem	Soil characteristics	Potential solution
Soil frequently saturated	Poorly drained	Ditch or tile
Low infiltration rate	Clay or compacted soils	Land shaping with ditches
Shallow impeding soil layers	Layer of low permeability	Ditches or tile with surface inlets*

**Surface inlets are usually standpipes or stone backfill that provides a means to attach a subsurface tile to the soil surface to drain ponded surface water.*

Lowering the water table has several crop production benefits:

1. Drainage removes excess soil water in the root zone, allowing for improved soil aeration. Prolonged exposure to saturated conditions and poor soil aeration can stress the crop, reducing yield (fig. 1).

2. Drainage can improve field trafficability, allowing more reliable field access while reducing compaction. Drier soils are less susceptible to compaction than wetter soils.

3. Drainage enables crops to establish deeper root systems in fields without impeding or compacted layers (fig. 1), allowing them greater access to nutrients and soil water.

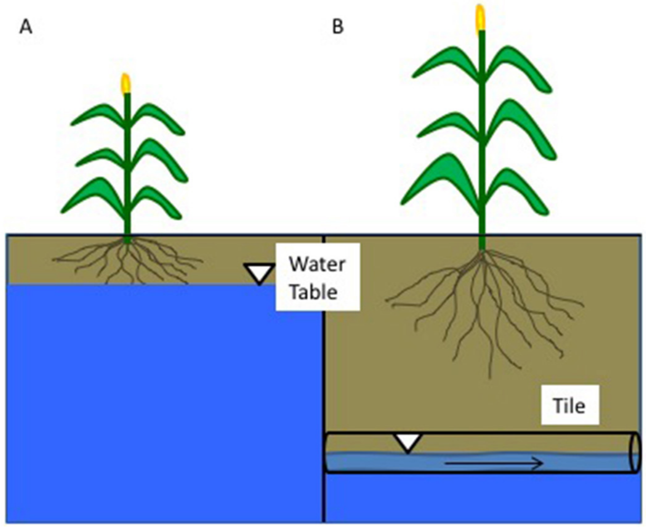

Figure 1. Poor aeration and shallow root systems (A) can be alleviated through drainage (B), which improves aeration and allows for deeper rooting.

4. Drainage can reduce the year-to-year variability in yields from poorly drained fields. Drainage can increase nitrification (the conversion of ammonia to nitrate) in most soils, providing more nitrate for plant uptake.

5. Removing excess soil water with drainage can help the soil warm up faster in the spring, allowing for earlier planting.

6. Subsurface drainage can help reduce surface erosion and surface runoff.

Drainage can also have negative consequences:

1. Drainage can increase the loss of nitrates, phosphates, and other chemicals that move easily through soil with drainage water. These soluble constituents can negatively impact downstream water bodies. For instance, agricultural drainage is associated with increased eutrophication or algal growth caused by nitrate export from drained fields (fig. 2). This is because drainage increases nitrification and reduces the opportunity for nitrate to be used by crops or soil microorganisms by removing soil water from a field more quickly.

2. Drainage alters the hydrology of a field. In undrained systems, the soil acts as a sponge to store water, providing it is not already saturated, and releases it slowly to adjacent streams or water bodies. Subsurface drainage can also enhance the sponge effect by lowering the water table, which allows more water to infiltrate during a storm event. However, drainage systems are designed to short-circuit the natural flow paths and lower the water table more quickly, directly transferring the water to adjacent streams or water bodies. Surface drainage systems can increase the flashiness of the system (the rapid rise and fall in stream flow), causing greater high flows (peak flows) and smaller low flows (baseflow). This increase in peak flows can worsen erosion in receiving streams and pollutant delivery to water bodies, while lower baseflows can harm fish and aquatic organisms that rely on adequate flow to survive.

3. Drainage systems (by way of hydrologic modifications) have contributed significantly to wetland loss in the United States. Hydrological modifications do not mean that wetlands are explicitly or purposely drained, but rather that alterations to water tables resulting from drainage can change adjacent wetland hydrology and function.

4. Surface ditches and land shaping can increase erosion and surface runoff.

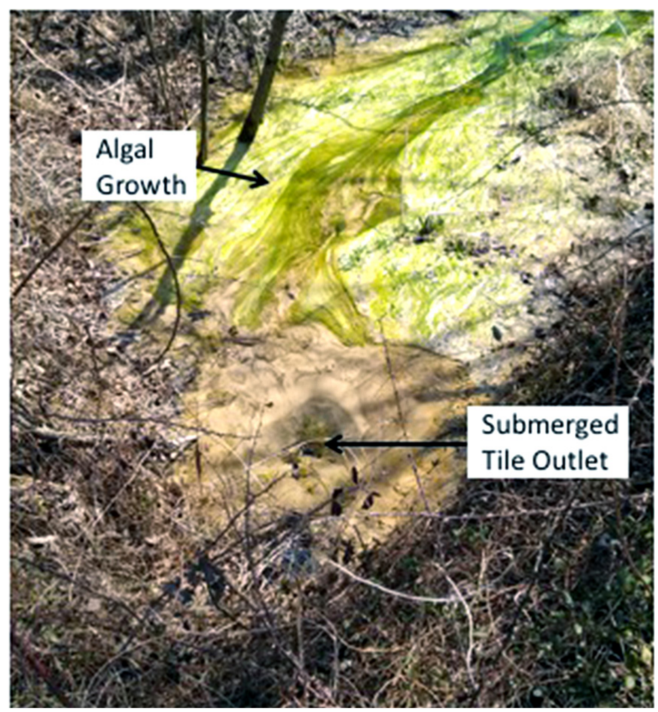

Figure 2. Tile outlet discharge causing water quality problems (algal growth) in receiving water body.

Drainage System Planning Considerations

There are many factors to consider when deciding whether or not to install a drainage system. Several factors that should be considered by anyone thinking about drainage are discussed in this publication.

Local, State, and Federal Regulations

Because there are many regulations that govern artificial drainage systems, it is critical that landowners (and whomever they might contract with to install or maintain the drainage system) understand all the applicable laws. The first step of any drainage project should include meetings with the Soil and Water Conservation District, the Natural Resources Conservation Service, and local watershed organizations, as appropriate, to determine what is required. This should be done well in advance of the intended installation. Typically, agricultural producers must file Form AD-1026 with their U.S. Department of Agriculture Farm Service Agency to ensure there will be no loss of USDA program benefits. This initiates a soils evaluation by NRCS to determine if wetlands could be impacted.

Easements and Rights of Way

An easement is the right to use the land of one person for a specific purpose to benefit another's interests. In drainage, this equates to the right (either inherent or acquired) of an upstream landowner to discharge drainage water to a downstream landowner. Natural drainage from an upstream property is an inherent right; that is, a downstream landowner cannot adversely affect this drainage by blocking or otherwise altering the upstream drainage patterns. Before the natural drainage patterns are altered by a drainage system, landowners may need to acquire an easement from the downstream landowner to discharge the resulting altered flow. Drainage associations or drainage districts manage many drainage systems, particularly large ditch and tile networks. Because these systems encompass large areas, there are generally easements or rights of way required to modify natural channels and to convey the water from the drained area. Landowners thinking about installing a drainage system should first consult with the appropriate legal or regulatory authorities. A good place to start planning or to get more information is to contact the local Soil and Water Conservation District or the NRCS.

Soil Properties

Detailed information about specific soil properties (e.g., soil type and texture, the existence of any soil layers that restrict water movement, the rate water moves in the soil) must be known to properly design and manage a drainage system. For example, clay soils generally conduct water much more slowly than

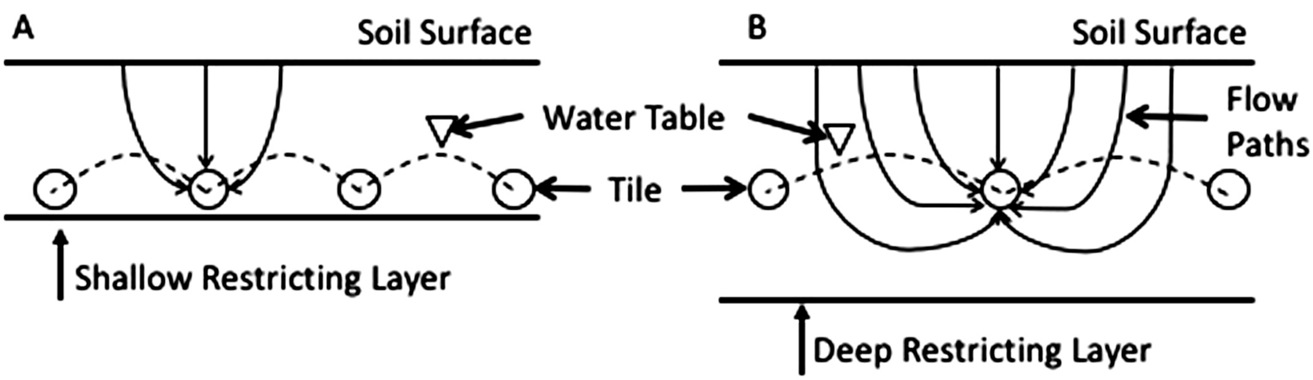

Figure 3. Effect of depth to restricting layer on drainage spacing. A drainage system installed in fields with shallow restricting layers in the soil needs to be spaced more closely together (A) and/or closer to the soil surface than a drainage system installed in fields with a deep restricting layer in order to achieve the same water table level (B). This is because the shallow restricting layer prevents soil water from reaching the tile via deeper flow paths (A). This can increase the cost of system installation or reduce the system effectiveness.

sand; thus, to adequately drain water from a clay soil, a surface system could be needed and tile drains will have to be spaced more closely. This will make installation more expensive. For sandy soils, which are more permeable, both surface ditches and tile drains can be spaced farther apart.

Soil depth is another important consideration; there must be adequate soil depth — 3 to 5 feet is generally recommended — to install a tile drainage system. In shallow soils, surface systems can be used, and tile drains must be installed more closely together or closer to the soil surface to adequately lower the water table (fig. 3). The shallow restricting layer reduces the amount of water that a drain can intercept because it cuts off the deeper flow paths that water can follow to the drain (fig. 3). Again, this makes installation more expensive. Subsurface drains should also be deep enough to provide protection against tillage operations, equipment loading, and frost. All subsurface drains in mineral soils should have at least 2 feet of soil cover over the drain to protect them against overloading from heavy machinery; organic soils should have at least 2.5 feet.

Another important consideration in system design is the drainage coefficient, which is the design capacity of a drainage system. The drainage coefficient is also defined as the desired water removal rate to support crop development and growth, and it depends on soil and crop type (table 2). The drainage coefficient is a measure of the amount of water (measured as the depth in inches) that needs to be drained from a soil in 24 hours. In the system design, the drainage coefficient will affect the spacing or the diameter of the tiles in a field.

Table. 2. Drainage coefficients.

	Drainage coefficient (inches/day)	
Soil type	**Field crops***	**Row crops***
Organic†	1/2-3/4	3/4-1 1/2
Mineral	3/8-1/2	1/2-3/4

**Field crops include crops such as hay or grain; row crops are crops such as corn or soybean.*

†Organic soils contain a minimum of 20% organic matter and are called Histosols. Mineral-based soils have low organic matter content, generally less than 10%, and are composed of primary (quartz, micas, feldspars) or secondary (silicate clays, iron oxide) minerals.

A properly designed drainage system will remove excess water from the root zone 24 to 48 hours after a heavy rain. NRCS guidelines consider additional factors when determining the desired drainage coefficient for a given drainage system and recommend that the drainage coefficient be increased if any of the following situations are encountered:

- The crop has high value.
- Soils have a coarse texture (higher sand content).
- Crops cannot tolerate wetness.
- The topography is flat.
- Crop residue is left on the soil surface.
- There is poor surface drainage (low soil infiltration rate or ponding).
- Crop evapotranspiration is low.
- Frequent and low-intensity precipitation is common.
- Field access times are critical.

Compacted soils or those with high clay content can result in low infiltration rates and water ponding in surface depressions. In these situations, land shaping or strategic placement of surface inlets could be an appropriate drainage option. In contrast, some fine, sandy soils and silty soils have insufficient colloidal material to hold the soil particles together. This can cause excessive movement of soil particles into subsurface drains. Special precautions, such as gravel filters or synthetic drainage envelopes, are often required to prevent drain clogging.

System Outlet

The location of the drainage system outlet is an important consideration and should be determined before any design begins. Drains may discharge by gravity into natural streams or water bodies, constructed open ditches, or larger underground drainage mains (fig. 4). Any of these outlets are suitable if they are deep enough and of sufficient capacity to convey water from the entire drainage system. Drainage system outlets should generally be located 3 to 5 feet below the soil surface. Where a gravity outlet is not available, pumping can be considered. Note that installing and maintaining a pump system adds considerable expense to any drainage system. Additional information on system outlets and outlet design can be found in the chapter on drainage in the NRCS "National Engineering Handbook" (see the Additional Resources section).

Topographic Assessment

The ultimate goal of a drainage system is to provide uniform drainage across a field, thereby reducing yield variability. Thus, consideration of the field topography (slope, slope length, and slope arrangement) must be considered in any system design. Topography influences water movement and drainage within a field. Steeper field slopes allow excess water to move laterally downslope in the soil, draining more rapidly than flatter fields. Fields with steep slopes tend to require less drainage (number of drains per unit field area) than flatter fields.

Localized wet spots can form where hill slopes converge, presenting unique challenges for drainage system design because these areas will require more drainage than other field areas. A topographic analysis can help identify potential problem spots. In more hilly terrain, topography can influence soil depth and soil physical characteristics such as permeability, texture, and water-holding capacity — all of which influence drainage system design.

Topography also influences where the outlet can be located. An outlet should be hydraulically down gradient of the system it drains; otherwise pumping will be required.

Finally, topography affects what type of system is most practical. There are two common ways that subsurface drainage systems are installed.

First, when drainage is consistently restricted across the field, the more complete and beneficial approach is to pattern drain an entire field at regular intervals (fig. 4A-C). Pattern drain spacing varies by soil type, depth, and topography, but installations of 50 to 150 feet for both ditches and subsurface drains are common in the Mid-Atlantic region. In pattern drainage systems, it is important that the tile lateral drains and/or field ditches are aligned parallel to the field slope contours. Tiles or ditches that are aligned across slope contours — especially where slopes exceed 5 percent — will not intercept much groundwater and will fail to adequately drain a field.

The second approach is placing random tile lines or ditches to drain a specific wet area in a field, also called a targeted approach (fig. 4D). This approach is appropriate when the rest of the field is reasonably well-drained but has local wet spots. Land shaping might also be appropriate to alleviate specific wet areas in the field when ponding is due to low-infiltration soils rather than a perched water table. Another option in fields that have limited surface drainage due to low-infiltration soils is to use a blind or surface inlet (table 1).

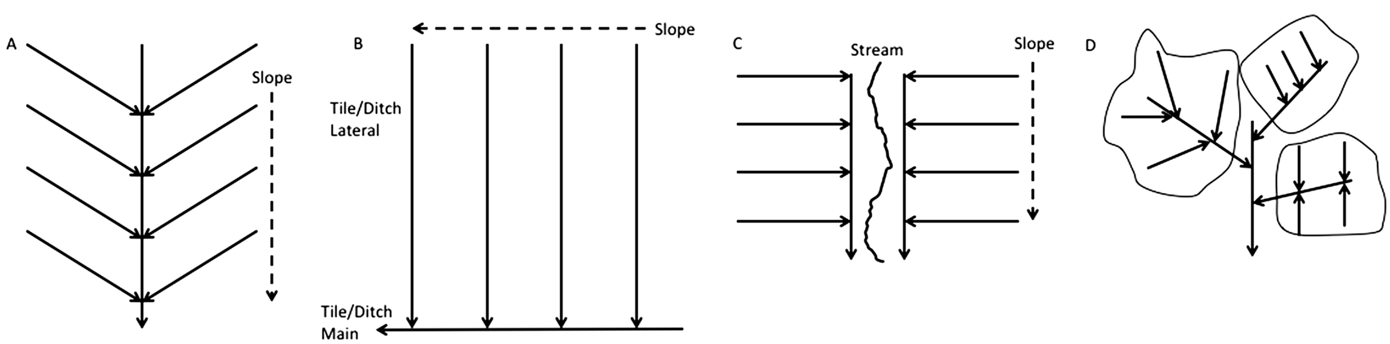

Figure 4. Various drainage system layouts. A, The herringbone system consists of parallel tile laterals that enter the main drain at an angle. This system is used for long, narrow areas with steeper slopes. B, The parallel system is similar to the herringbone system except that the laterals enter the main from only one side. This system is used on flat, uniform, and regularly shaped fields with consistent soil types. C, The double-main system is used where a landscape feature such as a stream or ditch divides the field. D, A random system is used where the field contains isolated saturated areas.

Economic Analysis

The economic benefit of a drainage system depends on several factors, including the crops being grown, the drainage intensity, whether financing is required, and the potential yield improvements from drainage. As a rough guideline, the cost of a subsurface drainage installation is about $1 per foot of tile, with the actual price determined by the tile spacing, the method of installation, and whether or not difficult excavation conditions are expected. Intensive tile installation can cost $800 to $1,000 per acre or more. Subsurface tile systems are generally more expensive to install than surface ditches due to specialized equipment needed for installation (tile plow or trencher, tile cart, specialized survey equipment, etc.), but they can be more economical because a subsurface tile system does not remove land from production like a surface ditch system does. While land shaping is the least expensive option and also does not remove land from production, this strategy only reduces surface ponding and does not remedy the effects of a perched water table or saturated, poorly drained soil.

Some questions that anyone considering a drainage system should ask include

- What is the potential yield improvement?
  - What is the NRCS soil-specific optimum yield value?
  - What is the yield of similarly managed well-drained soils?
  - What is the yield in an optimum weather year?
- What is the benefit of improved trafficability on field operations and yield?
- Is drainage truly the yield limiter?
- Is drainage a problem on a regular basis?
  - Across an entire field?
  - Or will targeted drainage achieve the same response?
- Is there a benefit to installing all the drainage at once?
- How does drainage cost compare to the cost of other strategies (e.g., deep tillage, subsoiling, soil modifications)?

Cropping Strategies

Cropping strategies are important to consider because (as stated above) they can change the economic payback period of any drainage system; higher yielding or higher value crops will benefit more from drainage than lower yielding, lower value crops. Cropping strategies also influence factors such as drainage depth or drainage spacing. Crops that are intolerant of saturated conditions might require greater drainage intensity than crops that can tolerate wet conditions for longer periods. Deep-rooted crops could require drains to be installed at a greater depth than shallow-rooted crops. If planting, harvesting, or field management operation timing are critical for specific crops to ensure adequate yield, this needs to be considered in the system design.

Maintenance Needs

Like any system, drainage systems require maintenance to perform correctly. The maintenance required depends on the drainage system type; tile and ditch systems have different maintenance needs. Developing a drainage system management plan is a good first step to ensuring that a drainage system continues to function correctly. Any drainage system management plan should include good documentation maps of the location of ditches, outlets, and buried tile and should begin with periodic inspections of the system. Ditch systems should be inspected regularly for any obstructions or impedance to flow in the ditch, bed erosion, or bank failures. Obstructions should be removed as they are encountered, and any bed erosion or bank failures should be repaired and comply with design standards (note that this could require consulting with an engineer or drainage contractor). Also, any junctions where two or more ditches meet should be inspected for erosion or scour and fixed as appropriate.

Vegetation can grow rapidly in ditches, which reduces the ability of the ditch to convey water. Mowing the bottoms of ditches is more effective than mowing the sides for water conveyance. Similarly, ditches can fill in with sediment from surrounding fields or upslope contributing areas, further reducing conveyance capacity.

A ditch management plan should include vegetation and sediment control measures. Vegetation can be controlled by mowing, pasturing of livestock, burning, applying chemicals, or mechanical removal (scraping), although pasturing of livestock can cause bank stability problems and using chemicals can increase off-site contamination. Sediment control usually involves periodic "dip-outs" (scraping) of sediments that have accumulated in the ditch.

Grade stabilization of ditch bottoms and sides is important as well. Over time, the ditch sidewalls, in particular, can change their slope, especially in sandier noncohesive soils, which affects the hydraulic function of the ditch (i.e., its ability to convey water). Grade stabilization should be employed periodically to ensure the ditch maintains its design capacity.

Tile systems and outlets should be inspected regularly as well. Given that these systems are underground and more difficult to visually inspect, one of the best times to assess system function is during periods of high drain flow. Verify that all tile outlets are flowing freely and that the flow is sediment-free. Sediment in the tile flow could indicate a failure in the tile system in the field. Any debris encountered at the outlets should be removed; a submerged tile outlet (e.g., fig. 2) can cause back pressure in the tile system and lead to blowouts. Walk the field in which the tiles are installed and make sure there are no blowouts, sinkholes, or animal burrows that could allow sediment or surface contamination to enter the tile system; repair them as necessary. Wet spots in new locations could be an indication of a clogged or damaged tile, and careful excavation and repair could be required. Crop growth is also a good indicator of a well-functioning tile system in which the field should dry evenly and produce similar yields. Changes in yield in different areas of the field could indicate a problem with the system.

Environmental Considerations

While drainage has clear benefits to crop production, there are also several negative environmental consequences of drainage. Because conventional drainage management emphasizes the export of water rather than the prudent management of local water tables — generally resulting in excessive drainage — there is the possibility of excessive nutrient export from tile-drained fields. In addition, routine ditch management practices, including scraping and vegetation management, can minimize the internal cycling of nutrients in ditch vegetation and destabilize ditch walls, resulting in erosion and water quality concerns. Some drainage best management practices to reduce off-site losses of undesirable contaminants into receiving waters begin with implementing good nutrient and pesticide management to reduce nutrient or herbicide losses from the plant root zone, using winter cover crops to sequester nutrients and reduce erosion, and rotating row crops with perennials in the cropping system.

Additional best management practices specific to the drainage system include

1. Avoid excessive drainage or store and recycle drainage water. Drain only what is needed to benefit the crop. Excessive drainage could remove valuable nutrients that would otherwise be used by crops and can lead to greater nutrient losses to waterways (fig. 2). Storing and recycling drainage water can be advantageous when droughty conditions occur at other times of the growing season and water is needed for irrigation purposes.

2. Consider treating or filtering drainage water before it is released to water bodies. For ditch systems, consider using two-stage ditch designs that provide flow capacity in the main channel and have vegetated benches that can facilitate removal of contaminants during high flows. Other methods to treat drainage water include constructed wetlands or biofilters/bioreactors. Bioreactors — shallow trenches filled with organic material, such as wood chips, and intended to promote nitrogen removal — have recently been approved as an NRCS conservation practice for tile drainage (NRCS Conservation Practice Standard: Denitrifying Bioreactor, Code 605; https://efotg.sc.egov.usda.gov/references/public/IA/Denitrifying_Bioreactor_605_STD_2015_10a.pdf).

3. Use water table management or the control of the water table by backing up the water in a tile or ditch system by mechanical means to improve water quality (fig. 5). By increasing drainage water residence time in a field, more nutrients can be removed and used by crops or adsorbed to soil particles. Water table management (by controlled drainage) can also improve crop water use, reducing drought stress and increasing yields. Care must be

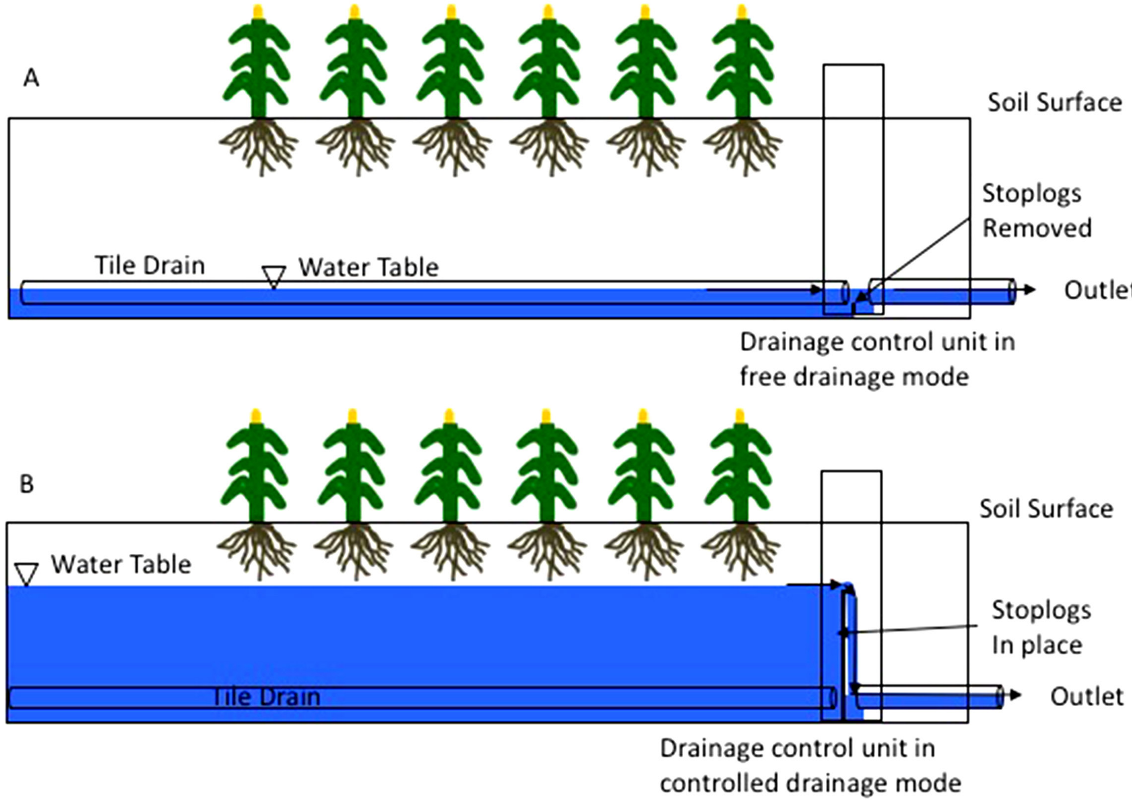

Figure 5. Example of how a drainage control unit can be used to adjust the water table in a field. If the stoplogs are removed from the drainage control unit, the drainage system is free-draining, and the water table falls to the level of the tiles. When the stoplogs in the drainage control unit are in place, water is backed up into the drainage system, raising the water table in the field to the level of the stoplogs. Note that the same effects are possible in ditch-drained systems.

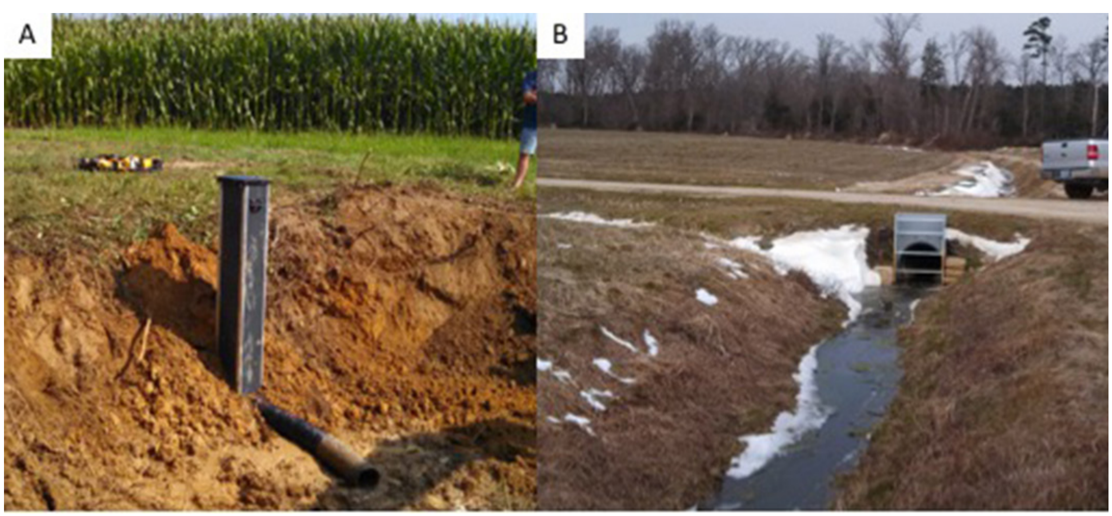

Figure 6. Controlled drainage retrofit on a tile system (A) and a ditch system (B).

taken to maintain the water table at a level that does not harm crops (fig. 5). An optimal use of controlled drainage is to close the drain during the winter months to prevent nutrient loss and then open it prior to planting to drain the soil. Water table management is often an easy and low-cost retrofit to existing tile or ditch systems (fig. 6).

4. Provide reliable and effective drainage with a well-designed and well-engineered drainage system. Shortcuts in the design can lead to severe erosion in and around the drainage system, excessive loss of productive land, and export of valuable fertile soil to adjacent water bodies where it can be problematic.

5. Follow the drainage management plan to ensure sound management of the drainage system and productive cropping in drained fields.

Summary

Drainage in the Mid-Atlantic region can improve crop yields and reduce year-to-year variability in those yields by removing excess soil water. Mismanagement of drainage systems or drainage discharge has environmental consequences as well. Producers should consider the costs, benefits, and consequences of adopting a drainage system before installation. This publication has provided the steps to follow when considering a drainage system and some management considerations of drainage system operation.

Resources

Additional Resources

Transforming Drainage. 2016. “Drainage Resources.” https://transformingdrainage.org/educational-resources/drainage-resources/.

USDA Natural Resources Conservation Service. 1971. Section 16, Chapter 5, “Open Ditches for Drainage – Design, Construction, and Maintenance.” In *National Engineering Handbook*, 5-1–52. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18366.wba.

USDA Natural Resources Conservation Service. 2016. “Drainage.” (Web page with links to drainage handbooks and other resources.) Accessed Dec. 6. www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/drainage/?cid=nrcs143_010853.

Related Virginia Cooperative Extension Publications

Easton, Z. M., and E. M. Bock. 2015. *Hydrology Basics and the Hydrologic Cycle*. VCE Publication BSE-191P. https://pubs.ext.vt.edu/BSE/BSE-191/BSE-191-PDF.pdf.

Easton, Z. M., and E. M. Bock. 2016. *Soil and Soil Water Relationships*. VCE Publication BSE-194P. https://pubs.ext.vt.edu/BSE/BSE-194/BSE-194-PDF.pdf.

Lassiter, E., and Z. M. Easton. 2013. *Denitrifying Bioreactors: An Emerging Best Management Practice to Improve Water Quality*. VCE Publication BSE-55P. http://pubs.ext.vt.edu/BSE/BSE-55/BSE-55-PDF.pdf.

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