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Agricultural Drainage

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1. Overview of agricultural drainage

Drainage refers to the process and practices used to remove excess water from the soil surface and from the soil profile. This bulletin briefly describes the history, need, types, and extent of Michigan drainage as well as the pros and cons, and environmental impact related to drainage.

2. Drainage history

The U.S. Swamp Land Acts of 1849 and 1850 provided federal funding to encourage drainage to make the swamp areas in the Midwest more habitable, and thereby encourage economic development. Through this program, many miles of streams were deepened and channelized to create drainage outlets with the result that large parts of the Corn Belt were drained. Once drained, these areas became recognized as having among the most fertile soils in the world.

Early medical professionals had suggested drainage in the Midwest as they found that it reduced malaria, although they did not know malaria was spread by mosquitoes at that time (Huffman et al., 2013). With the increase in drainage in 1860, the human death toll due to malaria started to decline in the upper Mississippi River Valley.

3. Drainage need

Agriculture is one of leading industries in the Midwest USA. In Michigan, there are over 300 agricultural commodities, and corn and soybean are the state's two leading crops with a combined planted area of 4.2 million acres, and a production value of $2.1 billion for grain corn and $1.5 billion for soybean in 2022 (USDA-NASS, 2023). Some of the most productive soils in Michigan require subsurface drainage for profitable crop production. Without drainage, crop production would not be able to meet the growing food demand because of poor crop yield due to excess water (Figure 1).

Figure 1- An example of water ponding from heavy rainfall during the early growth stage of soybean.

4. Surface drainage

Surface drainage is a cheap option to prevent surface water ponding caused by high-intensity rainfall. In this system, excess water flows over the artificially or naturally sloping ground toward vegetated shallow ditches or grassed waterways.

4.1. Vegetated shallow ditches

A vegetated shallow ditch is generally suitable in relatively flat fields (less than 0.5% slope) with poorly drained soils. In this system, the soil between the ditches is crowned to direct surface runoff into the vegetated shallow ditches (figures 3 and 4). These shallow ditches then empty into a drainage ditch. It is best if the ditch spacing matches a certain number of passes by the farm equipment. On heavy clay soil, the maximum ditch length should be about 800 ft with a minimum grade of 0.1% (Philips 1963). The ditch should have a minimum height of 6 inches and allow trafficability.

You can use a ditcher to make the shallow ditches. There are two general types of ditchers: V-shaped ditcher (Figure 2), or rotary ditcher where an impeller spins and throws soil away. Some ditchers come with GPS or laser grade control to maintain uniform grade.

Figure 2- A V-shaped ditcher with GPS grade control to maintain uniform grade (Photo credit: Chad Pool, NC State Univ.).

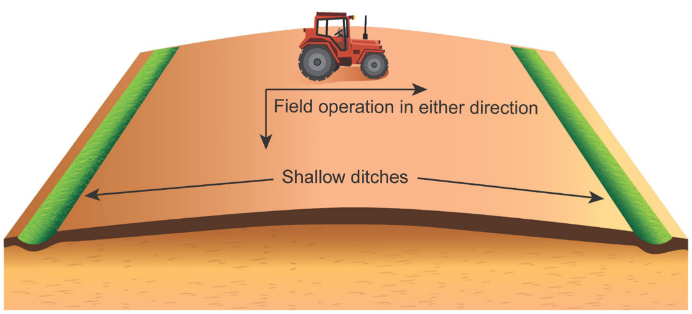


Figure 3- Diagram of vegetated shallow ditches with a crowned soil in between the ditches.

Figure 4- The vegetated shallow ditch is about 3-ft wide with 0.5 to 1.0-ft depth, and it was made using a V-shaped ditcher (Photo credit: Chad Pool, NC State Univ.).

4.2. Grassed waterways

A grassed waterway deals with surface runoff in a rolling landscape without causing erosion (Figure 5). In this method, vegetated natural waterways are created in low areas of the field to convey surface runoff into a drainage ditch and to prevent gullies. The grassed waterways can provide forage and wildlife habitat. They can also reduce peak flow by increasing the surface roughness.

Figure 5- A grassed waterway that deals with surface runoff without causing erosion.

5. Subsurface drainage

Surface drainage may be insufficient in poorly drained soils where the water table is naturally near the ground surface. In these cases, subsurface (tile) drainage is installed to remove the excess water and lower the water table (Figure 6). A drainage system should be able to lower the water table from the soil surface to 1-ft depth in less than 48 hours following a heavy rainfall (Ghane, 2025b).

In subsurface drainage systems, there are three general layouts: conventional pattern (parallel), contour, and targeted layouts (Figure 7). The contour layout is a subset of the pattern layout, which is used when laterals are following the contours too allow for controlled drainage.

A targeted layout is common in rolling landscapes where surface drainage provides enough drainage for field operations on most of the field except in isolated depressional areas where removal of excess water is needed for uniform field operations (Huffman et al., 2013). If the source of water is a naturally shallow water table, a targeted subsurface layout is suitable.

Blind inlets can drain excess water from depressional areas. They are suitable in places where the source of the excess water is mainly surface runoff. To learn about blind inlets, see Ghane (2025).

If a drainage layout map is unavailable, locate the drain pipes using these: Ground penetrating radar, tile locator, robotic pipe crawler, Google Earth images, and drone aerial imagery. In some cases, the soil above the pipe is drier and yield is greater.

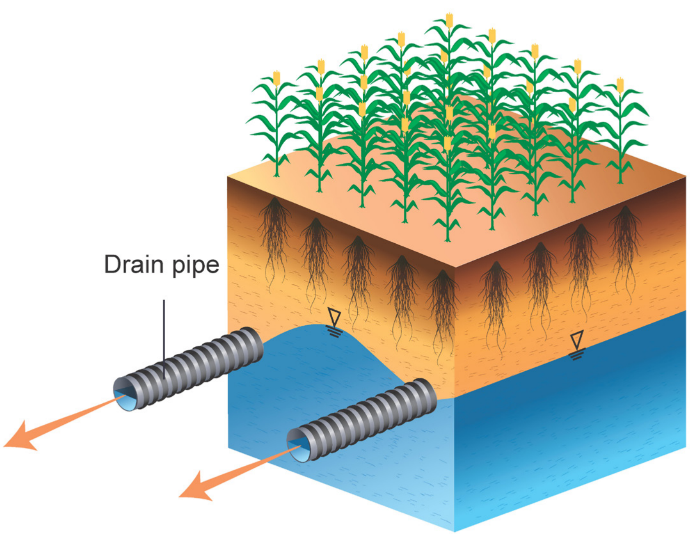


Figure 6- Diagram of a soil profile with subsurface drainage.

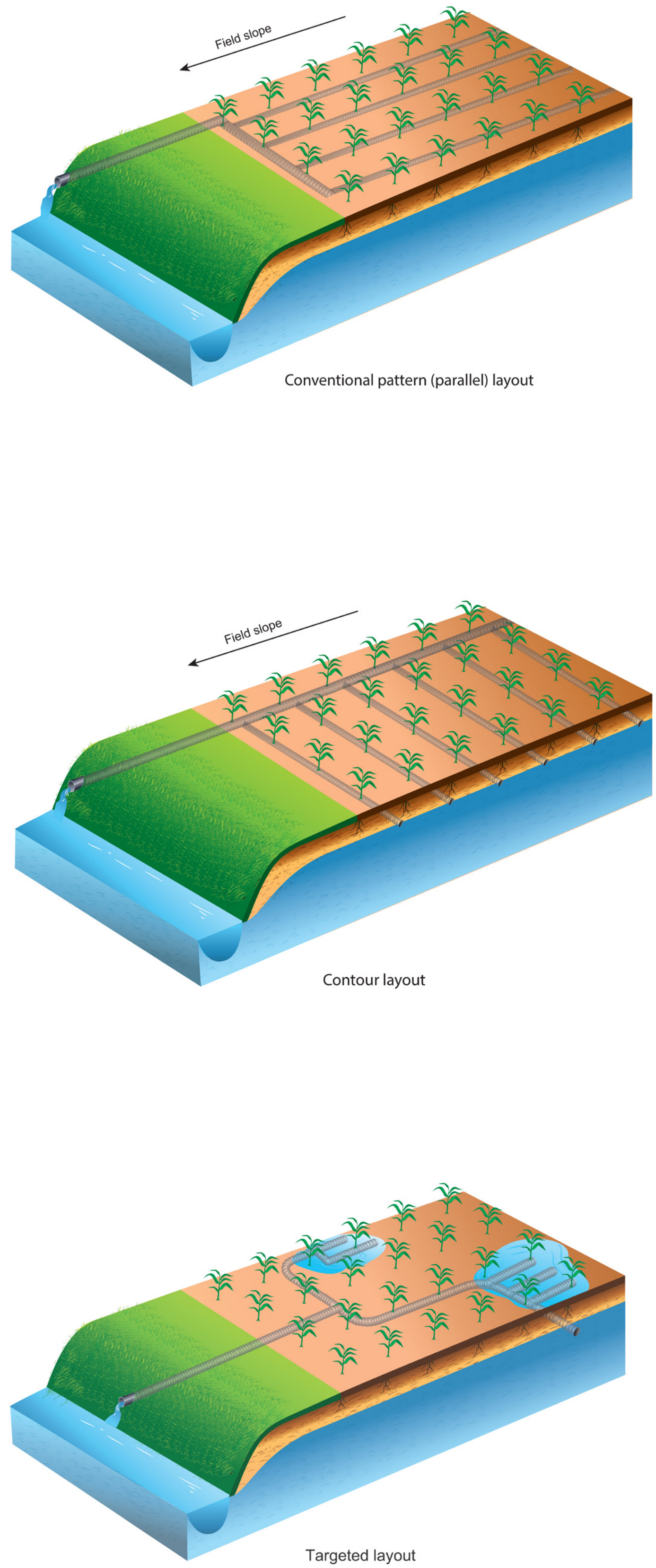


Figure 7- Subsurface drainage system layouts.

6. Water components at a subsurface-drained farm

To better understand subsurface drainage, we need to understand the water cycle components at the field scale (Figure 8). The water cycle components in a field with subsurface drainage are composed of precipitation, evaporation, transpiration, infiltration, surface runoff, lateral seepage, deep percolation, capillary rise, storage (on the surface and within the profile) and drainage discharge.

Precipitation is the primary source of water for crop use. As precipitation falls on the soil and crops, some of it evaporates and some of it infiltrates the soil to build a water table in the soil profile. Some of the water is held in the soil as soil water storage. The water in the soil profile can pass through the restrictive layer slowly in the process of deep percolation. Water can rise above the water table in the process of capillary rise that provides water for plant roots above the water table. Plants uptake water and release it in the process of transpiration. The combination of evaporation and transpiration is called evapotranspiration. When precipitation rate exceeds the infiltration capacity of the soil, water starts to accumulate on the surface, and with a sloping field, surface runoff will be generated.

Water in the soil profile moves toward the ditch through lateral seepage. The subsurface drainage system moves water from the soil profile to the drainage ditch or receiving stream.

The water balance in the drainage system is described as:

Drainage discharge = Precipitation - Evapotranspiration - Surface runoff - Lateral seepage - Deep percolation - Soil water storage

7. Causes of sediment loss in drainage discharge

Potential causes for sediment loss in drainage discharge include: (1) During the early period after installation, some sediment will enter the pipe and move with water following flow events (Stuyt et al., 2005). This is because the soil around the pipe was disturbed during installation. (2) A surface inlet moves sediment from surface runoff into the subsurface system. (3) A poor connection or a broken pipe can let sediment into the system. (4) Overly wide slots can allow sediment into the pipe (Ghane, 2025a). (5) In shrinking and swelling clay soil, high-intensity rainfall can cause rapid movement of water through macropores, thereby eroding the macropore walls and moving sediment into the system (Nazari et al., 2020).

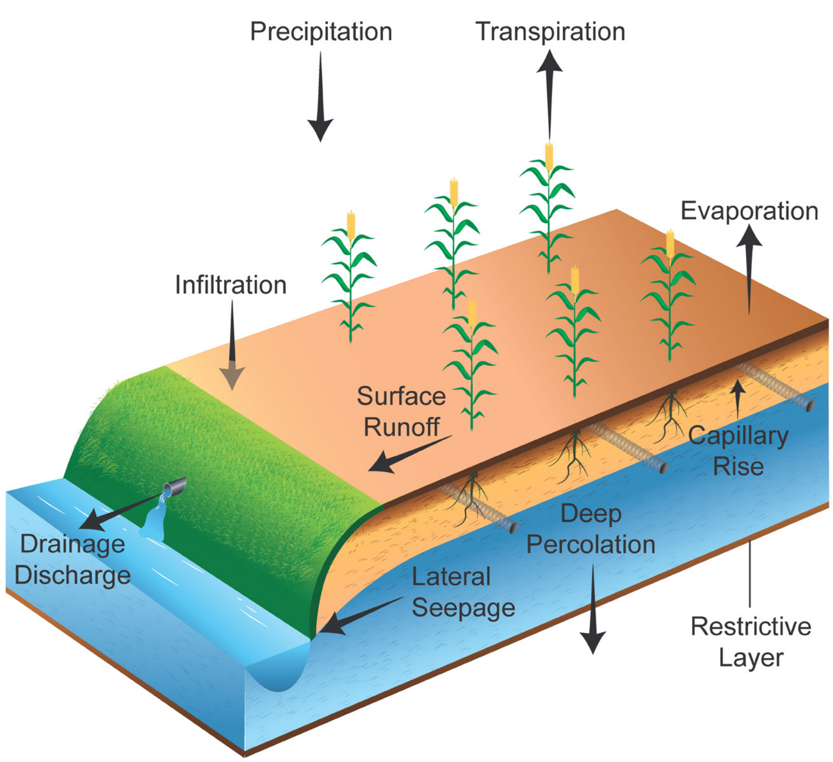


Figure 8- Water components at a subsurface-drained farm.

8. Midwest Drainage

In the Midwest USA, subsurface drainage is mostly concentrated in the corn belt (Figure 9). In Michigan, subsurface drainage is more concentrated in the southeast and the Thumb region where the dominant natural drainage classes are very poorly drained, poorly drained, and somewhat poorly drained. Drainage class identifies the frequency and duration of wet periods under natural conditions.

In the Midwest USA, the depth of lateral drain pipes range from 2.5 to 5 ft. In Michigan, shallow drain pipes are typically installed at a depth of 28 to 30 inches. In general, narrower drain spacing is needed for fine-textured soils (clay, clay loam, and loam) and the wider spacing is needed for coarse-textured soils (sand and sandy loam). Overall, there has been a trend for narrower drain spacing, which allows for a quicker water removal from the field.

The 2017 Census of Agriculture showed 3.0 million acres of subsurface-drained farms in Michigan, which is a 17% increase from the 2.5 million acres in 2012. This value is estimated to be around 3.5 million acres in 2022. This is mainly because high-intensity, heavy rainfall is becoming more frequent. Also, subsurface drainage pays well.

9. Economics of drainage

Subsurface drainage has a clear economic advantage. Percent corn yield increase can range from 20% to 80%. Payback period can range from 2 to 6 years for corn (Ghane et al., 2021).

The site-specific payback period depends on:

(1) Climate (temperature and rainfall).
(2) Drainage design (drain depth and spacing).
(3) Soil properties (saturated hydraulic conductivity and depth to restrictive layer).
(4) Economics (interest rate, depreciation, maintenance cost, pipe cost, installation cost, crop price).

Typically, drainage investment is done by the landowner because it increases the value of the land. When the land operator wants to invest in the drainage system, the rental value should not increase as the operator is paying for the drainage system. In addition, the operator and landowner should agree on having a long-term lease that provides enough time to pay off the loan (FarmProgress, 2010). The lease term should be greater than the amortization period of the drainage installation loan. Otherwise, a buyout clause should be added to the lease agreement.

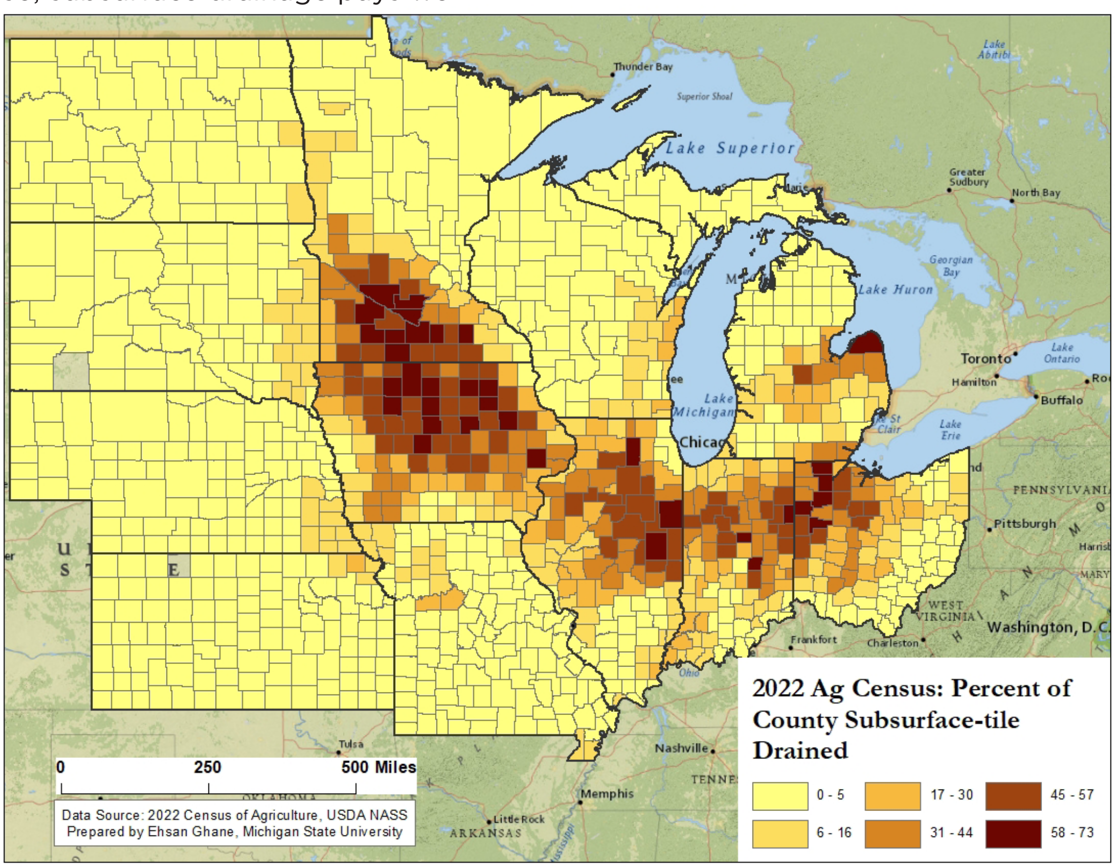


Figure 9- Map of the Midwest USA with the percent of county area that is subsurface drained.

10. Subsurface drainage outlet considerations

The location of the outlet of a drainage system is important to the proper water-removal function of the system. Place the outlet to allow free flow (unsubmerged condition) most of the time. Typically, water flows into the lateral drain pipes, which connect to submains and a main that conveys the water toward the system outlet. The invert of the outlet pipe should be at least 1 ft below the ditch bottom (Figure 10).

At times, the field is relatively flat with not enough grade to allow gravity flow of the water toward the outlet, or the drainage ditch is not deep enough to allow the outlet to flow into it. In these cases, a pump station is needed where the main moves drainage water into a sump from which it is pumped out to remove the excess water (Figure 8). For information about design and sizing of pumps stations, see Scherer (2015).

Figure 10- Top: Subsurface drainage outlet flowing into a drainage ditch that is at least 1 ft above the ditch bottom. Bottom: A relatively flat field with not enough grade to allow gravity flow of the drainage water into a drainage ditch, so the drainage discharge flows into a sump from which it is pumped out into the ditch.

11. Subsurface drainage pros and cons

Subsurface drainage reduces surface runoff by allowing water to infiltrate into the soil rather than flowing over the land. Draining the excess water from the soil profile provides the necessary aeration needed for proper crop root development (Figure 11). Drainage promotes deep root development and prevents the crop roots from drowning in too much water.

Drainage helps the soil dry sooner, which provides timely field operations while reducing soil compaction. Earlier drying of the soil allows earlier seed germination because the soil warms faster in spring. Crop yield is less variable from year to year with drainage. The overall impact of subsurface drainage is a healthier, more productive soil with more stable crop yields (Table 1).

Drainage improves soil aeration, thereby increasing biological activity, which leads to better soil structure by increasing soil aggregation. In contrast, an undrained field with prolonged waterlogged condition degrades the soil structure by breaking down soil aggregates.

When compared to an undrained field, drainage improves nitrogen use efficiency, leading to less nitrogen fertilizer input (Mass et al. 2022). Also, drainage reduces nitrous oxide (N2O) emissions (Kumar et al., 2014), which is about 300 times more potent than carbon dioxide (CO2).

A disadvantage of drainage is that it provides less opportunity for groundwater recharge due to reduced deep percolation, which may be important in locations where the aquifer is in decline.

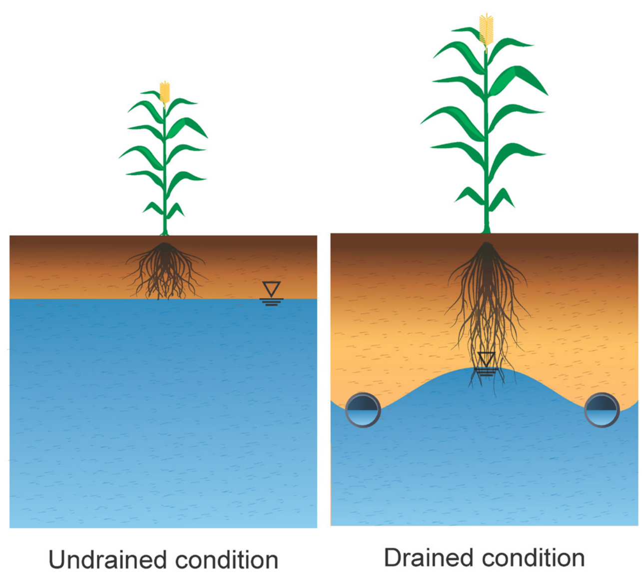


Figure 11- Crop root development for undrained and drained conditions..

Furthermore, when soil aeration is increased with water removal, oxidation of soil organic matter increases, thereby accelerating the loss of soil organic matter. Thus, it is important to combine drainage with regenerative agriculture (conservation tillage, cover crops, and diverse crop rotations) to build soil carbon.

Table 1. Pros and cons of subsurface drainage in humid regions.

Pros	Cons
Provides timely field operations and trafficability	Excess phosphorus transport
Reduces year-to-year crop yield variability	Excess nitrate transport
Reduces nitrous oxide (N2O) emissions	Less groundwater recharge
Reduces N fertilizer input by increasing N use efficiency	Accelerates loss of soil organic matter
Increases soil aeration	
Improves soil structure	
Decreases surface runoff	
Increases crop yield	

12. Environmental impact

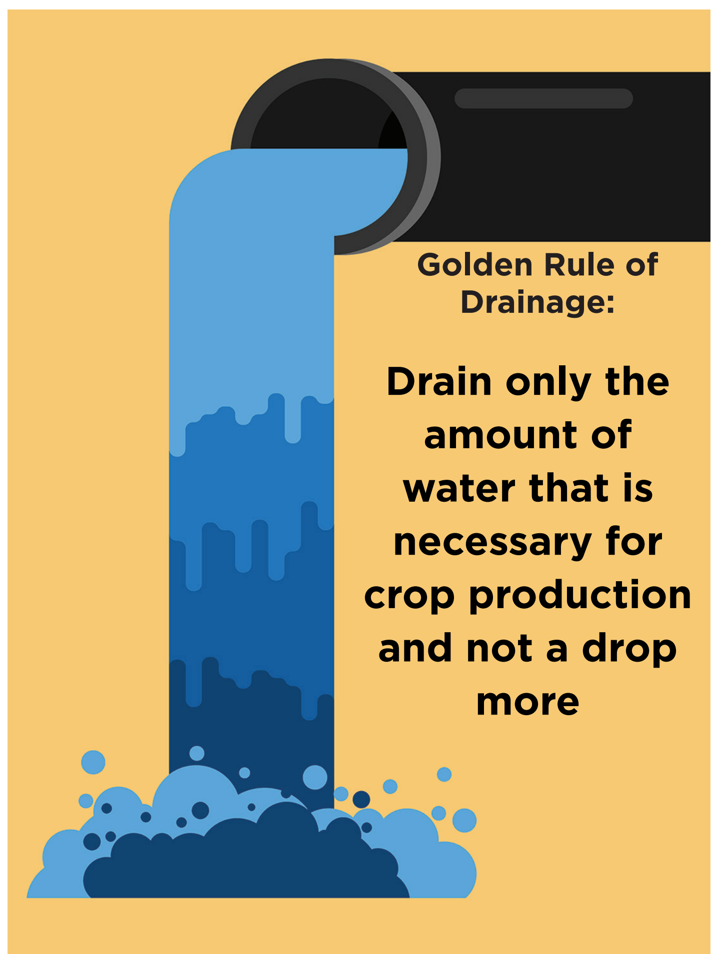
The two major pathways for nutrient transport from a subsurface-drained field are surface runoff and drainage discharge. While farmers need subsurface drainage for economical crop production, it can also transport nutrients to surface water (Table 1). Drainage discharge has been recognized as a considerable pathway for phosphorus loss from the field to surface water bodies (King et al., 2015). As excess phosphorus (P) gets into surface water, it can cause harmful algal blooms.

For fresh water bodies, P is the limiting nutrient for algae growth meaning that as P concentration increases, it stimulates an increase in algae growth. However, increases in nitrate concentration have been shown to increase algae toxin production in fresh water (Horst et al., 2014). Because freshwater surrounds Michigan, phosphorus is the primary nutrient of concern.

Western Lake Erie and the Saginaw Bay are the two most vulnerable water bodies surrounding Michigan due to their shallower water depth that provides warmer temperatures for algae. The western basin of Lake Erie has an average water depth of only 24 feet (up to 32 feet deep), whereas the average water depth of the eastern basin of Lake Erie is 80 feet (up to 200 feet deep) (NOAA). This explains the warmer water temperature in Lake Erie's western basin. The inner bay of Saginaw Bay has an average water depth of 15 feet (up to 45 feet deep) (McCormick and Schwab, 2008) that allows water to warm up faster and provide temperatures suitable for algal blooms.

13. Conclusions

Subsurface drainage has many benefits. It is needed to sustain agricultural production in many areas, but it can exacerbate nutrient loss. Solutions to address water quality issues are needed to reduce the transport of P and nitrogen to surface water bodies. Agricultural conservation practices such as nutrient management, controlled drainage, saturated buffers, wetlands, denitrifying woodchip bioreactors, and two-stage ditches are available to help address this water quality issue. Furthermore, other technologies such as P-filters with P-adsorbing media are being investigated as a solution. Keep in mind the Golden Rule of Drainage:



Expert Reviewed

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