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Shallow Drains

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1. Overview of shallow drains

Shallow drains refer to subsurface (tile) drain pipes installed at a depth of 2.5- to 3-ft. Shallow drains have a higher initial cost because they require a narrower drain spacing than deep drains to achieve the same water removal rate, but they are worth considering because of their benefits. These benefits include lowering of the water table more quickly, removing less total water from the soil profile, reducing nitrate loss, retaining more moisture in the root zone, and increasing crop yield under certain conditions (Figure 1). Another benefit is that shallow drains are not limited to relatively flat slopes like controlled drainage. They can be used on rolling or sloping land without any need of management.

In sections 2 and 3 of this bulletin, soil profile suitability and spacing needs of shallow drains are presented. In sections 4 to 9, results from a DRAINMOD modeling study from seven locations are summarized, which show the impacts of shallow drains on water-table depth, drainage discharge, crop yield, water quality, and profitability (Ghane and Askar 2021). In that computer modeling, 2.5-ft shallow drains installed at narrower optimum spacings were compared with 4.1-ft deep drains installed at wider optimum spacings, where in both cases the optimum drain spacing maximized economic return on investment. In Section 10, general considerations of shallow drains are presented.

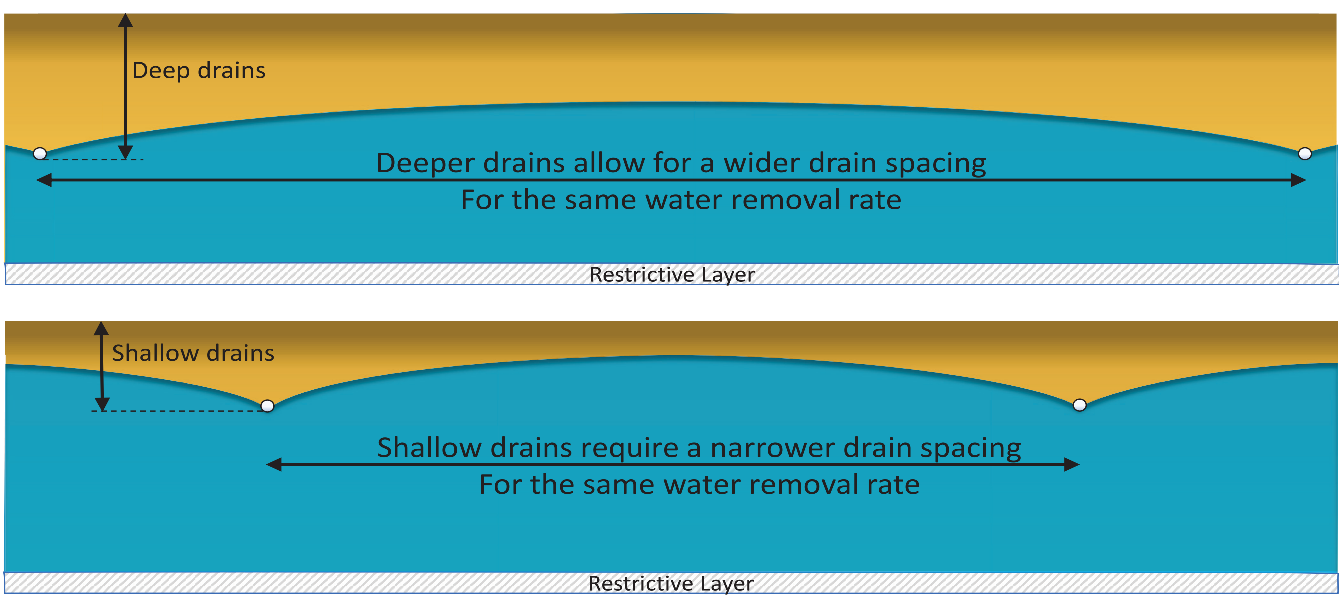


Figure 1- Shallow drains require a narrower drain spacing to achieve the same water removal rate as in a system with wider-spaced, deeper drains.

2. Where to install shallow drains

When a shallow permeable upper soil layer (less than 3-ft depth) sits on top of an impermeable restrictive layer (such as a clay pan), install 2.5- to 3-ft depth shallow drains while maintaining a minimum 2-ft pipe cover (Ghane, 2022b). This is because drains are always more effective when installed in more permeable soils. On the other hand, when the permeable upper soil layer is very deep (greater than 3-ft depth), deep drains can be installed at 3- to 5-ft depth for reducing the initial cost of the drainage system by achieving wider drain spacings. In that case, 2.5- to 3-ft shallow drains can also be installed. Overall, with a deeper restrictive layer, you have more flexibility to select a drain depth, but with a shallow restrictive layer, you may be restricted to shallow drains out of necessity.

3. Shallow drains need narrower drain spacings

Choosing a shallower drain depth allows for a narrower drain spacing to achieve the same water removal rate as in a system with deeper, wider spaced drain pipes (Figure 1). The Drain Spacing Tool helps with both steps 1 and 2. To learn more about the tool, see Ghane (2022b).

4. Shallow drains retain more moisture in the root zone

Shallow drains create a shallower average water table than deep drains (Figure 2). The computer modeling showed that 30-year average annual water table was at 2.5-ft depth for 2.5-ft shallow drains and 3.1-ft depth for 4.1-ft deep drains in Lansing, Michigan. This is because deep drains lower the water table to deeper depths than shallow drains (Figure 2). The shallower water-table depth of shallow drains retains more moisture in the root zone than deep drains.

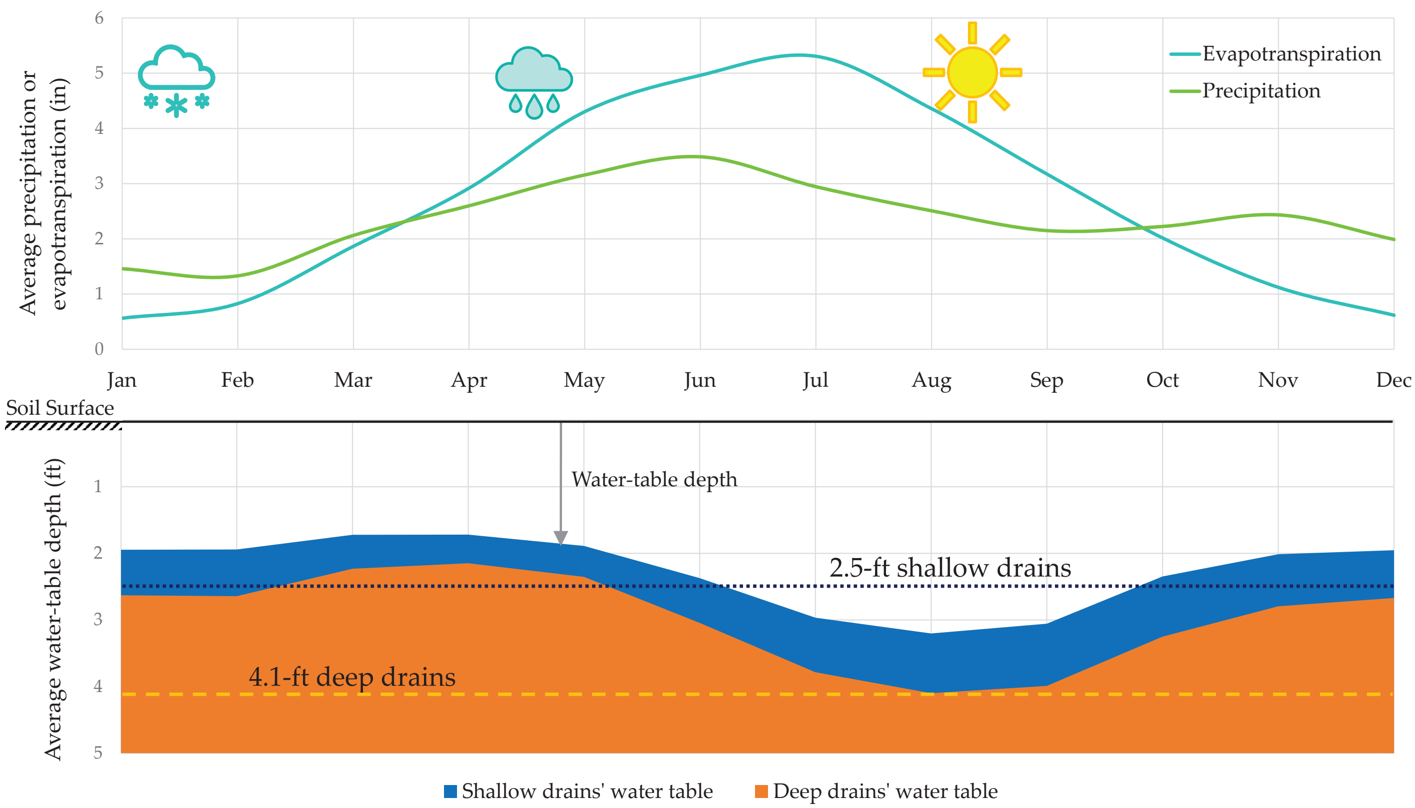


Figure 2- Thirty-year average water-table depth is shallower for shallow drains compared to deep drains. The soil surface is at the 0 ft depth. Shallow drains have less annual drainage discharge and flow over fewer days of the year. Data are for a silty clay loam soil in Lansing, Michigan.

5. Shallow drains reduce the annual drainage discharge and have fewer days of flow during the year

As the crop grows during the growing season, the crop water demand or evapotranspiration increases until it plateaus during the summer (Figure 2). With the increase in the crop water demand and decrease in precipitation during the summer, the average water table drops for both drain depths. The computer modeling showed that the average water table dropped below the level of 2.5-ft shallow drains in July, August, and September at the Lansing location (Figure 2). On a given day, when the water table drops below the level of the drains, they stop flowing. This means that shallow drains reduce annual drainage discharge and have fewer days of flow during the year than deep drains (Figure 3).

6. Shallow drains lower the water table more quickly

Shallow drains lower the water table from the soil surface to 1-ft depth more quickly than deep drains. For example, the 4.1-ft deep drains took 5.4 hours longer to lower the water table from the surface to 1-ft depth than 2.5-ft shallow drains in Lansing, Michigan. Other locations showed a similar trend. Lowering the water table more quickly results in removing water more quickly. A general rule is that a drainage system should lower the water table to approximately 1 ft below the soil surface within 24 hours following waterlogged conditions (Brown & Ward, 1997). Corn can tolerate waterlogged conditions up to about 24 hours without considerable yield loss, after which yield declines rapidly (Evans & Fausey, 1999). Climate scientists predict more frequent heavy rainfalls in the future (Sojka et al., 2020). Therefore, shallow drains reduce the risk of crop damage from waterlogged conditions following heavy rainfalls because they lower the water table more quickly than deep drains.

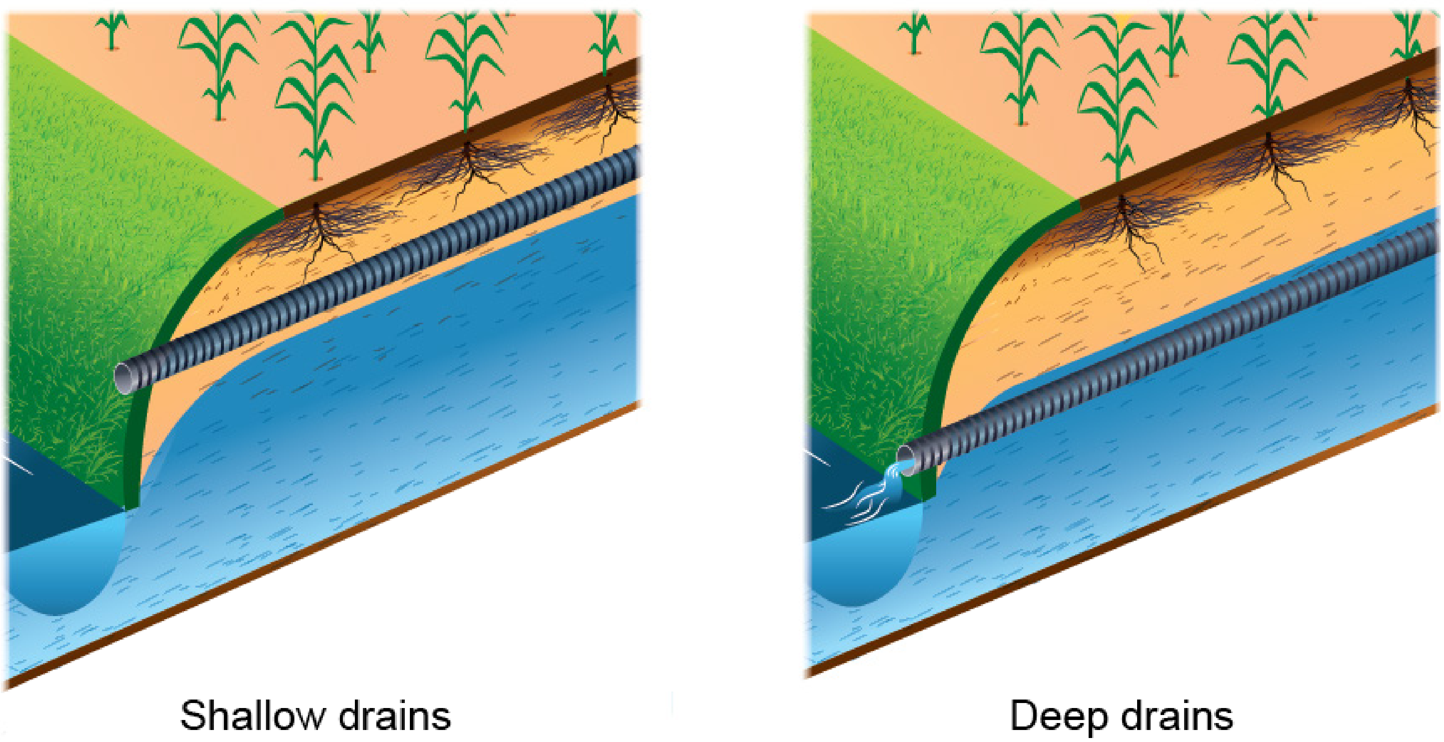


Figure 3- Shallow drains have fewer days of flow over the year, and they remove less annual drainage discharge than deep drains.

7. Impact of shallow drains on corn yield

7.1. Corn yield under shallow drains depends on location

Among the seven locations, Lansing had the highest long-term average corn yield increase of 1.8% with the lowest growing-season rainfall of 17.2 inches (Figure 4). Baton Rouge had the largest yield decline of -1.0% with the highest growing-season rainfall of 26.1 inches. Plymouth had the least uniform rainfall distribution over the growing season, which benefited corn yield under shallow drains. Corn yield generally benefited from shallow drains at locations with lower growing-season rainfall and less uniform rainfall distribution over the growing season.

7.2. Corn yield under shallow drains depends on soil type

The percent increase in long-term average corn yield from 4.1-ft deep to 2.5-ft shallow drains was highest in a coarse-textured sandy loam soil (Figure 5). The corn yield benefit from shallow drains in coarse-textured soil is greater than fine-textured soil because shallow drains supply more moisture to crop roots.

7.3. Corn yield under shallow drains depends on dry and wet years

The percent increase in long-term average corn yield with 2.5-ft shallow drains ranged from 1.5% to 6.5% in dry years at Waseca, Minnesota, and 1.1% to 2.2% at Lansing, Michigan (Figure 6). The other five locations also showed corn yield benefit from shallow drains during dry years. Shallow drains remove less annual drainage discharge (Section 5) and have a shallower average water-table depth (Section 4). The corn yield benefit from shallow drains is greater in dry years than wet years. As a result, shallow drains can reduce the risk of crop drought stress in dry years.

Climate scientists predict that wet seasons will become wetter and dry seasons will become drier in the future (Konapala et al., 2020). Research shows that the longer dry periods in the future can lead to crop yield decline (Adhikari et al., 2020). Therefore, less water removal during the summer with shallow drains may be beneficial to reduce drought stress in future summer seasons. Also, the wetter spring season may require lowering the water table more quickly, which is possible with shallow drains (Section 6). Overall, balancing the drainage design to manage both wetter spring and drier summer is needed.

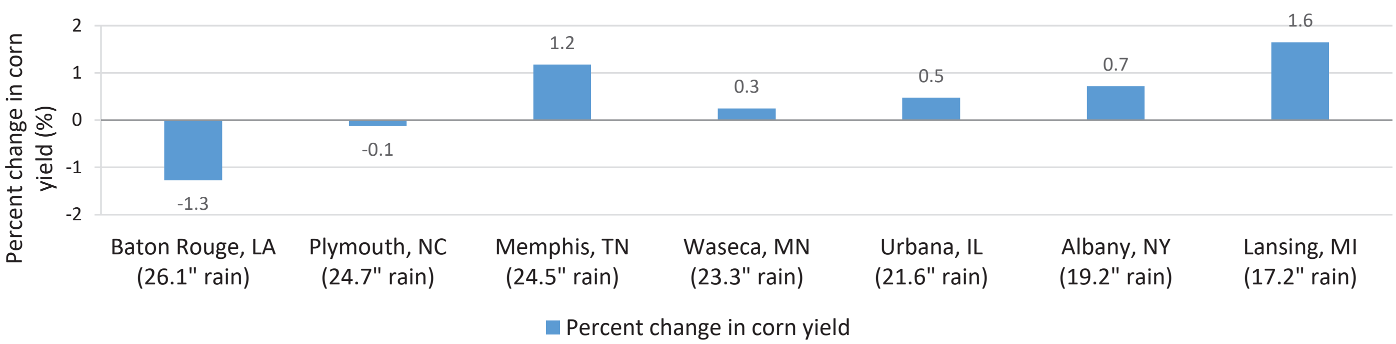


Figure 4- Percent change in 30-year average corn yield (2.5-ft shallow drains minus 4.1-ft deep drains). Our data show that corn yield generally benefited from shallow drains at locations with lower growing-season rainfall.

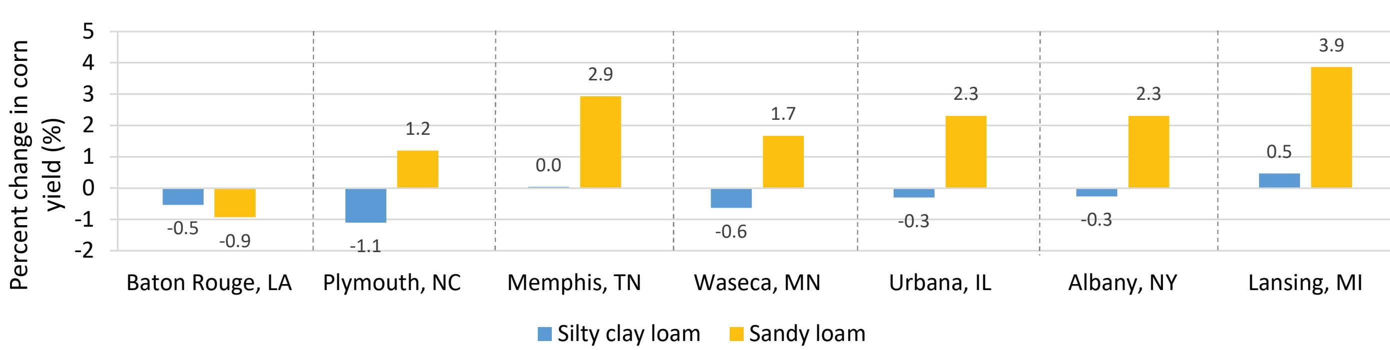


Figure 5- Percent change in 30-year average corn yield (2.5-ft shallow drains minus 4.1-ft deep drains). Corn yield for coarse-textured soil benefited more from the shallower water table resulting from shallow drains than fine-textured soil.

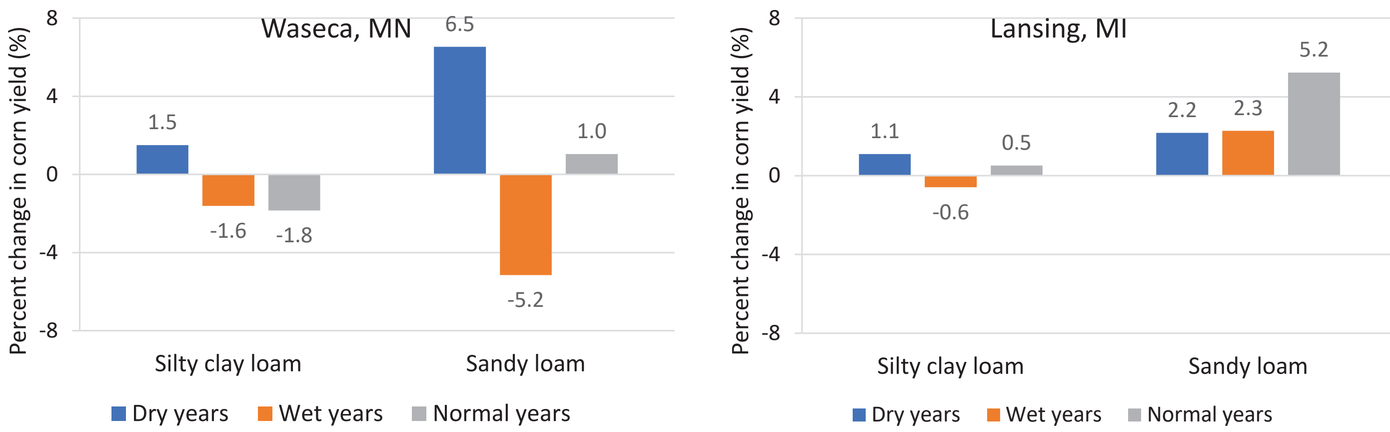


Figure 6- Percent change in 30-year average corn yield (2.5-ft shallow drains minus 4.1-ft deep drains). Shallow drains can increase corn yield in dry years and reduce yield in wet years. Shallow drains reduce year-to-year yield variability.

7.4. Corn yield under shallow drains has less year-to-year variability

Corn yield variation under shallow drains was 16.2%, while deep drains had yield variation of 17.4% over 30 years in Lansing. The other six locations also showed a similar trend. This is because water-table depth fluctuates less for shallow drains than deep drains, so shallow drains can provide more consistent moisture to the root zone from year to year. Overall, corn yield is more consistent over time with shallow drains than for deep drains.

7.5. Overall corn yield response to shallow drains

The corn yield response to shallow drains is site specific. Corn yield response primarily depends on location (Section 7.1), soil properties (Section 7.2), dry or wet year (Section 7.3), and drainage design (drain depth and spacing). Future research should focus on developing decision-support tools to predict crop yield for a given drain depth and spacing at a specific field.

8. Impact of shallow drains on water quality

8.1. Reducing nitrate load

Reducing drainage discharge is the primary method of reducing nitrate load from a subsurface-drained field (Ross et al., 2016), and shallow drains reduce drainage discharge (Craft et al., 2018). Therefore, shallow drains reduce nitrate load by reducing drainage discharge.

When designing a drainage system, make an informed drain depth decision by estimating the nitrate load reduction of shallow drains compared to deep drains. First, use the Drain Spacing Tool to estimate the average annual drainage discharge of shallow and deep drains. Then, use the Shallow Drains Tool to estimate the average annual nitrate load reduction of shallow drains compared to deep drains. To learn more about the Drain Spacing Tool, see Ghane (2022a). To use the Shallow Drains Tool, visit https://www.egr.msu.edu/bae/water/drainage/.

8.2. Phosphorus load

Few studies have investigated phosphorus loss from shallow drains compared to deep drains. Those studies have reported phosphorus load reduction from shallow drains (Fausey et al., 1995; Gramlich et al., 2018; King et al., 2015; Schwab et al., 1980). The general assumption is that shallow drains reduce the total phosphorus loss by reducing drainage discharge (King et al., 2015). However, more research is needed to confirm the effect of shallow drains on phosphorus loss. Stacking practices such as shallow drains with soil-health improving practices (reduced tillage, cover crops, diverse rotations, and manure or composting) and edge-of-field practices (filter strip, riparian buffer, and controlled drainage) can reduce phosphorus loss. More research is needed to determine the extent of phosphorus load reduction when stacking shallow drains with other conservation practices.

9. Profitability of shallow drains

Profitability was evaluated based on the benefit-cost ratio where annual benefit was from the increased corn yield and annual cost was from the drainage system installation.

Results showed that 2.5-ft shallow drains had a lower benefit-cost ratio because of their higher investment cost in narrower spacings than for 4.1-ft deep drains (Figure 7). Shallow drains gave a benefit-cost ratio of 13:1 for the sandy loam soil in Lansing, indicating that for every dollar invested in the shallow drains, the producer would receive $12. The payback period was 1.2 years for the shallow drains and 0.6 years for the deep drains for the sandy loam soil in Lansing.

In short, both shallow and deep drains pay well. Even though shallow drains can increase crop yield, they were less profitable than deep drains, but they are worth considering because of their benefits (sections 3 to 8).

Research showed that shallow drains become more profitable than deep drains when considering the benefit of reducing N loss from the farm. This benefit is equal to the cost of nitrate removal from a water treatment plant (Skaggs & Chescheir, 2003). This means a nutrient trading program can increase the adoption of this practice, where the water treatment plant pays the producer for reducing nitrate loss from their farm. The Shallow Drains Tool estimates the nitrate load reduction of shallow drains (see section 8.1).

10. Considerations for shallow drains

10.1. Annual crop roots do not pose a risk of clogging shallow drains

Roots of annual crops do not pose a risk of drain clogging when the drainage system is installed properly at typical depths ranging from 2.5 ft to 5 ft. The smaller, younger roots can enter the drainpipe, but they die after harvest and slowly decay, so their remains wash away.

When installing a drainage system, use fittings that have the least number of parts sticking into the pipe to reduce the chance of catching the roots flowing with the water in the drain. If the roots get caught by an obstruction, they can accumulate and clog the drain, or reduce drain flow.

Poor installation can cause root clogging because it creates an off-grade dip or hump in the drain that allows water to stand in the drain, thereby promoting root growth. For more information about root clogging mitigation and preventive measures, see Ghane (2022b).

10.2. Frost does not damage shallow drains

In some locations, frost reaches the level of the shallow drains, but it does not damage the drains. When drains are installed properly, water keeps moving in the drains toward the outlet, so water will not stand in the drains to freeze. If water stands in parts of the drains due to an off-grade dip or hump, it will not damage the drains because water has room to expand sideways in the drainpipe.

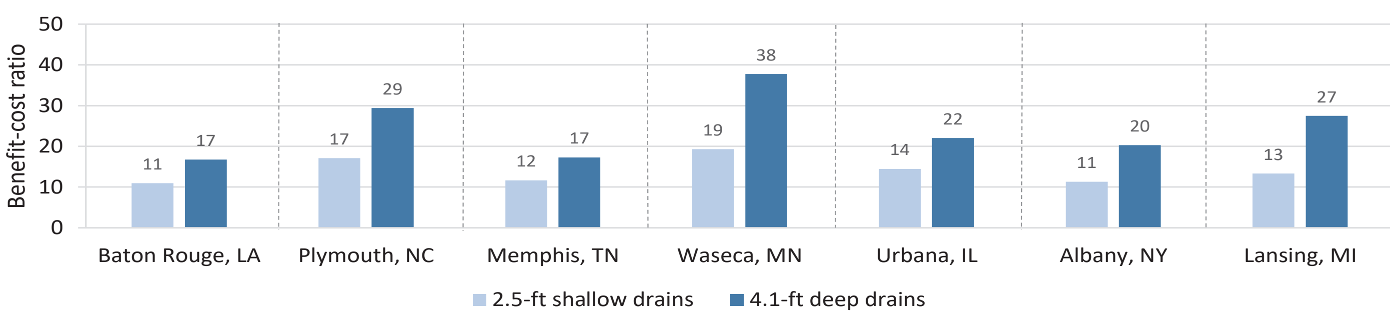


Figure 7- Benefit-cost ratio of the shallow and deep drains for the sandy loam soil. Annual benefit was from the increased corn yield, and annual cost was from the drainage system installation.

10.3. A bi-level drainage installation with both shallow and deep drains

In some cases, a field either has deep old clay tiles or existing deep perforated drains at a wide spacing. If you determine that your original drain spacing is too wide, and decide to install new drains at a shallow depth and narrower spacing, there are two options. The first option is to disconnect the old lateral drains from the main pipe, so they stop flowing. Then, install the new shallow drains at a narrower spacing for the entire field. The second option is to use a bi-level drainage design where the existing deep drains work in combination with the new shallow drains (Hornbuckle et al., 2007). In this case, the new drain spacing is half of the original value (Figure 8). The shallow and deep drains have a separate main, which allows each of them to be managed separately using control structures

A bi-level drainage system can be managed as follows:

In early spring, let the deep and shallow drains flow freely to prepare for field trafficability. In this case, the deep drains will lower the water table to a deeper depth to dry the soil more quickly, and the shallow drains will lower the water table more quickly following heavy rainfall compared to a single-depth design.

During the growing season, set the weir in the control structure of the deep drains close to the soil surface to stop the flow. This is as if the deep drains do not exist, and water can leave the field only through shallow drains at the original wider spacing. At the same time, manage the weir in the control structure of the shallow drains as you would for controlled drainage. This strategy allows removing less water from the field during the summer when the crop water demand is the highest (see top graph in Figure 2) compared to a single-depth design with controlled drainage. Also, less nutrients will be lost because of the reduced drainage discharge compared to a single-depth design with controlled drainage.

During early fall, remove all weirs from both control structures to let the deep and shallow drains flow freely to prepare for harvest, if the soil is wet. If the soil is dry, there may be no need to change the weir setting.

During late fall and winter, set the weirs in both control structures at the same elevation to manage water as you would for controlled drainage to reduce nutrient loss.

Field research in Australia showed that a bi-level system was more effective in reducing waterlogged conditions and drained the root zone more quickly than deeper, single-depth drains (Hornbuckle et al., 2007). Research is needed in the Midwest USA to quantify the benefits of bi-level drainage systems.

Overall, combining shallow with deep drains is a potential design solution when adding new shallow drains to an existing deep drainage system. The benefit of this system is quicker drying of the soil in spring, retaining more water for the crop during the growing season, and reducing more nutrients from leaving the field during the growing season compared to a single-depth design.

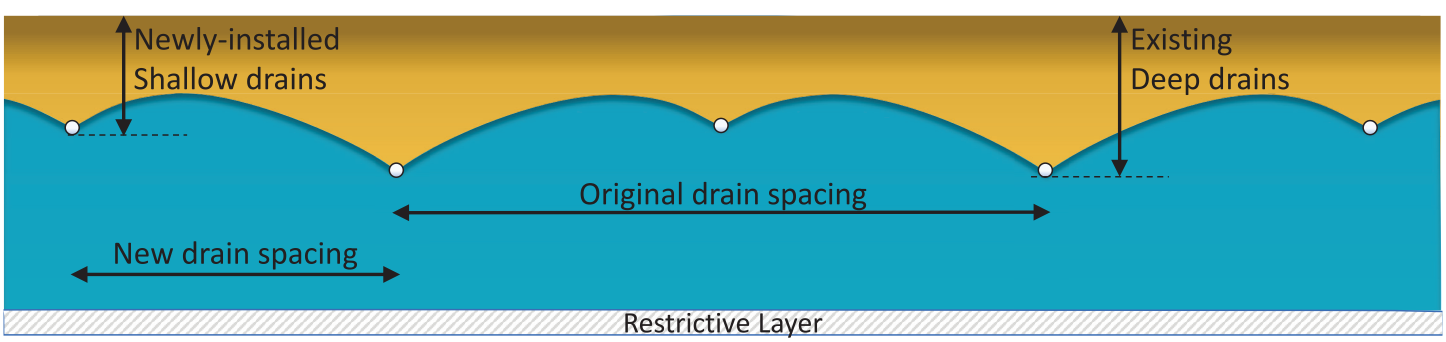
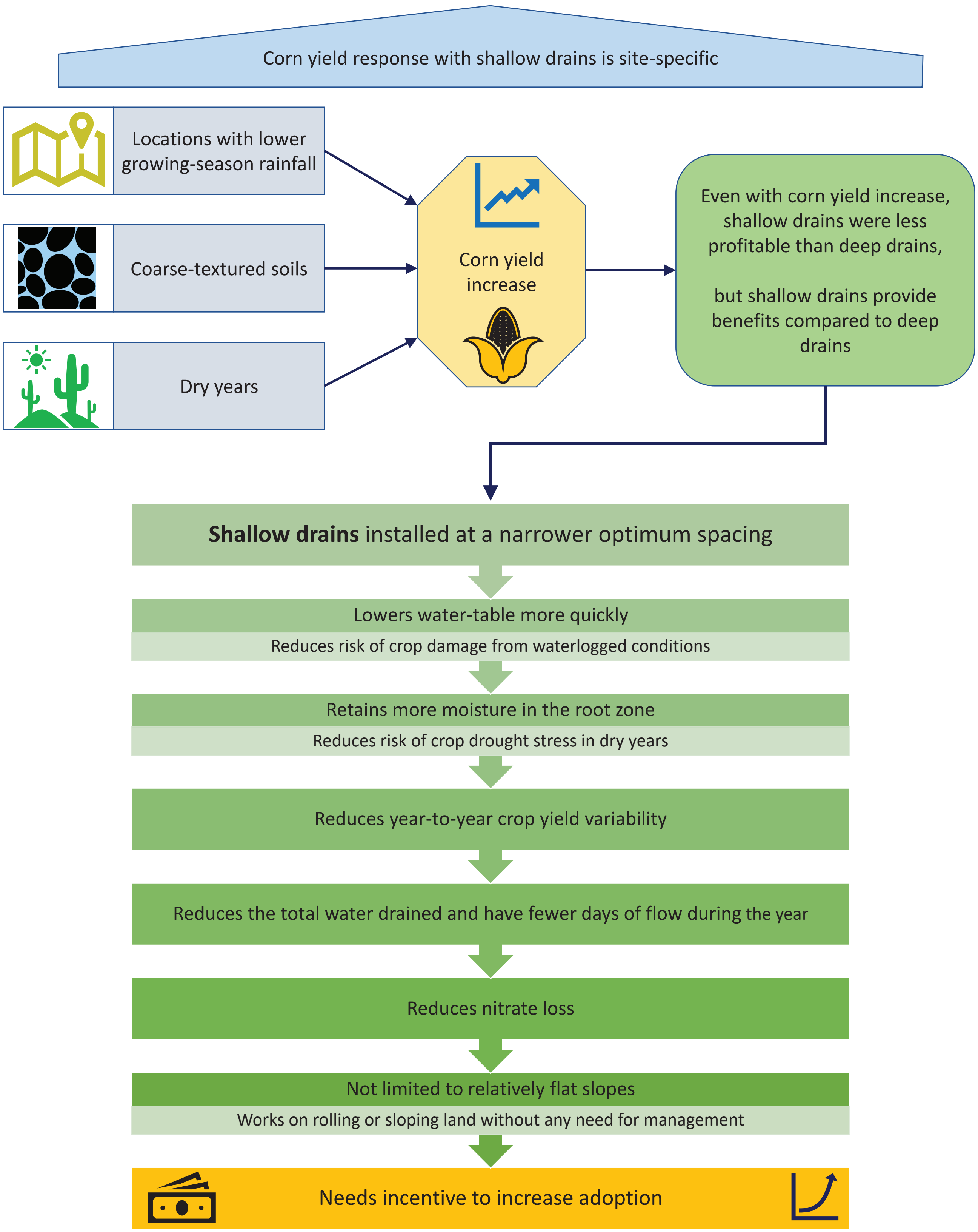


Figure 8- A bi-level drainage system where the original deep drains work in combination with the new shallow drains.

11. Summary



Corn yield response with shallow drains is site-specific
Locations with lower growing-season rainfall
Coarse-textured soils
Dry years
Corn yield increase
Even with corn yield increase, shallow drains were less profitable than deep drains,
but shallow drains provide benefits compared to deep drains
Shallow drains installed at a narrower optimum spacing
Lowers water-table more quickly
Reduces risk of crop damage from waterlogged conditions
Retains more moisture in the root zone
Reduces risk of crop drought stress in dry years
Reduces year-to-year crop yield variability
Reduces the total water drained and have fewer days of flow during the year
Reduces nitrate loss
Not limited to relatively flat slopes
Works on rolling or sloping land without any need for management
Needs incentive to increase adoption

Expert Reviewed

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