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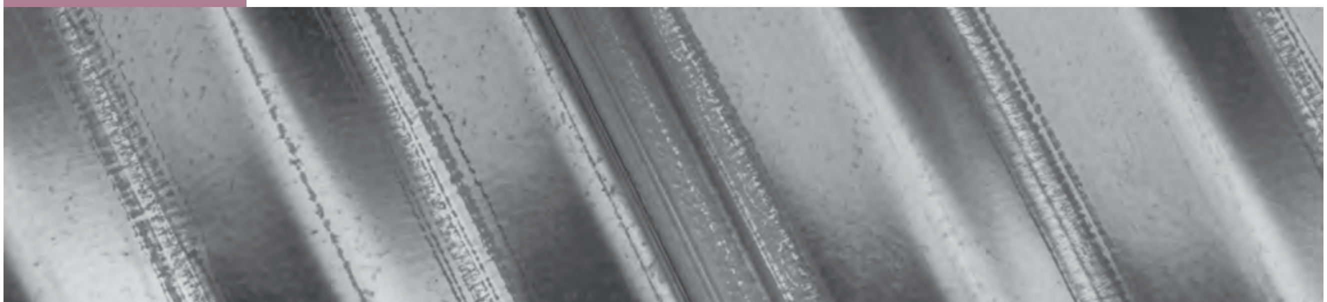

Understanding and Installing Drainage Systems

Juan Enciso[1], Xavier Périès[2], Luís A. Ribera[3], and Dean Santistevan[4]

Farmers can increase yields and net returns by installing artificial drainage systems on soils that have poor natural drainage. Artificial drainage systems can also increase land value, improve crop insurance coverage, and reclaim saline land.

When planning a drainage system, farmers should consider factors such as the types and functions of such systems, methods to detect drainage problems, design options, and the environmental effects of drainage installation.

Why artificial drainage is needed

Good drainage is essential for the success of irrigated agriculture: It ensures that the crop's root system has a good mixture of water and air and that the salt balance in the soil is favorable for plant growth.

Poor drainage causes several problems for agricultural production:

- Because the soil has little or no permeability, excess water accumulates on and below the surface after rainfall or irrigation (Fig. 1).
- Water tables that remain high for 48 hours or longer can saturate the soil and leave too little oxygen in the soil pores for the root system, damaging the plant.
- Agricultural machinery is difficult to move on wet ground for soil preparation.
- Bacteria that provide nitrogen to the crops cannot grow.
- Nutrient processes and transformations are impeded, such as the prevention of usable forms of nitrogen and sulfur.
- The soil temperatures are 7 to 14 degrees F lower than that of similar soil with good drainage. This impedes germination and slows crop growth, making the plants more susceptible to diseases.

* [1]Assistant Professor and Extension Specialist, [2]Extension Associate and, [3]Assistant Professor and Extension Economist; [4]Field Engineer (USDA-NRCS, Colorado)

Figure 1. Typical field with poor natural percolation. Water ponds for several days after a heavy rainfall storm or heavy irrigation.

Poor drainage can occur in arid and humid areas and can be caused by natural or human reasons, including:

- The presence of semi-permeable or impermeable layers of soil
- Over-irrigation
- Proximity to reservoirs or coastal areas
- Canal seepage

When the rate of water input is greater than the natural drainage capacity, the water table rises. Coastal areas—where the altitude ranges from 10 to 100 feet above sea level—generally need regional collective drainage systems. An on-farm drainage system may also be required where the water table is high, depending on the area's topography, soil type, and soil conditions.

Most agricultural soils are alluvial soils formed by materials carried by water and deposited on the lower parts of a valley. These soils may have layers of coarse and fine materials such as sand, clay, silt, and gravel.

Some alluvial soils have poor natural drainage, and artificial drainage may be needed to remove excess water from an irrigated field. Artificial drainage systems can lower high water tables, keep salts from building up, increase crop yields, and make irrigation successful. In general, farmers have noticed big increases in yield after the installation of a drainage system.

To optimize production potential, the water table should be below 3 feet deep for field crops and below 4 feet for citrus. A shallower water table may require artificial drainage. In the Rio Grande Valley, a water table in any soil within 30 inches of the soil surface is a definite problem.

As the water table rises, salts can move upward and accumulate closer to the surface, mainly because more water evaporates from the soil and transpires from plants than is gained through rainfall. A drainage system allows salts to leach downward with rainfall or irrigation.

The benefits of removing salts include improved germination, enhanced crop yield, and an improved growth environment for crops that are less salt tolerant. Growers may need to add soil amendments where the soil has too much sodium and/or a lack of calcium. Poor drainage is also connected with high levels of calcium carbonates.

Once a drainage system has been installed, the collective drainage systems must be maintained properly.

Types of drainage systems

The main types of drains are surface and subsurface.

Surface drains (also referred to as open drains) are typically ditches from which low-gravity conditions remove excess surface water from agricultural land. When deep enough, the ditches can also provide relief to adjacent areas. Surface drainage also can be used as an outlet for collection and disposal of water from subsurface drainage systems.

Surface drainage can be achieved by building ditches, improving natural channels, or shaping the land. Open ditches have a low initial cost and are easy to inspect. Disadvantages to these systems include that they reduce the cropping area, require a right-of-way, and have high maintenance costs.

Subsurface drains (closed drains) are installed underground to remove excess groundwater below the ground surface. These systems are often called tile drains. In the past, perforated clay tile and concrete pipe sections (laterals) were used to help drain agricultural land. Today, perforated corrugated polyethylene pipe is used instead of tiles.

To keep silt and sand from clogging the system and to increase water flow through the pipe, the laterals are surrounded by a nylon envelope or "sock" (Fig. 2).

A subsurface drainage system should be complemented by an open drainage system.

Function of the drains

Both types of drainage systems can be divided into two classes: relief drainage and interception drainage. Relief drains are used when the water table is close to the ground surface and the area is static and flat. Interception drains prevent or reduce water flowing to the problem area.

In planning a subsurface drainage system, the designer must evaluate the site conditions and decide which type of drainage system to install.

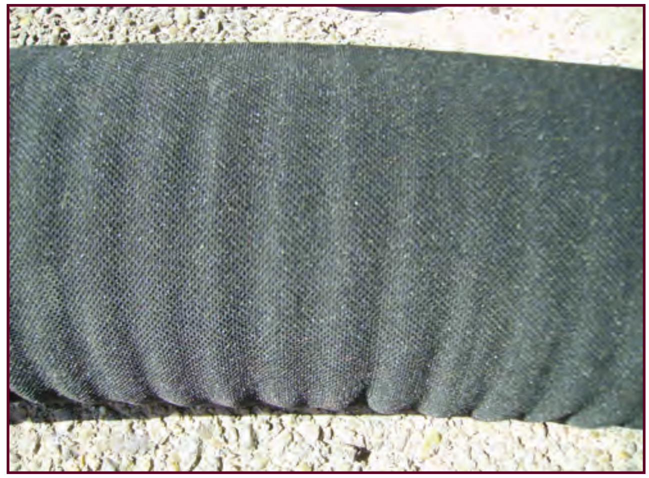

Figure 2. The perforated lateral (drain corrugated pipe) can be covered by a “sock” (right).

Relief drains for subsurface drainage use a system of polyethylene pipe laterals to lower a high water table. The laterals drain the field by gravity. At the lower part of the field, the laterals are connected to a collector drain (Fig. 3).

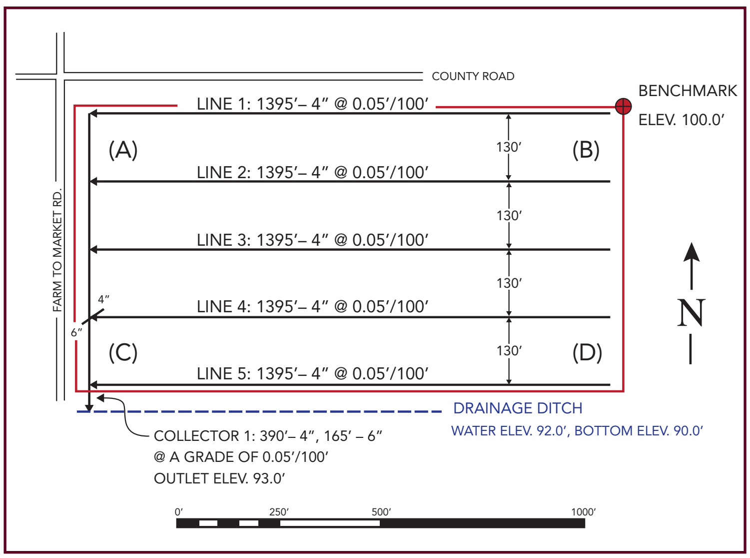

Figure 3. Typical design layout of a subsurface drain system that shows the spacing, size, and grade of laterals and the collector and the outlet of ground waters.

The collector drain receives the flow from all of the laterals and generally discharges into an open drainage ditch. If the outlet point is at lower elevation than the water level in the drainage ditch, a sump well must be installed to temporarily hold the ground water and pump it to the drainage ditch (Fig. 4).

The intention is to maintain the ground water at a level below that of the root zone for a given crop. The Natural Resource Conservation Service requires that the installation be at least 5 feet deep.

The most common relief drain system in the Lower Rio Grande Valley consists of parallel lateral drains located perpendicular to the main drain (Fig. 3). The drain’s arrangement can vary according to the site location. The arrangement can be random, consist of two parallel systems, or have the laterals connected to the collector at an angle.

The laterals in the main system are spaced at any interval according to the site conditions, permeability, and soil type. Most relief drainage parallel systems are composed of laterals that are spaced between 100 and 150 feet apart, depending on the soil texture. The laterals are installed at a grade of between 0.025 foot per 100 feet to 0.1 foot per 100 feet as shown in the example of Figure 3 and Table 1.

The overall effectiveness of artificial drainage can be improved by the use of relief drainage systems in conjunction with other best management practices, such as land leveling.

Field No. 1			
Locate	Ground elevation (ft)	Proposed elevation (ft)	Depth (ft)
A	99.70	93.34	6.36
B	99.05	94.05	5.00
C	98.60	93.08	5.52
D	99.30	93.78	5.52

Table. 1. Existing ground elevations, proposed elevations of subsurface lines, and depth of cover for field locations shown in Figure 3.

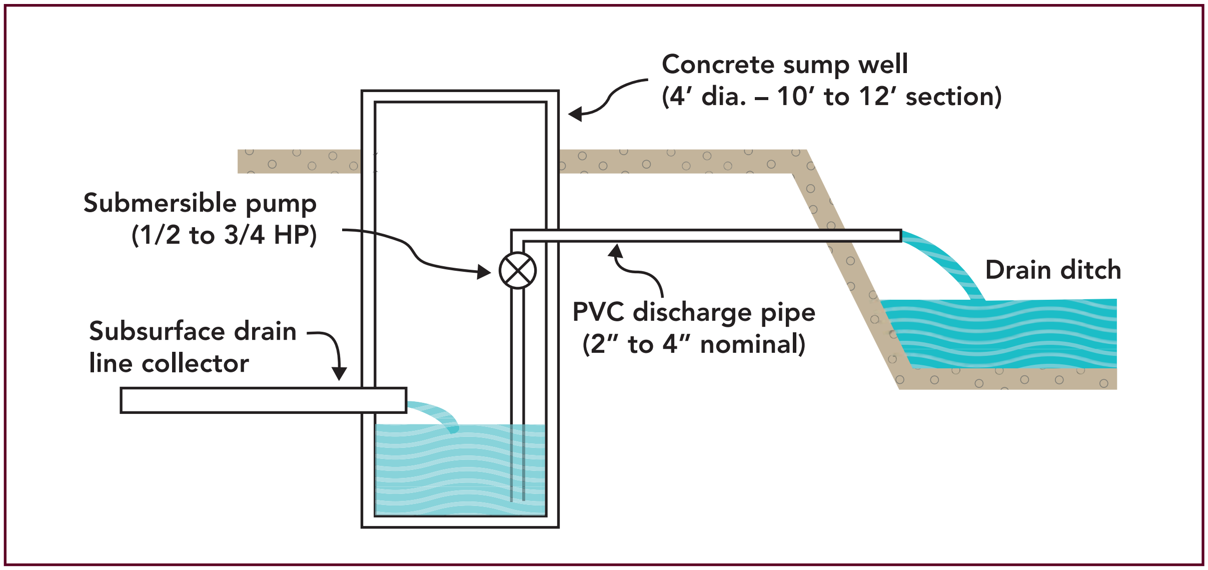

Figure 4. Typical sump well schematic showing the transfer of ground water into a drainage ditch.

Interception drains are placed perpendicular to subsurface flows to capture water and reduce the creation of excessively wet areas. On agricultural land, interceptor drain lines are often installed along earthen irrigation canals that have high seepage potential. In this situation, an open drain can be used to intercept excess water from the leaky canal.

When the conduct drains are closed, the depth of the interceptor line will vary with that of the water table.

Well drainage

Well drainage systems pump water from deep wells to lower and maintain the water table at a level suitable for proper crop growth. The pumped water can sometimes be used for irrigation if it is of good quality and has low salinity.

When designing a well drainage system, several test wells must be installed to determine the drawdown and the spacing of the wells. This method of drainage is expensive, and its application is limited to lands that produce a high return value per acre.

Monitoring water tables

Before any subsurface drain system is installed, the water tables must be monitored to determine whether drainage is needed or to evaluate the performance of the drainage system. An observation well can help the designer study the fluctuation of water tables and monitor salinity in the water during the growing season.

Observation wells consist of open auger holes drilled at various locations in which a perforated PVC pipe (of about 1 to 2 inches in diameter) is pushed into the soil profile (Fig. 5). The PVC pipe is commonly referred as piezometer. Several piezometers must be installed to determine the direction of the groundwater flow and fluctuations of the water table during the year.

Topographic maps and soil surveys are also useful when monitoring water tables. The field topography can indicate seep areas or low areas in the soil.

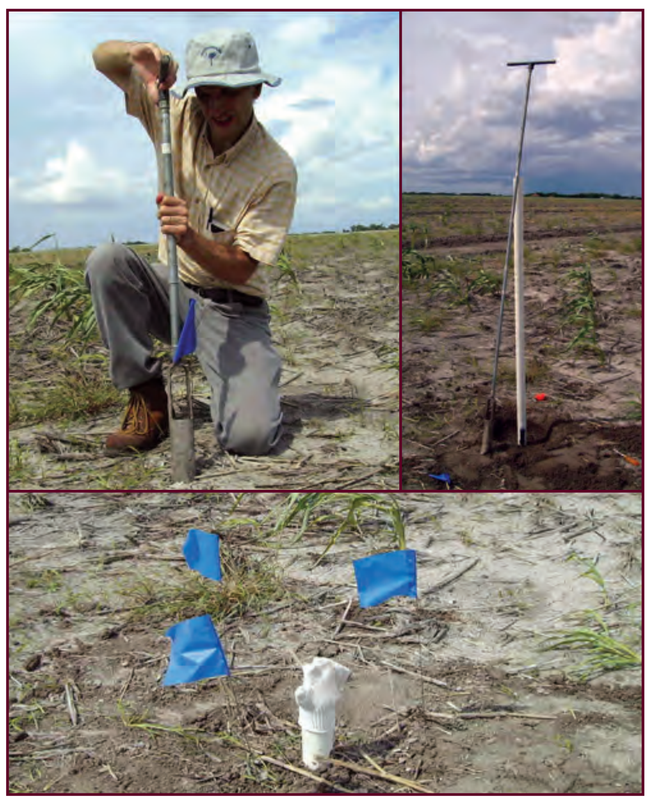

Figure 5. Installing a piezometer (2-inch PVC tube) up to 9 feet deep with a 2-inch auger to monitor fluctuations of the water table level.

Drainage design considerations

A drainage system should be designed to remove excess gravitational water and lower the water table far enough from the ground surface so it does not interfere with plant growth.

The system designer must determine:

- The desired depth to which the water table should be lowered (Fig. 6)
- The amount of rainfall received and the amount of irrigation to be applied
- The proper depth and spacing of the relief and collector lines
- The maximum length of laterals
- The material and diameter of the pipe
- The slope grade at which the lines should be installed

The design should take into consideration critical soil properties (permeability, hydraulic conductivity, drainage coefficient) that will determine the drainage water relief outflow rate, the drain depth, and spacing.

Permeability and hydraulic conductivity

Permeability is the capacity of the soil to transmit water. Soil can have low, moderate or high permeability (Table 2).

The hydraulic conductivity is a numerical value of a soil's permeability. It represents the speed that water seeps through the soil; this speed is determined by several properties such as pore size, structure of the soil, and soil chemistry.

Sandy soils have higher permeability and higher hydraulic conductivities than do clay soils (Table 2). A designer needs to know the soil texture and conductivity to determine the size of the drains.

Drainage coefficient or water relief outflow rate

The drainage coefficient is the rate of water removal needed to obtain the desired protection of the crop from excess water. It is based on local field experience and is generally expressed in flow rate per unit of area.

Most drainage systems are designed to remove 0.005 to 0.01 inch of water per hour. The designer determines the drainage coefficient according the deep percolation expected, rainfall received, and irrigation depths applied. The designer then uses the drainage coefficients and the amount of area to be drained to determine the diameter of the lateral and collector drains needed.

Drain depth and spacing

The spacing between drain lines may vary from 50 to 175 feet, depending on the soil type, the drain depth, and the crop grown (Table 2).

In soils with moderate permeability, the drains can be spaced between 100 and 150 feet apart. They must be spaced more closely in soils with low permeability. A closer spacing reduces the amount of time to drain a certain volume of water but increases the cost of the system. The spacing will also be influenced by the pipe diameter of the interceptor lines.

The depth of installation of the laterals is affected by the drain spacing, the crop and soil texture, and the desired drop of the water table. The drains are usually placed at a minimum depth of 6.5 feet (minimum of 5 feet at the upper end) in arid areas and at 5 feet in humid areas.

Soil type	Soil permeability	Drain spacing (feet) and drainage efficiency for various hydraulic conductivities	Drain depth (feet)
Raymond-Rio Clay Loam Olmito-Runn Silty Clay	Very low to low	Fair drainage (hydraulic conductivity of 0.5 in/hr) 66–100	5.0–6.0
Hidalgo Sandy Clay Loam Laredo Silty Clay Loam	Moderately low to moderate	Good drainage (hydraulic conductivity of 1.0 in/hr) 79–150	5.0–6.0
Willacy-Pharr-McAllen Fine Sandy Loam	Moderately high	Excellent drainage (hydraulic conductivity of 1.5 in/hr) 97–175	5.0–6.0

Table 2. Examples of drain lateral spacing and depth usually adopted in the Lower Rio Grande Valley, Texas, for different soils. (Source: USDA/NRCS)

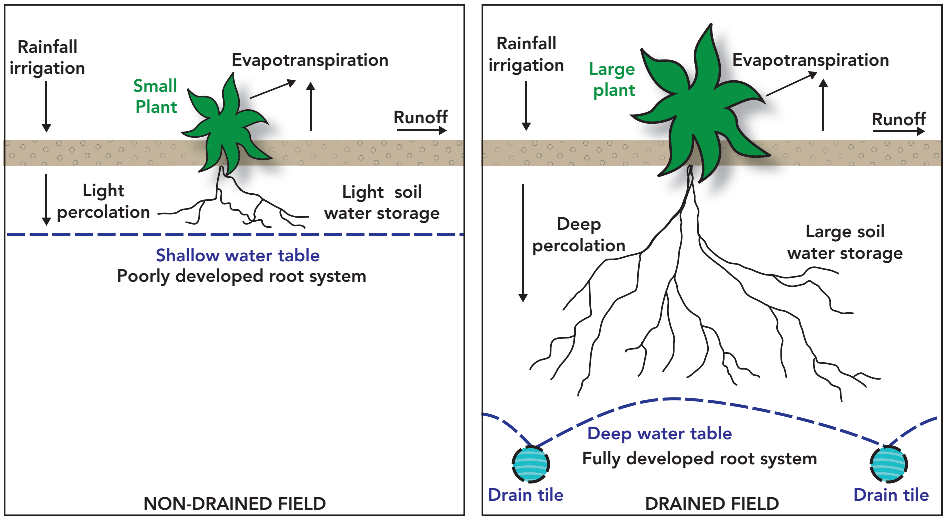

Fig. 6. Comparison of water table level in drained and undrained conditions with root and plant development and water flux exchanges (water balance).

Installing a relief drainage system: a step-by-step process

To install a drainage system, follow these steps:

1. **Analyze the economic feasibility** of installing a drainage system to ensure that the predicted net return will offset the initial cost.
2. **Review regulations and assess the environmental impact** of building the drainage system. Consider ways to avoid any harm to the environment, and adopt best management practices to protect the water quality of the area.
3. **Conduct field studies** to determine the characteristics of the soil profile, such as soil texture and structure, stratification of the soil layers, field topography, soil variability on the farm, hydraulic conductivity of the soil (movement of a volume of water per hour, both laterally and vertically). Determine the hydraulic conductivity in several parts of the field. Know the variables of irrigation management, such as maximum rainfall and irrigation depths.
4. **Design the drainage system.** During the design process, determine the depth of installation of the relief laterals, the maximum length and diameter of the laterals and collector lines, and the grade of the drainage pipes.
5. **Install the drainage system:**
   a. The trencher machine is moved to the desired starting position (Fig. 7).
   b. A back hoe digs a hole where the trencher will install the first drainage lateral (Fig. 8).
   c. The trencher machines starts trenching (Fig. 9)
   d. The trencher lays the pipe at the desired depth (Fig. 10) at the bottom of the trench as shown in Fig. 11.
   e. The trencher machine injects the drainage pipe as it uncoils from its roll (Fig. 12).
   f. The grade of the trencher is determined by a global position system or laser system such as the one shown in Fig. 13.
   g. The laterals are tied to the collector using tees (Figs. 14 and 15).

Figure 7. Moving the trencher to install the subsurface drain pipe.

Figure 8. Digging a hole to start installing the subsurface drain.

Figure 10. A trenching machine is used to install an interceptor drain lateral. The two disks help backfill the trench.

Figure 9. Installing an interceptor drain tile.

Figure 11. The interceptor drain lateral is placed at the bottom of the trench.

Figure 12. The machine unrolls the polyethylene pipe as it is laid into the soil by the trencher.

Figure 13. A dual grade laser gives the grade to the trencher.

Figure 14. Collector drain tee.

Figure 15. The interceptor drain is connected to the collector drain.

Economics of installing drainage systems

To be cost effective and generate a return on the investment, the artificial drainage system must be designed properly. In the Lower Rio Grande Valley, the cost of an on-farm drainage system can range from $400 to $600 per acre.

The cost of a drainage system depends on several factors, including the drain spacing, the length and diameter of the collectors, the number of outlets, and the elevation and proximity of the open drains. The elevation of the drain ditch will determine whether the system will require a sump pump and electricity.

The period needed to obtain a return on investment for the installment of the drainage system depends on factors such as actual and potential crop yield gains after the installation of the system, compared to the losses of crop value from salinity and water table conditions before drainage.

Table 3 shows a yield loss scenario for grain sorghum and sugarcane, to estimate the number of years to recover the investment on a drainage system that costs $934.92 per acre ($600 cost of drainage plus interest cost of $334.92 for a 10-year loan at 9 percent interest rate), based on a 10-year lifetime. A 10 percent yield loss on grain sorghum and sugarcane represents a gross return loss of $58.80 and $120.00 per acre, respectively, or an average of $89.40 per acre, assuming a 50-50 percent mix of grain sorghum and sugarcane. A yearly cost of $93.49/acre for the drainage system ($600 per acre plus $334.92 depreciated over 10 years) leads to a return of investment of $-4.09 per acre ($89.40 - $93.49). Also, it will take 15.9 years to recover

Crop	Yield lb/acre (drained)	Price		Yield loss	Value of loss	Returns of investment per acre*	Years to recover investment*
Grain sorghum	6,000	$ 9.80	/cwt	10%	$ 58.80		15.9
Sugarcane (sugar)	10,000	$ 0.12	/lb	10%	$ 120.00	$ (4.09)	7.8
Grain sorghum	6,000	$ 9.80	/cwt	20%	$ 117.60		8.0
Sugarcane (sugar)	10,000	$ 0.12	/lb	20%	$ 240.00	$ 85.31	3.9
Grain sorghum	6,000	$ 9.80	/cwt	30%	$ 176.40		5.3
Sugarcane (sugar)	10,000	$ 0.12	/lb	30%	$ 360.00	$ 174.71	2.6
Grain sorghum	6,000	$ 9.80	/cwt	40%	$ 235.20		4.0
Sugarcane (sugar)	10,000	$ 0.12	/lb	40%	$ 480.00	$ 264.11	1.9
Grain sorghum	6,000	$ 9.80	/cwt	50%	$ 294.00		3.2
Sugarcane (sugar)	10,000	$ 0.12	/lb	50%	$ 600.00	$ 353.51	1.6

*Figures are based on a $600 per acre cost of drainage, a $334.92 per acre interest cost for a 10-year loan at 9.0% rate and depreciated over a 10-year period.

Table 3. Example of a projected return on investment for the installment of subsurface drainage on land where salinity substantially reduced yield

the investment on the drainage system for grain sorghum alone and 7.8 years for sugarcane alone.

Similarly, a 20 percent yield loss represents a gross returns loss of $117.60 and $240.00 per acre for grain sorghum and sugarcane, respectively. The return of investment is $85.31 per acre on a 50-50 percent mix of grain and cane, and it will take 8.0 and 3.9 years to recover the initial investment on the drainage system for sorghum and cane, respectively.

Farmers' experiences with the performance of subsurface drainage

Farmers in the Lower Rio Grande Valley of Texas have reported two main reasons for installing drainage systems:

- To alleviate high water tables and salinity problems, which has caused poor germination and yield loss
- To improve poor water infiltration, which has impeded field operations

The farmers attributed these problems to several causes: the natural soil texture of the region characterized by poor hydraulic conductivity; long-term overirrigation, especially for crops such as sugarcane; and seepage from irrigation canals.

The growers mentioned that irrigation districts in the late 1960s greatly reduced the seepage problems by replacing canals with pipelines, which enabled these soils to recover completely. Unfortunately, after Hurricane Beulah swept through in 1967, some farmers noticed that the water table rose drastically. The storm saturated the soil profile for a long period, and salt accumulated in some fields.

Some farmers installed drainage systems to counteract the use of saline runoff water on good, nonsaline soils over several years. Saline had built up in the soils, precipitating the need for drainage systems to reclaim the fields.

Some farmers also noted that their fields were located on low topographical places and in some instances their soils presented clay barriers in the lower profile, resulting in stagnant water and salt buildup especially after a big rainfall or irrigation event.

Relief drainage has been extensively used to lower water table and leach the salts accumulated over the years on the soil surface. Some growers have working systems made of either clay tiles that were installed in the 1940s, surrounded by a gravel layer and a tarpaper on the outside to limit clogging. Other systems made of concrete tiles with fiberglass joints were installed in the 1960s.

Several farmers have installed drainage systems over several seasons according to their available budgets. Some farmers installed drains at 200-foot spacing even if they were recommended for 100-foot spacing. Most of them later added additional drain lines between those lines. However, some growers installed subsurface drainage little by little—such as one lateral line at a time—whenever they felt it was needed, without any design.

Recently, several government programs have offered cost-sharing for the installation of the systems under the supervision and design of a field engineer. These programs, such as the Environmental Quality Incentives Program under the Natural Resource Conservation Service, have resulted in the most efficient systems, which have benefited the farmers. The farmer, in exchange, needs to adopt the best irrigation management practices to reduce environmental impacts.

In some clay soils, water from upper irrigated lands resulted in stagnant water downhill. Interception drainage was installed in those soils to capture that water. It has been also installed to capture seeping water coming from irrigation canals.

In some cases, these interceptors have been enough to improve and restore soil and salt conditions and avoid the cost of a large-scale drainage relief system. However, each field was previously laser-leveled and separated by a few feet of elevation against the next one.

Farmers also mentioned that in some cases, the installation of a subsurface drainage system did not improve their conditions, especially in Olmito clay soils.

Environmental considerations

Water that drains from a property may have been polluted by sediment, nutrients, and pesticides. Runoff from agricultural lands and irrigation sometimes causes natural streams to have low levels of dissolved oxygen. These levels may be too low to meet the requirements for aquatic life designated by the State of Texas and described in the Texas Water Quality Standards (TAC §§307.1-307.10).

An indication of low quality could be the increase of fish kills in natural streams. Because water is a precious resource, drainage water may be reused or managed to avoid harming the environment.

To reduce the runoff of nutrients, residues, and sediment from agricultural lands:

- Avoid over-fertilization, and control the placement and timing of fertilizer applications.
- Manage pests responsibly by monitoring thresholds and taking into account beneficial and harmful pests.
- Rotate crops and manage residue to avoid transporting sediment in which nutrients and pesticides can attach.
- Apply leaching irrigation depths but avoid overirrigation and waste by scheduling irrigation.

Where necessary, consider the following additional practices also to reduce erosion and runoff: leveling irrigation land, installing grade stabilization structures, reducing tillage, and installing filter strips between the drainage ditches and irrigated field. Filter strips are areas of herbaceous vegetation situated between cropland, grazing land, or disturbed land (including forestland) and environmentally sensitive areas. The use of artificial drainage practices on lands that are or have a potential to be wetlands is strictly prohibited.

Summary

Soils with poor natural drainage can reduce yields and profits for farmers. Those problems can be solved by installing a properly designed an artificial drainage system. In addition to the agricultural factors, farmers need to consider the environmental effects of installing an on-farm drainage system.

Acknowledgments

Valuable suggestions and recommendations were made for this manuscript by Boyd Davis, who owns a company (B&F Trenching and Drainage, Edinburg) that installs drains, and John Whitfield, who has installed several drain systems on his farm. Lou Garza and Bob Wiedenfeld also made suggestions to improve this manuscript.

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