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Subirrigation in Agricultural Fields

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In agricultural production fields, subirrigation is an irrigation practice to control the water table at certain levels by elevating or lowering it. This is accomplished by artificially adding water to the soil profile underground to moisten the crop root-zone for a determined period. It is essentially a water table management method and a reverse process of drainage.

In some cases, subirrigation also is referred to as *subsurface irrigation, seepage irrigation,* or *reverse drainage irrigation.* Subirrigation is sometimes confused with subsurface drip irrigation, but they are two significantly different methods of water management. In this publication, subirrigation for crops in agricultural fields is considered. Some of the main components and basic principles of subirrigation systems as well as some of the considerations and aspects for successful implementation of the method are presented.

References used in this publication (Criddle and Kalisvaart. 1966; Brown et al., 1997; Hillel, 1998, and Skaggs, 1999) are listed at the end in the References section rather than within the text.

The Subirrigation Process

Subirrigation regulates the shallow groundwater table by artificially adding water to the field underground. When water is being applied to the crop root-zone, a balance between water and air (oxygen) should be maintained for optimum crop water uptake, growth, and biomass/yield development by adjusting the wetting duration. In most but not all cases, water is applied to the soil profile below the soil surface via drain tiles or perforated pipes. Water is moved into or from the tiles or pipes due to the difference in elevation gradient between the groundwater table and the elevation of the tile or pipe. The primary objective of both drainage and subirrigation is to create a favorable environment for optimum growth and function of plant roots to enhance crop development and yield production.

Subirrigation for Multiple Purposes

Areas with high degrees of drainage requirements could potentially use subirrigation for both drainage and irrigation purposes, presenting a unique opportunity to utilize the system for multiple purposes. When tile drains or perforated pipes are used to drain the excess water from the field, this water can be stored in collection or reuse pits (tailwater recycling). The stored water can be pumped from the reuse pit through the feeder pipe into the perforated pipe system to irrigate the field. The result is significantly enhanced water conservation and water use efficiency, as a new water source is not used in the process.

Water can be applied to subirrigated fields using open/aboveground ditch systems. Field ditches (water furrows or lateral ditches) are designed to deliver the water to the field (or remove it) based on field and soil characteristics. Subirrigation systems also use underground pipes or tile drains to control water tables to water the field.

Subirrigation in the Horticultural Industry

Subirrigation is used extensively in the horticultural industry in greenhouses and open nursery plant production systems. It primarily relies on capillary action—capillary rise or upward flux of water due to the total potential difference between the two points—via a wicking material (capillary mat). This provides plants with water and nutrients from a water or solution source placed under the nursery, vegetable, or fruit containers. The wicking material keeps the substrate (soil medium in containers) wet with capillarity and enables plant roots to extract water from the reservoir as needed.

Another application of subirrigation in the nursery industry is to flood an area, supply sufficient water to the plant containers to a desired water depth, and then allow the water to retreat (also referred to as the ebb and flow method). Subirrigation probably is more commonly used in the nursery industry than in agricultural fields.

Successful Implementation in Agricultural Production

For successful implementation of subirrigation in agricultural fields, the soil should have a high permeability while also needing drainage. The soil should be free of salts, as well as suspended silt and clay particles, to prevent clogging the tiles, which may keep the system from functioning properly. In some conditions, due to natural and topographical characteristics the groundwater table is high enough that it can be managed for crop root-zone irrigation. This works by raising the water table close to the surface to wet the crop root-zone, the most traditional form of subirrigation or subsurface irrigation.

In many cases, tile drains are used to control the water. Thus, subirrigation controls the groundwater level by changing the elevation of the drain outlet using ditches or buried perforated pipe systems. A control structure and a sump (submersible) pump moves the water close to the surface to the crop root-zone and drains it from the root-zone once the desired wetting is achieved.

Favorable conditions for the most effective operation of subirrigation are an impermeable subsoil at a depth of about 4–6 ft, a highly permeable loam, sand, or sandy loam surface soil, and a relatively uniform field slope. In summer, the water table can be raised to irrigate the crops *(subirrigation mode, Figure 1a)*. The control structure is similar to gates that move up or down in irrigation canals to control water delivery for surface irrigation. It can be adjusted in the fall and spring for drainage to remove excess water from the field so that field operations can proceed *(drainage mode, Figure 1b)*.

When precipitation and/or upward water movement exceeds the rate of evapotranspiration, the water table will be higher than the tile or perforated pipeline. In this case, tiles or perforated pipes serve as the drainage system. In most cases, the subirrigation system only works when drainage is needed in the field.

However, in sandy soils, drainage is not necessarily required for successful implementation of subirrigation. The elevation difference of the water levels in the subirrigated field is influenced by the quantity of water that is discharged or supplied to the tiles, the permeability of the soil profile below the groundwater table, the thickness of the permeable layer, and the spacing between the tile lines. The spacing between the tiles can be adjusted based on the slope and soil physical characteristics as well as the amount of water that can be discharged from or supplied to the system. Generally, however, tile spacing has minimal influence on the evapotranspiration rate and seepage.

The thickness of the soil that conducts the water and the difference in water level are nearly proportional to the square of the distance between the tiles. Favorable soil physical characteristics that allow free lateral movement of water, rapid capillary movement in the crop root-zone, and slow downward movement in the subsoil are essential for successful implementation of subirrigation.

Technically, subirrigation can be divided into three categories:

- subirrigation to saturation,
- controlled injection subirrigation, and
- constant water level subirrigation.

Subirrigation to Saturation

In the *subirrigation to saturation* method, water is injected into the drainage tiles until the soil surface is completely wetted (flooded) and reached near saturation. Then the outlet plug is removed and the excess water drained. This method can result in significant water losses. It also can leach salts and other chemicals, including fertilizers, below the root-zone, and may cause water quality challenges. Additionally, it is a very inefficient way of irrigating a field.

Controlled Injection Subirrigation

With *controlled injection subirrigation*, when the soil matric potential has reached a desired level, a predetermined amount of water is delivered into the subirrigation tiles to wet the soil by capillary rising in roughly 2–4 hours. The amount of time depends on numerous factors, including soil physical characteristics, water discharge (delivery) rate, initial wetness of the upper soil profile, tile capacity, and other factors.

The main difficulty with this approach is uneven distribution of nutrients from the lower to the upper end of the field, as is the case with most surface irrigation methods. Uneven distribution of nutrients can cause uneven uptake, which may result in nonuniform crop growth and development, and spatial crop yields within the field. Salt accumulation at the soil surface can also be an issue, so routine monitoring of the surface soil salt concentration is required.

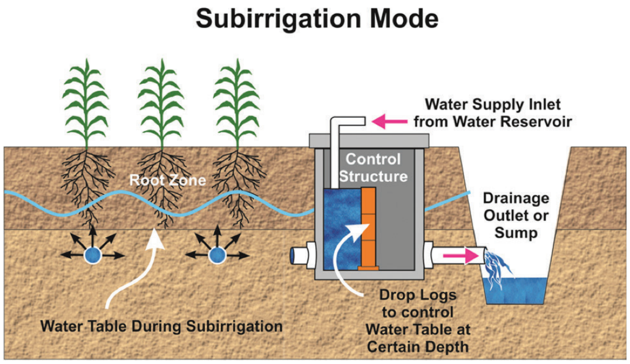

Figure 1a. Basic components of a subirrigation system operated in a subirrigation mode (adopted from Brown et al., 1997).

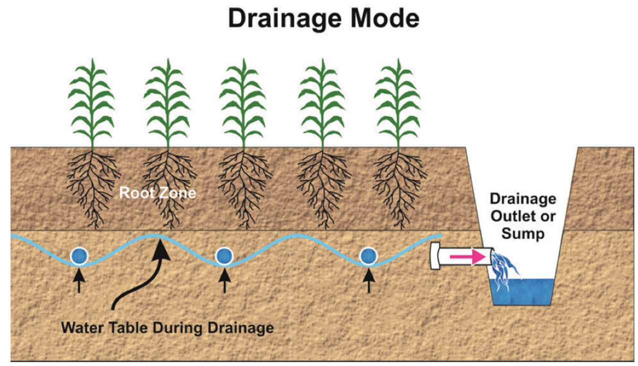

Figure 1b. Basic components of a subirrigation system operated in a drainage mode (adopted from Brown et al., 1997).

Constant Water Level Subirrigation

Constant Water Level Subirrigation, which also is used extensively for potted plants and large-scale nursery operations, is sometimes referred to as bottom-up irrigation. This method maintains a constant water level in the topsoil (e.g., 1–2 inches below the soil surface) with a float valve. Salt accumulation in the topsoil can be a significant issue that requires periodic leaching of salts using sprinkler irrigation.

Subdrainage Mode

When a subirrigation system is operated in a subdrainage mode, subsurface drainage removes excess gravitational water from the crop root-zone, providing optimum soil moisture levels and improving field trafficability and aeration. This, in turn, may enhance crop productivity. In coarse-textured soils with subsurface drainage, a common issue is excessive drainage because the water table can be rapidly drained and lowered below the tile drain level. This process may result in crop water stress during dry and hot summer periods. During dry periods, the tile exit drains can be blocked to retain any potential precipitation water in the soil profile. Therefore, even when subirrigation is practiced in soils that have adequate permeability, a high water table, proper slope, and the design, installation, and proper management and operation of this system is critical for successful application of the system.

Subirrigation Planning and Design

Subirrigation can be designed and installed in two primary ways: (i) the supply and discharge structures are partially combined; or (ii) both structures are completely separated.

Many factors can affect system design. A typical field plot layout with the system's main components with water discharge and supply structures partially combined on a flat field is presented in *Figure 2*. Water supply and discharge structures are separated.

A general layout and plan about how to supply water to the field as well as the direction, amount, and storage, etc., have to be developed during the subirrigation planning and design stage. Additionally, potential impact(s) of subirrigation to neighboring fields must be considered. Thus, a comprehensive survey and evaluation of the subirrigated field is essential.

The survey should include the slope, water discharge and supply entry points, as well as the suitability of the field for placing weirs, which are low obstruction devices. Weirs are built across the water delivery canals to raise the water level to divert the water to a field for surface irrigation. Construction of channels and ditches should minimize or eliminate the impact of subirrigated operations in neighboring fields.

Steady-State and Transient Modes

In most cases, subirrigation systems are designed to operate in either steady-state or transient modes. With steady-state mode, the water level is maintained at a constant elevation in the drains. This method is relatively straightforward and easy to manage. However, it may not be able to take full advantage of rainfall and can lead to a considerable reduction in water application, especially in humid areas.

In the transient mode, water is pumped into the drains and maintained at a high level until the water table is raised to wet or moisten the crop root-zone. The raise in the water table should be managed to be able to wet the root-zone of the crop under consideration. After the root-zone is wetted, irrigation stops and the water table level gradually decreases due to gravitational downward movement of water and evapotranspiration losses.

Subirrigation and the Weather

Subirrigation practices should be managed in conjunction with the weather forecast. If rainfall occurs during the period when the water table is deep (not raised with irrigation), a portion of the rainfall can be captured in the upper soil profile and used for meeting crop water requirements. This may result in less water application using the transient mode when the rainfall forecast is considered. After the water table draws down to a threshold depth in a certain period, the subirrigation process is repeated. The amount of time is a function of several factors, including evapotranspiration rate, soil physical characteristics, etc. Thus, while the steady-state mode is a somewhat continuous or constant irrigation, the transient mode is a series of irrigation events with some pauses between the irrigations.

Subirrigation in Silty or Clay Soils

Practicing subirrigation in soils with silt or clay layers (even with good permeability) can present challenges. These soils generally have a slow capillary rise or upward water flux (movement) and often lose their permeability under subirrigation. Thus, subirrigation in such soils may work in the initial stages, but when saturated conditions are attained, these soils often become less permeable or even impermeable and lose their suitability for subirrigation.

Water and Soil Salinity

In some cases, depending on the salinity levels of the water and soil, subirrigated lands can develop salinity and alkali conditions by upward capillary water movement from the shallow water table. When the water evaporates from the topsoil, the salt concentration can build up, which may result in less productive soil conditions. If this salt buildup cannot be removed via a water leaching requirement, subirrigation may need to be discontinued and other irrigation methods (e.g., sprinkler) may be needed to leach the salt. A *leaching requirement* is an estimate of the required amount of water to apply to the soil surface to move salt downward in the soil profile to maintain soil-water salinity within acceptable or tolerable levels and prevent or minimize yield reduction due to salinity.

Subirrigation in the Midwest

The feasibility of using subirrigation systems in Midwestern states, including Nebraska, is limited, because in most areas the water table is well below the crop root-zone. Some subirrigation is practiced in North and South Dakota,

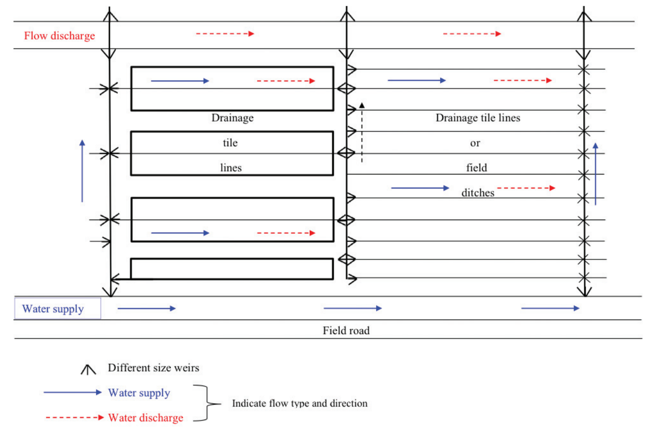

Figure 2. Schematic representation of some of the main components and a typical field layout of a subsurface irrigation system in a horizontally positioned field (adopted from Criddle and Kalisvaart, 1966).

Minnesota, Michigan, Indiana, and Ohio in areas with a high degree of drainage requirements in coarse-textured soils.

One of the few possible locations in Nebraska for this system to be viable might be the Central Platte Natural Resources District along the Platte River in central Nebraska where the water table is shallow with fine sandy loam soils. However, fine sandy loam without impermeable subsoil generally will not have high enough permeability for subirrigation. This means the soils won't have fast enough capillary rise to meet the crops' evapotranspiration demand without a water supply rate that is greater (or at least equal) to the crop evapotranspiration.

If soil layers of low permeability and slow capillary rise occur in the soil profile above the groundwater table, subirrigation practices may not be successful. This is because in dry periods the capillary rise will not be sufficient to keep pace with the crop water requirement, especially during peak evapotranspiration months (usually July and August). Additionally, in wet periods the drainage will not be fast enough to drain the water from the crop root-zone.

California (Sacramento-San Joaquin Delta) and central-south central Florida have large areas that are successfully irrigated by subirrigation. Most of the considerations for practicing subirrigation in arid and semiarid regions also apply to practicing subirrigation in humid regions.

Summary

- Subirrigation practice is generally limited to areas with highly permeable soils for a considerable depth (5–6 ft), a relatively uniform and gradual/gentle slope, and restricted natural subdrainage. If the subirrigated soil is not highly permeable, the rate of capillary rise may not be sufficient to keep pace with the evapotranspiration requirement of the crops. The soil texture in the subirrigated field should be relatively uniform, and water drainage is necessary.

- A requirement is a restricted layer in the soil profile upon which a perched or temporary water table can be developed beneath the crop root-zone. The restricted layer may be clay, bedrock, or naturally shallow groundwater.
- Before subirrigation is planned or practiced, soil samples should be taken to determine: (i) the presence of any restricted layer and its topography and physical properties; (ii) water table depth and contours of the natural water table; and (iii) hydraulic conductivity and soil physical properties (particle size distribution, etc.) of the restricted layer as well as the soil profile above and below that layer.
- The optimum spacing between the water supply points to the tiles should be determined so that the depth from the land surface and the water table will not vary beyond determined or defined limits because of evapotranspiration or potential precipitation.
- The potential impact(s) on neighboring fields for controlling the water table in the subirrigated field should be assessed, and the necessary field leveling should be conducted to maintain a controlled water flow to and within the field. Carefully planned, designed, and implemented subirrigation can be beneficial for the field in which it is practice. However, if the aforementioned precautions are not taken, this practice could negatively impact neighboring fields.
- For successful subirrigation, both soil and water should be salt free, especially if additional water is not available for meeting the leaching requirement to remove the salts. If the proportion of exchangeable sodium (salt) concentration increases, soil becomes increasingly dispersed and impermeable to water and airflow. Because of decreased permeability, subirrigation becomes impossible. Water and soil should also be free of suspended silt and clay particles to prevent clogging tile lines.
- Depending on the conditions in which the subirrigation system is being planned or practiced, the labor requirement is usually minimal for a well-designed system.
- Evaporation losses from the soil surface can be minimal compared with other surface or sprinkler irrigation methods. However, if the upward movement of water is not achieved uniformly, plant germination, nutrient uptake, etc., can be slow and/or nonuniform, causing increased spatial variability in the field.
- The choices for crops that can be grown under subirrigation may be fewer than those grown under other irrigation methods because rooting depth and other characteristics are more important with subirrigation than other irrigation methods.

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