Subirrigation is a method of applying water below the ground surface, to raise or maintain the water table. Water is supplied through the subsurface drainage system using control structures to regulate the water level. In very permeable soils water may be supplied through open ditches. Before investing in subirrigation, consider the following factors: Are your soils suitable? Do you have a dependable water supply? Will the average crop yield response to the added investment and management costs? Are you prepared to provide daily care (labor and management) during the growing season? If you can answer yes to these questions, subirrigation may be a good idea, but fine textured heavy soils may be damaged.

Soil: The ideal soil for subirrigation would have high horizontal hydraulic conductivity (permeability), a slowly permeable layer below the root zone and drain, and nearly level topography. If there is no restrictive layer, water will be lost. Uneven or sloping topography will require more water control structures.

Drainage: The most frequent water management need for cropland in the midwest is improved drainage. Drainage can be accomplished by a combination of surface improvements such as land grading or surface field ditches and subsurface drains. When irrigation water is added, a more intensive drainage system is needed. In addition to more detailed topographic and soil survey information used in subirrigation design, field hydraulic conductivity measurements are necessary.

Water Supply: A water supply is usually needed in the driest time of the year. Intermittent streams may have inadequate flow, so the expected flow rate should be compared to the needed supply. Wells, ponds and reservoirs are used frequently for irrigation water supply. Match well yield and pumping capacity to the acres to be subirrigated. The net seasonal irrigation water requirements in the region range from 4 to 19 inches depending on crop, location and weather. (1 acre inch of water = 27,154 gallons.) Allow for evaporation and seepage losses from ponds used for an irrigation water supply.

<table>
<thead>
<tr>
<th>Inches per day</th>
<th>1</th>
<th>10</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>2.3</td>
<td>23</td>
<td>113</td>
<td>227</td>
</tr>
<tr>
<td>0.20</td>
<td>4.5</td>
<td>45</td>
<td>227</td>
<td>453</td>
</tr>
<tr>
<td>0.30</td>
<td>6.8</td>
<td>68</td>
<td>340</td>
<td>680</td>
</tr>
</tbody>
</table>

*Based on pumping 20-hour per day.

Pump Capacities and Rates: The required irrigation pump capacity can be computed in gallons per minute (gpm) using the formula \( Q = \frac{453 \times A \times D/H}{10} \) where \( Q \) = pump capacity in gpm; \( A \) = acres irrigated; \( D \) = design daily crop water use rate; \( H \) = hours of pump operation per day.

Example: A pump to irrigate 10 acres in 1 day operating 20 hours to apply 0.25 inch/day would require a pump capacity as follows:

\[ Q = \frac{453 \times 10 \times 0.25}{20} = 57 \text{ gpm} \]

Controlling the Water Table: There is very little research data regarding the best depth of water table for various soils and crops in our region of the U.S. Control levels are estimated from information on crop rooting depth and farmer experience. In general, coarse textured (sandy) soils will require a higher water table for...
Operating the System: Manual controls require at least daily checking and operation of the pump and water control structures. Water levels change more rapidly near the subsurface drain than midway between drains, so it is advisable to have inspection wells midway between drains for each soil type and each water control level. Automatic water level control reduces the time required to operate the system. A high water table increases the hazard of excess water problems following rainfall. Automatic overflow to discharge excess water and runoff from heavy rains should be provided. Avoid lowering the water table rapidly because it may cause soil to be moved into the drains.

Water Table Management: Water table management is precise subirrigation. Open ditches and subsurface drains are used. Other forms of subsurface water application and/or control have sometimes been referred to as water control or subsurface irrigation.

In controlled drainage the drains are either totally blocked or an overflow structure is placed in the drain system to prevent lowering of the water table below the desired level. In this method of management, no additional water is added to maintain the water table at the desired depth.

In subirrigation, the drains are regulated by means of weirs or dams to control the water table elevation and water is added as needed to maintain the water table at the desired level.

A. Desirable Site Conditions

(1) Restrictive Layer: The soil must have a restrictive layer that allows a build up of the water table or a naturally high water table for some other reason, that limits deep seepage losses to a practical value. The authors suggest that the restrictive layer should have a permeability of one-tenth or less of the vertical permeability in the root zone soil. In highly permeable soil, the permeability of the restrictive layer must be much less than one-tenth of the root zone soil. Ten feet is a reasonable maximum depth for the restrictive layer. Too shallow a restrictive layer necessitates close spacing of the subsurface drain lines.

The allowable deep seepage and horizontal losses will depend on the available water supply, the cost to provide this water, and your ability to adequately maintain the water table depth. A loss of 0.05 inches per day would require a continuous supply rate of 0.3 gpm/acre to balance the loss. The water use of the crop is from 4 to 6 gpm/acre. A typical drainage coefficient of three-eights of an inch/24 hours is equal to about 7 gpm/acre. Very slowly permeable soils have permeability estimates at or below 0.06 inches per hour or 1.44 inches per day. One-tenth of this (0.14 inches per day) is about 2.6 gpm for each acre or about half the evapotranspiration of the crop.

For water table management to be successful, the soils must need subsurface drainage and respond well when drained, but all soils which need subsurface drainage are not necessarily suitable for water table management.

(2) Horizontal Hydraulic Conductivity: A high horizontal conductivity allows the drain and/or supply lines to be farther apart and still maintain an adequate water table height during periods of high evapotranspiration. But, a high horizontal conductivity, especially if the impermeable layer is deep, may allow excessive loss through horizontal flow. Field measurement of both horizontal and vertical conductivity and of the different layers of the soil is desirable before designing a water table management system.

(3) Topography: To maintain a uniform depth from the surface to the water table, the surface topography should be nearly level (less than 1.0 percent slope). A field with considerable undulation of the surface could result in excessive variation of the depth to water table and might make water table management impractical unless the surface can be graded. It is important to maintain a nearly uniform depth from the water table to the surface.

B. System Design

To design a water table management system, the following soils data is needed: hydraulic conductivity, drainable pore space, upward flux rate, (capillary rise), infiltration rate, surface roughness (storage) and topography.

The design must take into account the costs of constructing, operating and maintaining the water management system, and it must consider the limits of the soil, plant and water resources. The designer must determine the layout of the
system and the depth and spacing of the drains. The slope, hydraulic grade line, and the size of
the lines must be determined for both irrigation and drainage. In conventional drainage, the main
drain size increases at the lower end; however, in water table management, if irrigation water
enters the system only at the upper end, greater capacity at the upper end may be required.
Control structures will be needed, at least
in the main line, to assist in maintaining a
uniform water table depth. They must have
provisions for adjusting the water level (weir
setting) that can be easily changed. Seepage
control, at least around the last or lower
structure, may be necessary.
It may be necessary to install a drainage
restriction in the main to prevent flow from the
upper level land overloading the main, and
flooding the lower land.
The designer must consider the crops to be
grown so that the average annual yield responses
to drainage and/or irrigation can be estimated.

C. System Management

The objective of a water management system
is to provide a soil/water environment that
provides for the optimum plant growth.

The dominant water management problem in the
humid regions such as Ohio, Michigan, Indiana and
Illinois, is excess water which affects plant
growth by reducing soil aeration. The water
table is used as a reference, but there is a
capillary fringe above the water table. Near
saturation may occur for some distance above the
water table, especially in clay soil. Roots do
not generally penetrate saturated soil.

Drainage requirements for optimum plant
growth are determined largely by the volume and
oxygen content of air in the soil. The need for
air depends on the type of crop, the soil,
availability of plant nutrients, climatic
conditions, biological activity and soil and crop
management practices.

Research data from The Netherlands gives the
general relationship between small grain crops
yields and constant water table depth during the
growing season, Figure 1. In a peat soil, the
highest crop yields occurred with the water table
one foot below the surface. However, in a heavy
textured soil, the highest yield occurred with
the water table four feet below the surface and
for a light soil the highest yield was obtained
with the water table at 1.5 feet.

Where the crop uses water from the water
table, yields for a constant water table down to
a depth of 2.5 feet increase and then decrease
rapidly for water tables below 3.3 feet. With
the average water table depth less than 4 feet,
yields decreased as fluctuations in water table
increased; however, when the average water table
depth was greater than 4 feet, fluctuations
generally caused an increase in yields. The
above data are for small grain (rye) on sandy
soil.

A management simulation program called
DRAINMOD has been developed to predict corn
yields based on soil and water conditions. It is
estimated that corn yield will not be reduced by
excess water and poor drainage if the soil is not
saturated (including the capillary fringe) closer
than one foot to the soil surface. The capillary
rise will be higher in a fine textured soil like
clay, than it will be in a coarse textured sand.
Consideration must be given crop growth stage
and root depth. Figure 2 shows root depth for corn.
A deficit soil water, or drought condition,
causes the greatest reduction in corn yield
during the silking stage.

There is considerable lag time between
changes in the water table at the drains and
midway between drains. For example: calculations
by Skaggs for a sandy loam show it would take 80
to 110 hours to raise the water table from a five
foot depth to one foot midway between drains 60
feet apart. This computation assumes 8 percent
of the soil volume is filled with water and
evapotranspiration and deep seepage is less than
one-fourth inch per day.

Calculations and water management
simulations predict that the average optimum
water table depth on Kokomo silty clay loam soil
with Columbus, Ohio weather is 2.5 feet for a
corn crop.

Irrigation Scheduling with water table
control consists of regulating the water table
level to provide an adequate upward flux of water
into the root zone while not unduly restricting
plant root development. Control structures are
adjusted to maintain desired depth to water table
and, if needed, water is added.

As an example, the control setting may be
low in the spring to provide drainage for seed
bed preparation and planting, raised to provide
moisture for germination and then gradually
lowered as the roots develop. If heavy rain is
received it may be necessary to temporarily lower
the control to provide more rapid drainage. The
controls are lowered in the fall as crop maturity
is reached to provide for better dry down and harvest conditions.

The water supply rate should be adjusted to maintain the water table at the desired depth from day to day. Some daily cycling of the water table can be expected as the plants remove water during the day. During the midseason, evapotranspiration rates will average 0.20 - 0.30 inches per day. This is the equivalent to 3.8-5.7 gpm/acre continuously over a 24 hour period. Adequate water must be available to maintain the water table depth during these high mid-summer evapotranspiration periods. Additional water must be added to replenish any seepage losses.

Predicted relative corn yield for the Maumee loamy sand and Indiana weather (1952-1973) are plotted as a function of subsurface drain spacing in Figure 3 (Skaggs, 1984). For drainage alone, Skaggs (1984) recommended 300 ft. drain spacing for drainage alone and 150 ft. spacing for subirrigation based on assumed costs and corn prices.

The effect of subirrigation on year to year variation in yields is shown in Table 2. By supplying irrigation water during dry periods the predicted relative corn yield, as affected by soil water stresses, was greater than 90% in 19 of the 22 years of the simulation. It was greater than 85% in the other 3 years. When only drainage is provided, predicted relative yields were less than 50% in 3 of 22 years and less than 75% in 10 of 22 years.

Note that the simulations do not account for seepage losses at the field boundary. This will not be a problem for the interior of large fields, but for soils with high conductivities, such as the Maumee, it could be difficult to maintain a high water table near the field boundaries if adjacent fields are drained.

Table 2: Effect of Subirrigation on Year-to-Year Variation in Corn for A Maumee Loamy Sand at Indianapolis, IN. Good Surface Drainage Was Assumed for All Cases

<table>
<thead>
<tr>
<th>Good Drainage L=300 ft (90m)</th>
<th>Subirrigation Drainage L=150 ft (45m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation period</td>
<td>22 years</td>
</tr>
<tr>
<td>Average yield</td>
<td>75%</td>
</tr>
<tr>
<td>Number years relative yield 90% or more</td>
<td>8</td>
</tr>
<tr>
<td>Number years yield 75% or more</td>
<td>12</td>
</tr>
<tr>
<td>Number years yield 50% or more</td>
<td>19</td>
</tr>
<tr>
<td>Number years yield 50% or less</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3: Effect of drain spacing on average predicted relative yields for a Maumee sandy loam (Indiana). Recommended drain spacings are 300 feet for drainage alone and 150 feet for subirrigation.

The relative yield of about 75% occurs for drain spacing of about 250 ft. Subirrigation gives higher yields at closer drain spacings. Skaggs