Lecture 4: Irrigation Water Requirements

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Evapotranspiration

Evaporation: Process of water movement, in the vapor form, into the atmosphere from soil, water, or plant surfaces

Transpiration: Evaporation of water from plant stomata into the atmosphere

Evapotranspiration: Sum of evaporation and transpiration (abbreviated “ET”)

Consumptive use: Sum of ET and the water taken up the plant and retained in the plant tissue (magnitude approximately equal to ET, and often used interchangeably)
Magnitude of ET

- Generally tenths of an inch per day, or tens of inches per growing season
- Varies with type of plant, growth stage, weather, soil water content, etc.
- **Transpiration ratio**: Ratio of the mass of water transpired to the mass of plant dry matter produced (g H₂O/g dry matter)
- Typical values:
  - 250 for sorghum
  - 500 for wheat
  - 900 for alfalfa
Plant Water Use Patterns

Daily Water Use: peaks late in afternoon; very little water use at night

DAILY CROP WATER USE PATTERN

Alfalfa:
June 26, 1986
Wheat Growth Stage

<table>
<thead>
<tr>
<th>Feekes</th>
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<td>Zadoks</td>
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<td>39</td>
<td>45</td>
<td>50</td>
<td>60</td>
<td>90</td>
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</tbody>
</table>
Corn Growth Stage
Plant Water Use Patterns

Seasonal Use Pattern: Peak period affects design

Corn Water Use Pattern

Irrigation system must be able to meet peak water use rate or the crop may be lost.
CROP WATER REQUIREMENTS

The depth of water to meet evapotranspiration of a disease-free crop growing in large fields without restricting conditions on soil profile, soil moisture and fertility, thus achieving full production potential.

\[ E_{\text{crop}} = K_c E_{\text{ref}} \]

The specific characteristics of the crop are represented by the crop coefficient \( k \),

and the meteorological conditions by the reference crop evaporation \( E_{\text{ref}} \).

\( E_{\text{ref}} \) refers to the evapotranspiration of grass and the crop coefficients correspond to this reference evapotranspiration.

**Reference crop evapotranspiration \( (E_{\text{ref}}) \):** The rate of evapotranspiration from an extensive surface of an 8 to 15 cm tall green grass cover of uniform height, completely shading the ground and not short of water.
E\textsubscript{ref} is most accurately computed with the **Penman formula** for grass, but this requires data on wind, humidity, temperature and sunshine or radiation.

If data on wind and humidity are lacking a less accurate estimate of E\textsubscript{ref} is obtained with the **radiation method**, an empirical equation relating the reference crop evapotranspiration to climatic data.

**Blaney & Criddle** (1950) provide the least accurate method, but it only requires data on temperature.

Finally, reasonable estimates of E\textsubscript{ref} may be obtained from evaporation pans which are properly sited.

<table>
<thead>
<tr>
<th>Method</th>
<th>Error (%)</th>
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<tbody>
<tr>
<td>Penman</td>
<td>10</td>
</tr>
<tr>
<td>Pan</td>
<td>15</td>
</tr>
<tr>
<td>Radiation</td>
<td>20</td>
</tr>
<tr>
<td>Blaney &amp; Criddle</td>
<td>25</td>
</tr>
</tbody>
</table>
Evapotranspiration is calculated from Penman formula

\[
ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \left( \frac{900}{T - 273} \right) \times U_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34U_2)}
\]

\(R_n\) = The remain of radiation on the plant surface (M J m\(^{-2}\) day\(^{-1}\)),  
\(G\) = The adsorbed amount of radiation by the earth (M J m\(^{-2}\) day\(^{-1}\)),  
\(T\) = The mean temperature at 2 m height (\(^0\)C),  
\(U_2\) = wind speed at 2 meters height (m s\(^{-1}\)),  
\(e_s\) = Saturated air pressure (kPa),  
\(e_a\) = vapor pressure (kPa),  
\(\Delta\) = Vapor pressure at temperature (kPa \(^0\)C\(^{-1}\)) and  
\(\partial\) = constant (kPa \(^0\)C\(^{-1}\))
Evapotranspiration formulas

\[ ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \left( \frac{900}{T - 273} \right) U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34U_2)} \]

\[ e_s = \frac{e_{(T_{\text{max}})}^0 + e_{(T_{\text{min}})}^0}{2} \]
\[ \gamma = 0.665 \times 10^{-3} \times P \]
\[ e_a = \frac{RH_{\text{mean}}}{100} \times \frac{e_{(T_{\text{max}})}^0 + e_{(T_{\text{min}})}^0}{2} \]

\[ R_n = R_{ns} - R_{nl} \]
\[ R_{ns} = 0.77 \times R_s \]
\[ R_{nl} = \sigma \left( \frac{T_{\text{max}} - T_{\text{min}}}{2} \right) \left( 0.34 - 0.14 \sqrt{e_a} \right) \left( \frac{R_s}{R_{so}} - 0.35 \right) \]

\[ U_2 = U_z \times \left( \frac{4.87}{\ln(67.8Z - 5.42)} \right)^{5.26} \]
\[ P = 101.3 \times \left( \frac{293 - 0.0065Z}{293} \right)^{5.26} \]
\[ R_s = \left( 0.25 + 0.5 \left( \frac{n}{N} \right) \right) R_a \]
\[ \Delta = 4098 \left( \frac{e^0(T)}{T + 237.3} \right) \]
**Crop coefficients ($K_c$):** Tall crops like maize have a crop coefficient greater than one while others may, for different reasons, (e.g. waxy leaves of citrus) transpire less than the reference (grass) crop ($K_c < 1$).

To establish the crop coefficient curve the growing season is divided into four stages:

I. initial stage from sowing/planting date until the percentage of the soil covered by the crop $S_c$ is 10%.

II. crop development stage from $S_c < = 10$ to $S_c = 70\text{-}80\%$,

III. mid-season stage from $S_c = 70\text{-}80\%$ to start of maturing.

IV. late season stage from start of maturing to full maturity or harvest.
Crop coefficients
Example of crop coefficient ($K_c$) curve

$S_c \approx 70-80\%$ (Soil cover)

$S_c \approx 10\%$

begin

harvest

I  II  III  IV

APR  MAY  JUN  JUL  AUG  SEP  OCT
For the construction of the crop coefficient curve the following procedure applies

1. Establish planting/sowing date (local information or table, examples are given in table 1)

2. Determine crop development stages (local information or table, examples are given).

3. The evaporation during the initial stage depends on the wetness of the almost bare soil. Estimate irrigation or rainfall frequency and derive \( k \) for the initial stage from figure 1.

4. The effect of wind on the rate of transpiration is larger for crops which are taller than the reference crop. This effect is more pronounced in dry than in humid climates. The mid-season \( k_c \)-value is therefore read from a table in relation to wind speed and humidity (examples are given in table 1) and plotted as a straight line.

5. Read \( K_c \)-value for late season stage from table (examples are given in Table 1). Assume straight line between end of mid-season and end of growing period.

6. Assume for the crop development stage a straight line between the end of the initial stage and the start of the mid-season period.
Examples of crop development stages

**Cotton:** March planting Egypt, April-May planting Pakistan, etc. 30/50/60/55 and (195); etc.

**Maize:** Spring planting East Africa high lands 30/50/60/40 and (180); late cool season planting, warm desert climates 24/40/45/30 and (140); etc.

**Suger beet:** Coastal Lebanon, mid-November planting 45/75/80/30 and (230); early summer planting 25/35/50/50 and (160); etc.
Figure 1. Average $K_c$ value for initial crop development stage

$K_c$ value as a function of $E_{ref}$, mm/day, during initial stage with different recurrence intervals of irrigation or significant rain:
- 2 days
- 4 days
- 7 days
- 10 days
- 20 days
Table 1. Examples of crop coefficient $K_c$

<table>
<thead>
<tr>
<th></th>
<th>Humidity</th>
<th>$\text{RH}_{\text{min}} &gt; 70%$</th>
<th>$\text{RH}_{\text{min}} &lt; 20%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>crop</td>
<td>Wind m.s$^{-1}$</td>
<td>0–5</td>
<td>5–8</td>
</tr>
<tr>
<td>cotton</td>
<td>3</td>
<td>1.05</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>maize</td>
<td>3</td>
<td>1.05</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td>sugar beet</td>
<td>3</td>
<td>1.05</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.90</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Leaching of salts
Leaching requirements

An annual application of 1000 mm of irrigation water containing only 250 mg/l dissolved salts will add 2,500 kg salts to each ha each year. To prevent Stalinization of the top soil salts have to be washed down which is known as leaching.

LEACHING: Leaching is the process of removal of soluble material by the passage of water through soil.

The leaching requirement is the ratio between the drainable excess and the quantity of irrigation water applied to keep the salt content in the root zone below the crop tolerance level.

The tolerance level is found from relations between crop yield and the salt concentration of the saturation extract.

The saturation extract is obtained by mixing a soil sample with distilled water until it glistens. The solution is extracted from the paste with a suction filter after which the electrical conductivity ECe is measured.
Consider for the computation of the leaching requirement the water balance of the root zone. Neglecting storage effects the equation may be written as:

\[ P_e + I = D + E_{\text{crop}} \]

where

- \( P_e \) is the effective precipitation.
- \( I \) is the irrigation.
- \( D \) is the net drainage (percolation from the root zone minus capillary rise).

Neglecting the accumulation of salts in the root zone, the salt balance can be expressed as:

\[ I C_i = D C_d \]

where \( C_i \) and \( C_d \) are the salt concentrations of the irrigation and drainage water, respectively.

Changes in salt content due to fertilizer, crop growth or salty rainwater are not taken into consideration. Since the electrical conductivity EC of a solute is a reliable
Leaching requirements calculation

For surface irrigation method including sprinkler

\[
LR = \frac{EC_i}{5EC_e - EC_i}
\]

For drip irrigation method

\[
LR = \frac{EC_i}{(2 \text{ max}) \times EC_e}
\]

Where:

LR is the leaching requirements

EC\(_i\) is the electrical conductivity of irrigation water

EC\(_e\) is the electrical conductivity of the root zone-soil extraction.

Max. EC\(_e\) = Maximum tolerable Electrical conductivity of the soil saturation extract for a given crop
Examples of crop salt tolerance levels $EC_e$ in mmho/cm

<table>
<thead>
<tr>
<th>Yield potential</th>
<th>100%</th>
<th>90%</th>
<th>75%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>7.7</td>
<td>9.6</td>
<td>13.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Maize</td>
<td>1.7</td>
<td>2.5</td>
<td>3.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Sugarcane beet</td>
<td>7.0</td>
<td>8.7</td>
<td>11.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

The efficiency of leaching depends on:

1. The amount of water applied,
2. Uniformity of water distribution, and
3. The adequacy of drainage
Leaching requirements based on irrigation frequency for irrigation water EC = 3.5 ds/m
### Net irrigation requirements

\[ I_n = E_{crop} - (G_e + W_b + P_e) \]

### Irrigation requirements

\[ I = \frac{E_{crop} - (G_e + W_b + P_e)}{1 - LR} \]

Where:

- \( G_e \) is the groundwater contribution
- \( P_e \) is the effective precipitation

**Effective precipitation empirical formula**

\( P_e = 0.8 \cdot P - 25 \)  
for average rainfall (P) > 75 mm/month

\( P_e = 0.6 \cdot P - 10 \)  
for average rainfall (P) < 75 mm/month

\( W_b \) is stored soil water at the beginning of the account period. For preliminary planning net irrigation requirements are usually computed for monthly or 10-day periods.