Improving Agricultural Water Management in the Arkansas Valley Using Lysimetric Studies

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A reliable method of estimating crop consumptive water use (ET) is needed for the Lower Arkansas Valley of Colorado.

- 95,160 hectares irrigated
- 2.1 billion cubic meters of irrigation water per year (85% of total diversions)

Underlying issues:
- Arkansas River Compact
- ASCE Penman-Monteith Equation for calculating ET
- Hydrologic-Institutional (HI) model for compact compliance
Lysimeter project

- One reference lysimeter (1.5 m x 1.5 m x 2.4 m) to measure $ET_r$ (completed in 2009)
- One crop lysimeter (3.0 m x 3.0 m x 2.4 m) to measure $ET_c$ (completed in 2006)
- Network of 12 weather stations along the Arkansas Valley (part of COAgMet)
- Lysimeters located at CSU-Arkansas Valley Research Center (AVRC), Rocky Ford, Colorado

1,274 m (4179 ft) above MSL
300 mm (11.8 in) avg. annual precip.
Rocky Ford clay loam soil
Estimation of crop evapotranspiration ($ET_c$)

$$ET_c = ET_{rs} \times K_{cr}$$

where

$ET_{rs} = \text{reference crop ET (tall reference like alfalfa)}$

$= \text{the ET rate from a uniform surface of dense, actively growing vegetation (hypothetical crop) having specified height (50 cm or 20 inches for alfalfa) and surface resistance (to vapor transport), not short of soil water, and representing an expanse of at least 100 m (328 ft) of the same or similar vegetation (ASCE-Standardized Reference ET equation)}$

$K_{cr} = \text{crop coefficient based on tall reference}$

$$K_{cr} = \frac{ET_c}{ET_{rs}}$$
Energy supply (net radiation) at a vegetated surface

Symbol definitions:

- $R_s$: incoming solar radiation
- $R_n$: net radiation at the surface
- $R_{ld}$: long wave radiation going downward
- $R_{lu}$: long wave radiation going upward
- $G$: ground heat flux
- $\alpha$: reflection coefficient or albedo

Note: Solar radiation is primarily shortwave while the earth’s radiation is primarily longwave. Shortwave radiation is less than 4.0 micrometers in length while longwave radiation is greater than 4.0 micrometers.
Factors driving turbulent transport of water vapor

Typical vapor ($e$), temperature ($T$), and wind ($u$) profiles above a vegetated surface

Symbol definitions:
- $e_a$ = actual vapor pressure of air
- $e_s$ = saturation vapor pressure
- $T_a$ = air temperature
- $T_s$ = surface temperature
- $u_z$ = wind speed at height $z$

https://www.youtube.com/watch?v=e1TbkLIDWys
Example of a weather station with well-maintained surroundings (well-watered clipped grass) (Good source of weather data for Penman-Monteith equation)
Example of a weather station with non-ideal surroundings (dryland) (Bad source of weather data for Penman-Monteith equation)
ASCE Penman-Monteith ET equation

\[
ET_{rs} = \frac{0.408 \Delta (R_n - G) + \gamma \frac{C_n}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + C_d u_2)}
\]

- **Net radiation**
- **Ground heat flux**
- **Air temperature**
- **Wind speed**
- **Humidity**
Weighing lysimeter

• Measurement of \( ET_r \) or \( ET_c \) by water balance is best achieved with a weighing lysimeter.

• Precision weighing lysimeters measure water loss and gain from a control volume of cropped soil by tracking the change in mass of the control volume, with an accuracy of a few hundredths of a millimeter of water.
Adequate fetch is required to have fully adjusted conditions.

Recommended crop height:fetch ratio is 1:50.
Example:
0.5 m crop height needs 25 m fetch
1 m crop height needs 50 m fetch
Acquisition of Undisturbed Soil Monolith
Lysimeter installation

Mechanical advantage = 1:100
Load cell resolution

**Interface ® SM-50 load cell**

Capacity: 22.7 kg  
(2270 kg equivalent range in monolith)  
Non-linearity & hysteresis: 0.05%  
Resolution: 0.13 mm H₂O
Weighing scale calibration (0.02% std. dev.)

mass (kg) = 685.4 x LC – 142.9; \( r^2 = 0.999 \)

mm H\textsubscript{2}O = 74.6 x LC – 15.7; where LC = load cell output (mV/V)

320-kg drums

4.5-kg ammo boxes
Effect of Wind on Scale Readings

Rocky Ford crop lysimeter
17-22 June 2010
0.5 Hz load cell readings for 5 minutes

Load cell readings are averaged over 15 minutes (450 readings) to filter wind noise.
Irrigation and Management
Lysimeter Water Balance

\[ ET_c = P + \text{Irr} - D + \Delta S \]

where:

- \( ET_c \) = crop evapotranspiration
- \( P \) = precipitation
- \( \text{Irr} \) = irrigation
- \( D \) = drainage
- \( \Delta S \) = change in profile soil water content
Example load cell output, lysimeter ET$_c$, and ASCE Penman-Monteith ET$_r$ on 9/30/2009
Seasonal water balance for alfalfa

Periods: 4/1/'08 – 11/5/'08; 3/24/'09 – 10/5/'09; 3/31/'10 – 10/28/'10; 4/6/'11 – 11/30/'11
(218 days) (195 days) (211 days) (238 days)
Getting daily crop coefficient ($K_c$) values

- Precipitation
- Radiation ($R_s$, $R_n$, PAR)
- Temperature (air, canopy, soil)
- Wind (speed, direction)
- Humidity ($e_a$)
- Atmospheric pressure
- Soil water content (Neutron probe)
- Soil heat flux
- ET(atmometer)

$ET_c$ from lysimeter

$ET_{rs}$ from weather data and ASCE-PME

$$K_{cr} = \frac{ET_c}{ET_{rs}}$$
Uniformity of soil moisture in lysimeter and surrounding field

Large Lysimeter Soil Moisture at each Access Tube (8/30/2010)

Volumetric moisture content (m$^3$ m$^{-3}$)

Profile soil water (cm)
Monolith avg. = 39.6
Exterior avg. = 35.9
Difference, % = 10.4 %
Uniformity of canopy height on lysimeter and surrounding field

Alfalfa Canopy Height in 2010
(inside and outside of lysimeter)
Corn on the large lysimeter (12 June 2013)
Seasonal corn crop coefficient ($K_{cr}$) curve for 2013 at Rocky Ford, CO
Irrigation Scheduler using cloud services

- eRAMS = environmental Risk Assessment and Management System
- CSIP = Cloud Services Innovation Platform
- CoAgMet = Colorado Agricultural Meteorological Network
- NCWCD = Northern Colorado Water Conservancy District
- REST = representational state transfer distributed-computing specifications for web services
- SSURGO = USDA Soil Survey Geographic Database
- VM = virtual machine
Daily Water Balance of the Soil Profile:

\[ D_c = D_p + ET_c - P - \text{Irr} + SRO \]

*(if \( D_c < 0 \), then \( D_c = 0 \))

- \( P \) = precipitation
- \( \text{Irr} \) = irrigation
- \( ET_c \) = crop evapotranspiration
- \( SRO \) = surface runoff
- \( D_c \) = current deficit (net Irr req’t.)
- \( D_p \) = previous deficit
- \( DP \) = deep percolation; if \( D_c < 0 \)
- \( C \) = capillary rise (assumed 0)
- \( L \) = lateral flow (0 net)

Source:
http://soils.usda.gov/education/resources/k_12/lessons/profile/
ater rrigation cheduling for fficient Application

WISE
Irrigation Schedule - Graph

Below is a graph displaying your current plant available water or soil water deficit, depending on the option selected. To change the view select a different graph type from the "Select Graph" dropdown box below. Some graph entries, such as rain and irrigation, are directly editable from the graph. Click and drag these lines to change their value or enter values directly in the "Value" tab. After changes are made, the "Update" button at the bottom of the page can be clicked to save changes.

Graph Style
Print Chart
Calculated water balance components using actual and WISE-recommended irrigations for center pivot irrigated corn at Greeley, CO in 2011 (13 June – 10 October).

<table>
<thead>
<tr>
<th>Water balance component</th>
<th>With actual irrigations (mm)</th>
<th>With recommended irrigations (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ET_c$ (mm)</td>
<td>501</td>
<td>501</td>
</tr>
<tr>
<td>Gross Irr (mm)</td>
<td>511</td>
<td>372</td>
</tr>
<tr>
<td>$P$ (mm)</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>DP + SRO (mm)</td>
<td>146</td>
<td>37</td>
</tr>
<tr>
<td>$\Delta S$ (mm)</td>
<td>12</td>
<td>42</td>
</tr>
</tbody>
</table>

$\Delta S = \text{change in soil water storage in managed root zone (1050 mm)}$

Scheduling using WISE:
- 27% savings in gross irrigation
- 75% reduction in deep percolation (DP) and surface runoff (SRO)
WISE Smart phone Apps

https://itunes.apple.com/app/id928128681

For more information, go to http://wise.colostate.edu/
or see:

WISE Project Team

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