Improving Agricultural Water Management in the Arkansas Valley Using Lysimetric Studies

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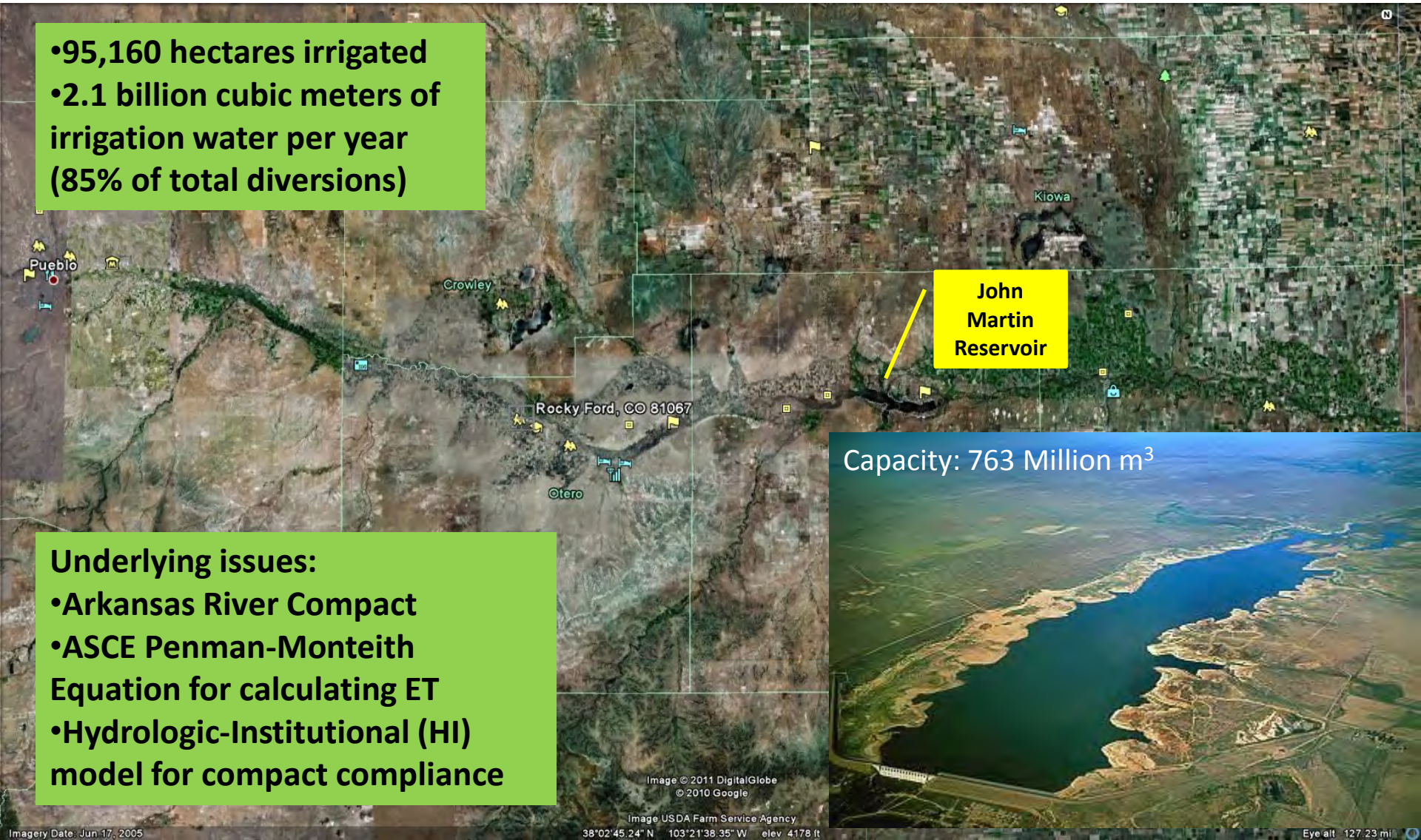
COLORADO DIVISION OF WATER RESOURCES
DEPARTMENT OF NATURAL RESOURCES

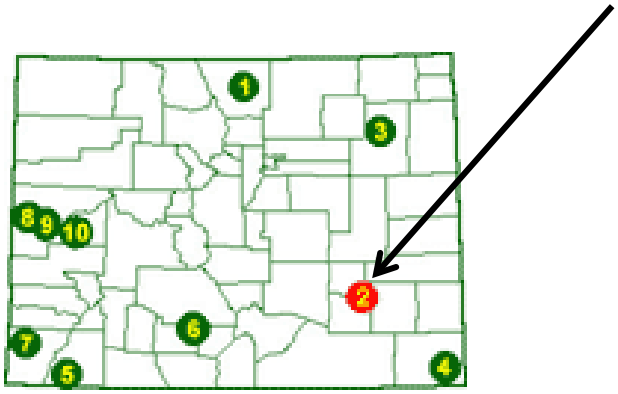
USDA
United States Department of Agriculture
National Institute of Food and Agriculture

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



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

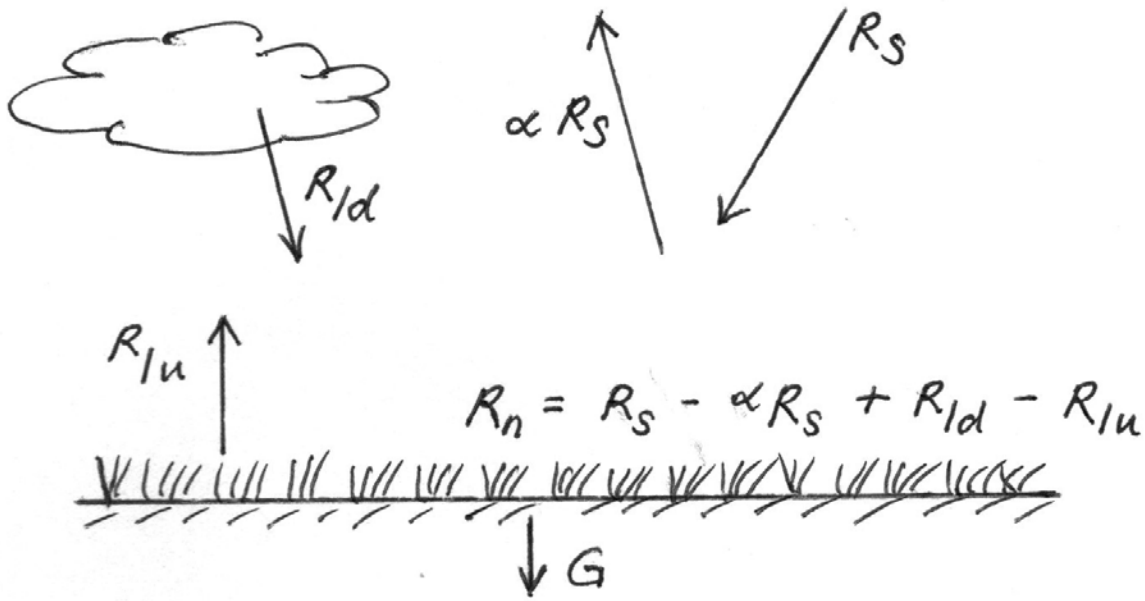
ET_{rs} = reference crop ET (tall reference like alfalfa)

= 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} = crop coefficient based on tall reference

$$= \frac{ET_c}{ET_{rs}}$$

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

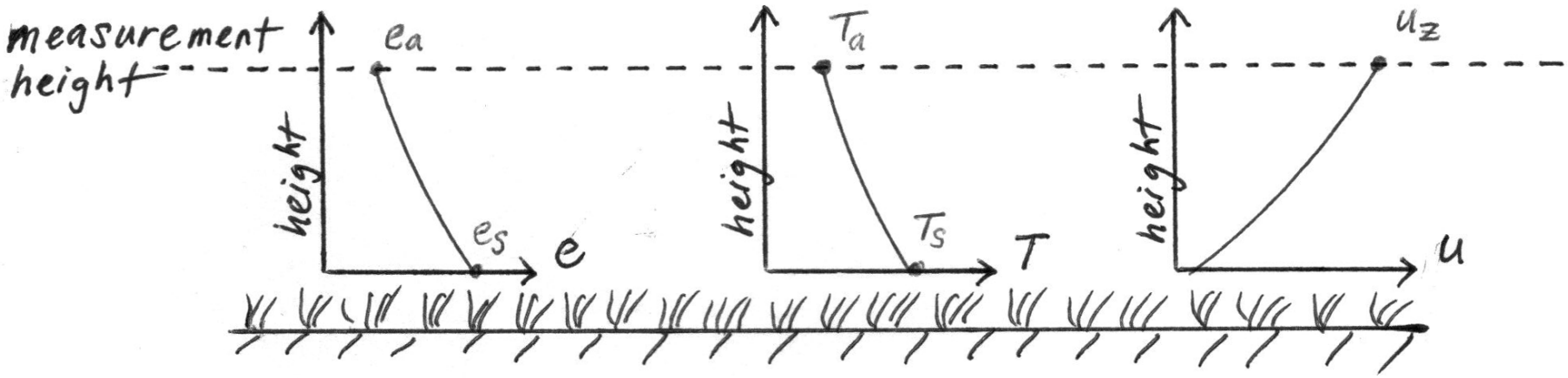
α = reflection coefficient or albedo

R_{lu} = long wave radiation going upward

G = ground heat flux

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

Ground heat flux

Net radiation

Air temperature

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

Wind speed

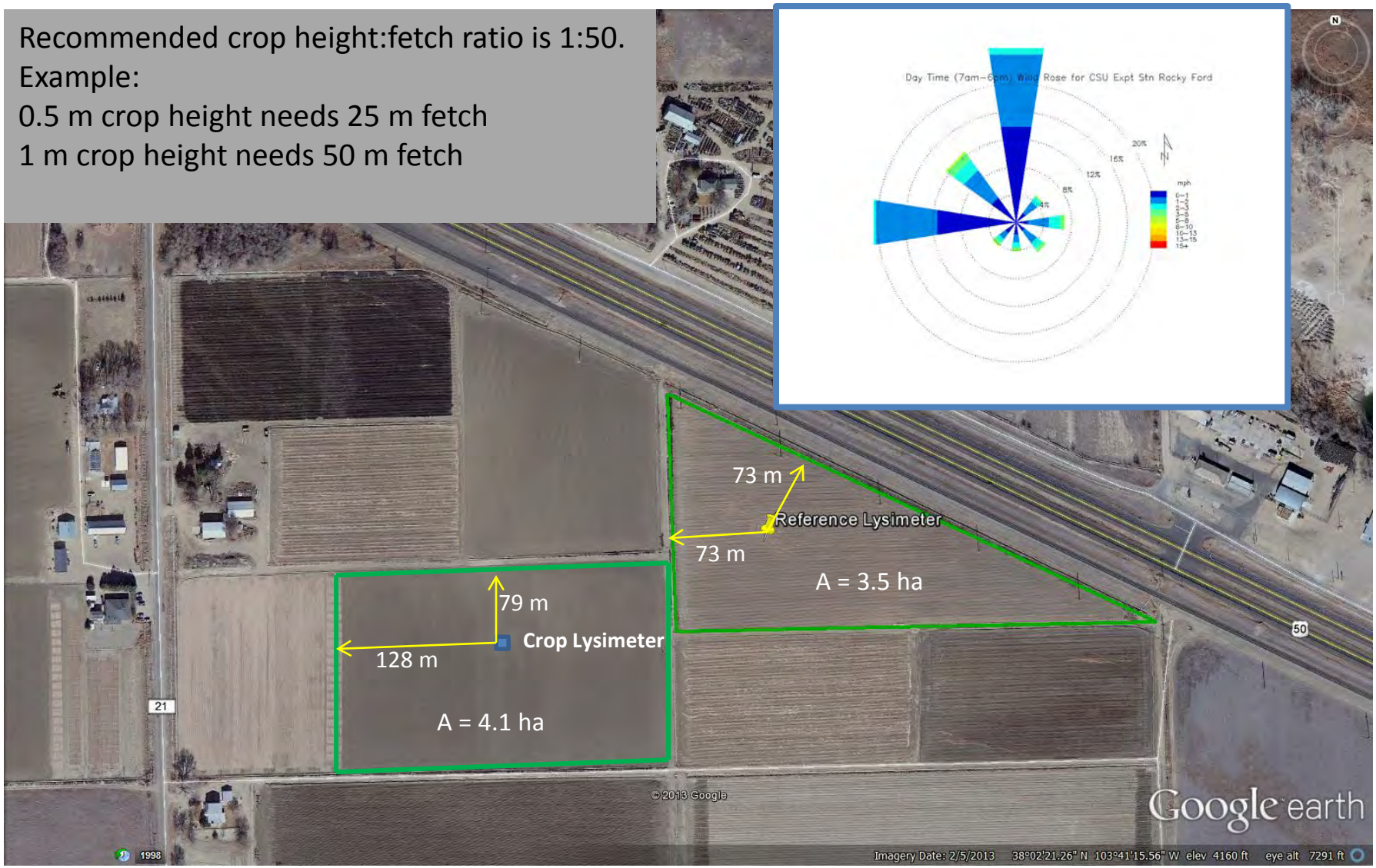
Humidity

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.

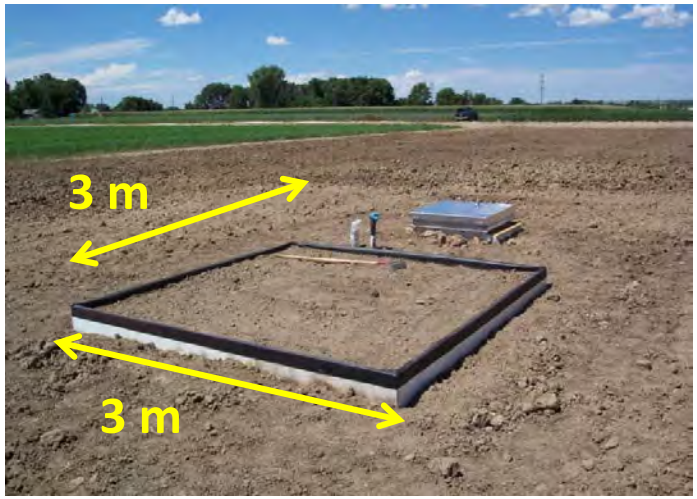
Recommended crop height:fetch ratio is 1:50.
Example:
0.5 m crop height needs 25 m fetch
1 m crop height needs 50 m fetch



Acquisition of Undisturbed Soil Monolith

Lysimeter installation

Mechanical advantage = 1:100



Load cell resolution

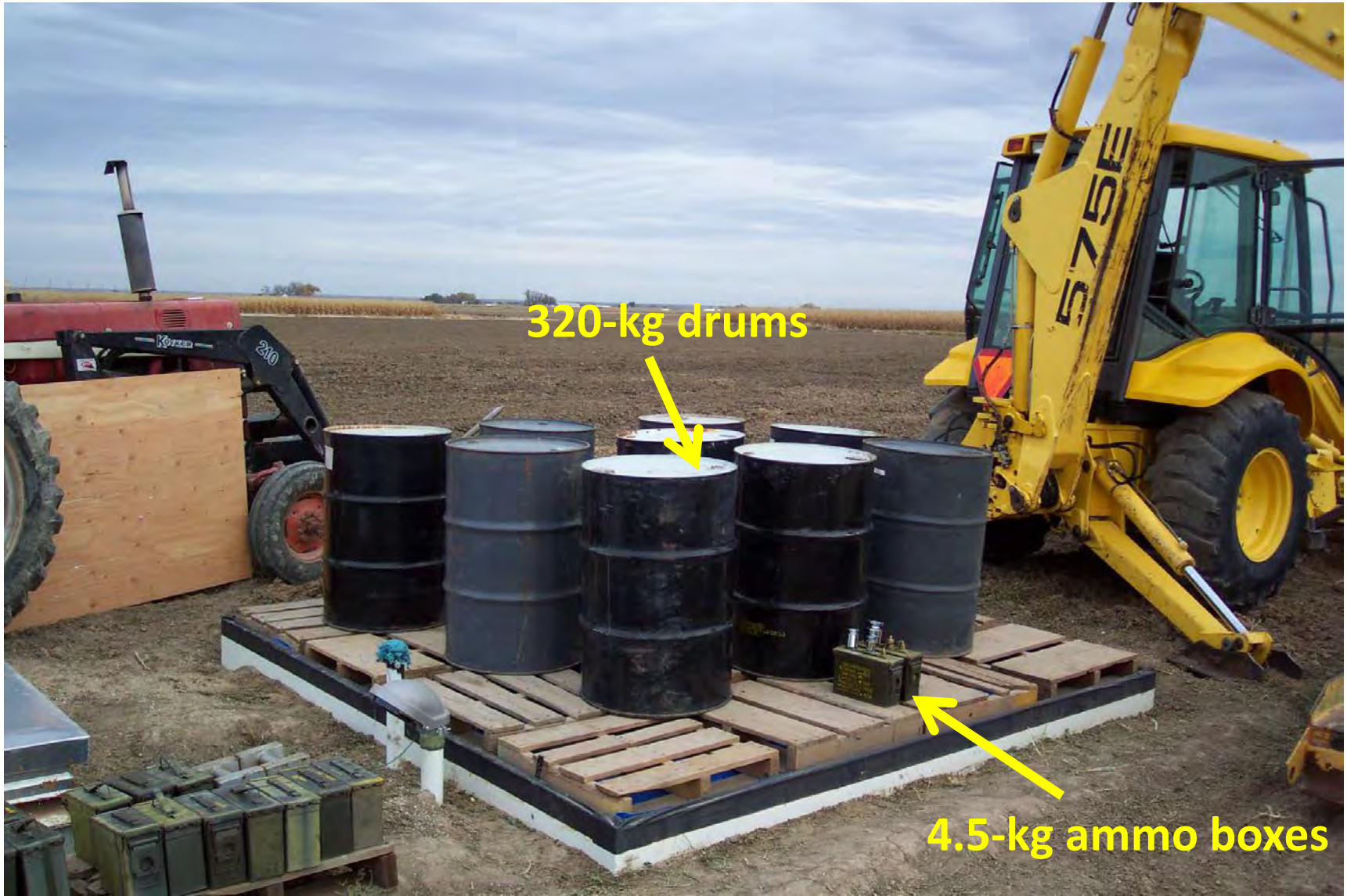
Interface ® SM-50 load cell

Capacity: 22.7 kg
(2270 kg equivalent range in monolith)
Non-linearity & hysterisis: 0.05%
Resolution: 0.13 mm H_2O

Weighing scale calibration (0.02% std. dev.)

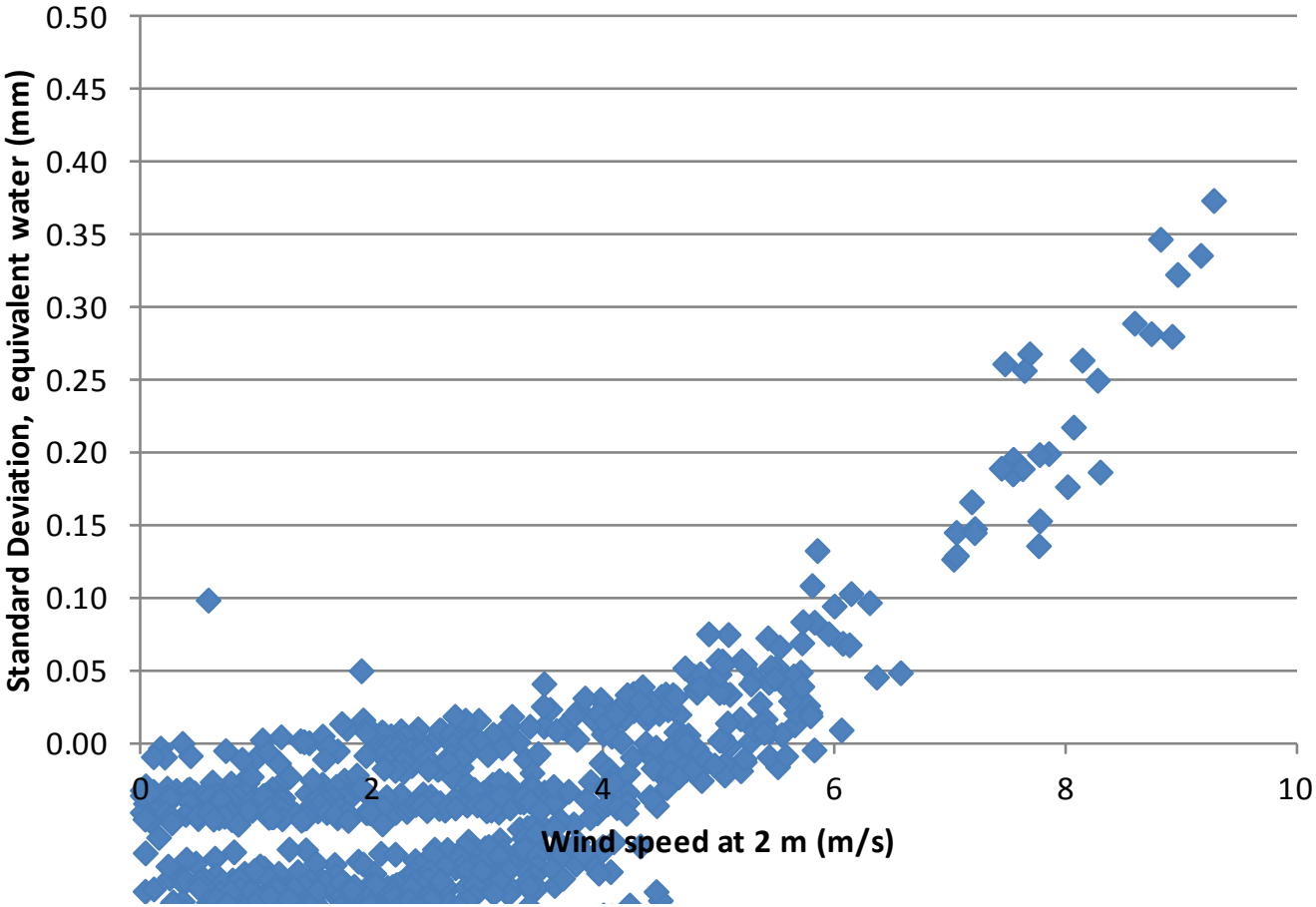
mass (kg) = 685.4 x LC – 142.9; $r^2 = 0.999$

mm H_2O = 74.6 x LC – 15.7; where LC = load cell output (mV/V)



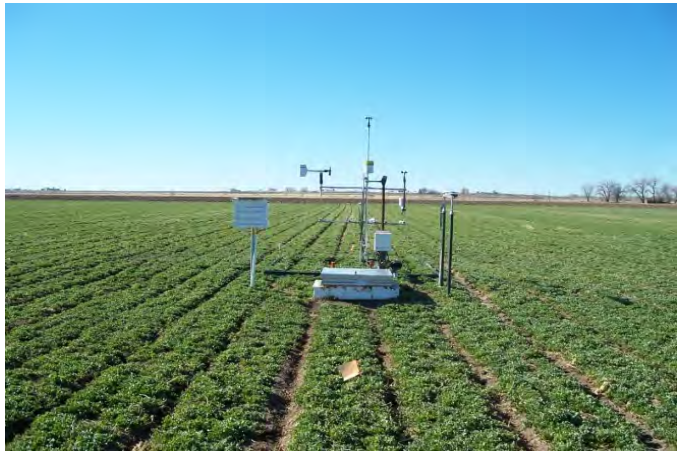
Effect of Wind on Scale Readings

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

$$ET_c = P + Irr - D + \Delta S$$

where:

ET_c = crop evapotranspiration

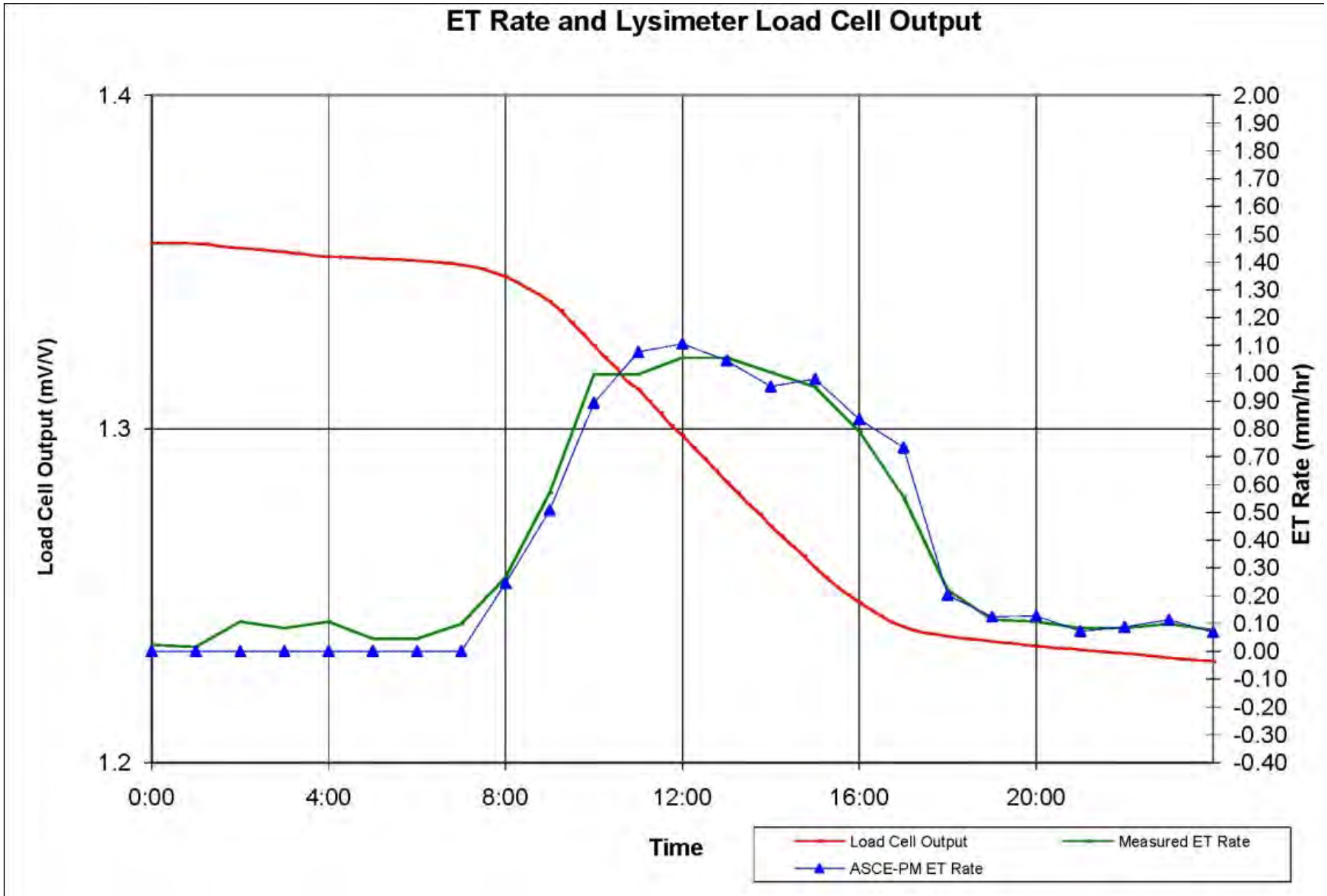
P = precipitation

Irr = irrigation

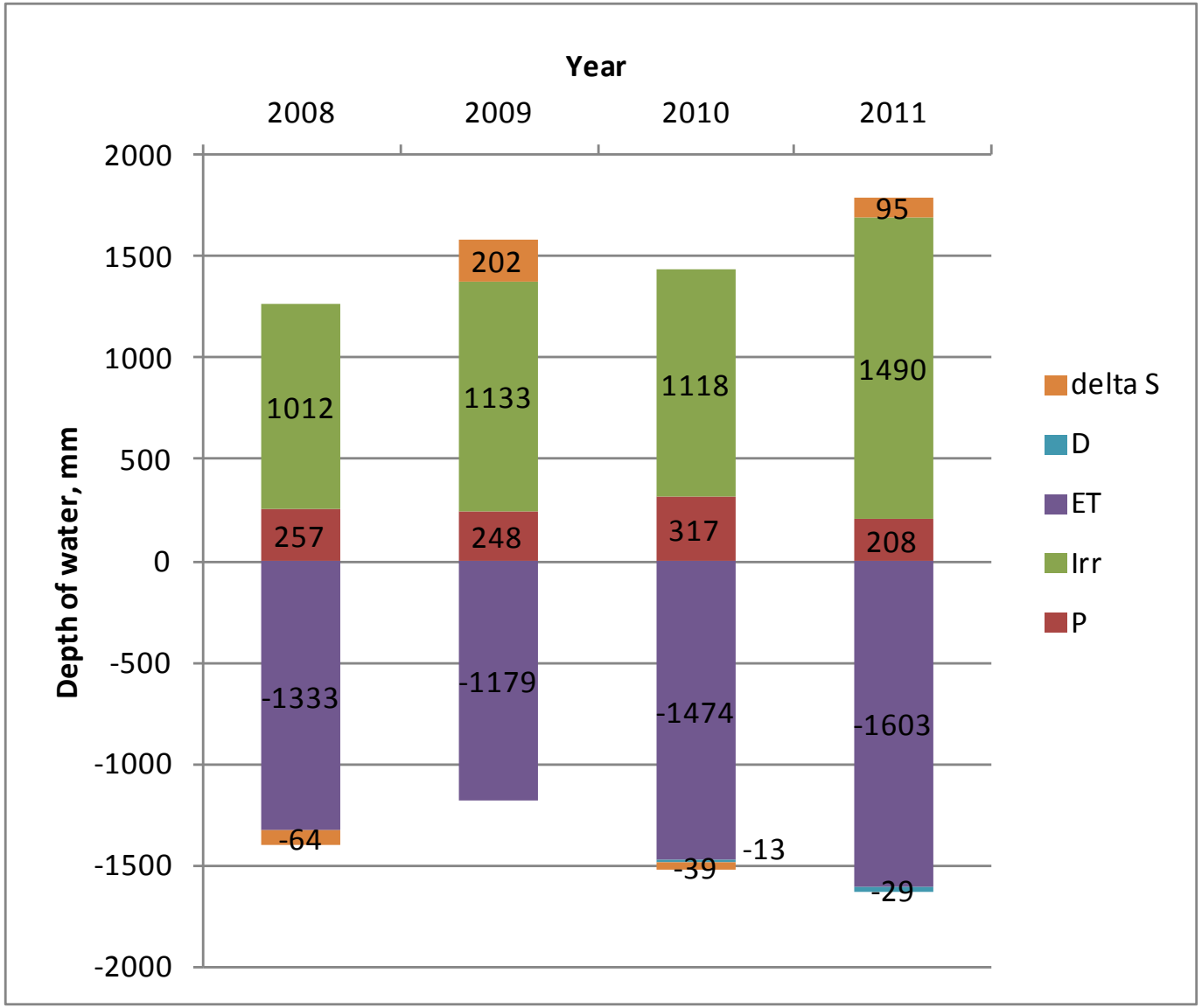
D = drainage

ΔS = change in profile soil water content

Example load cell output, lysimeter ET_c, and ASCE Penman-Monteith ET_r on 9/30/2009

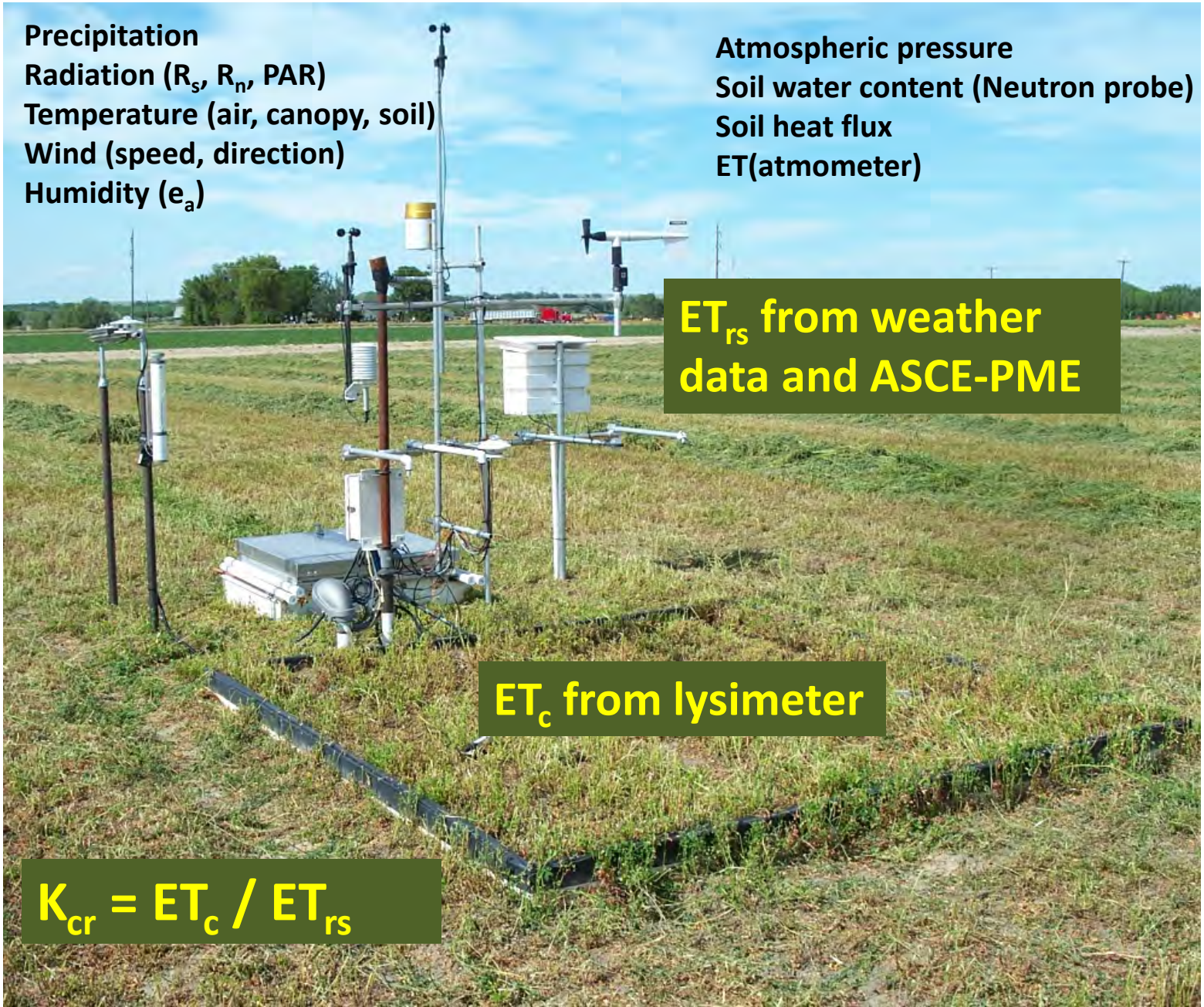


Seasonal water balance for alfalfa



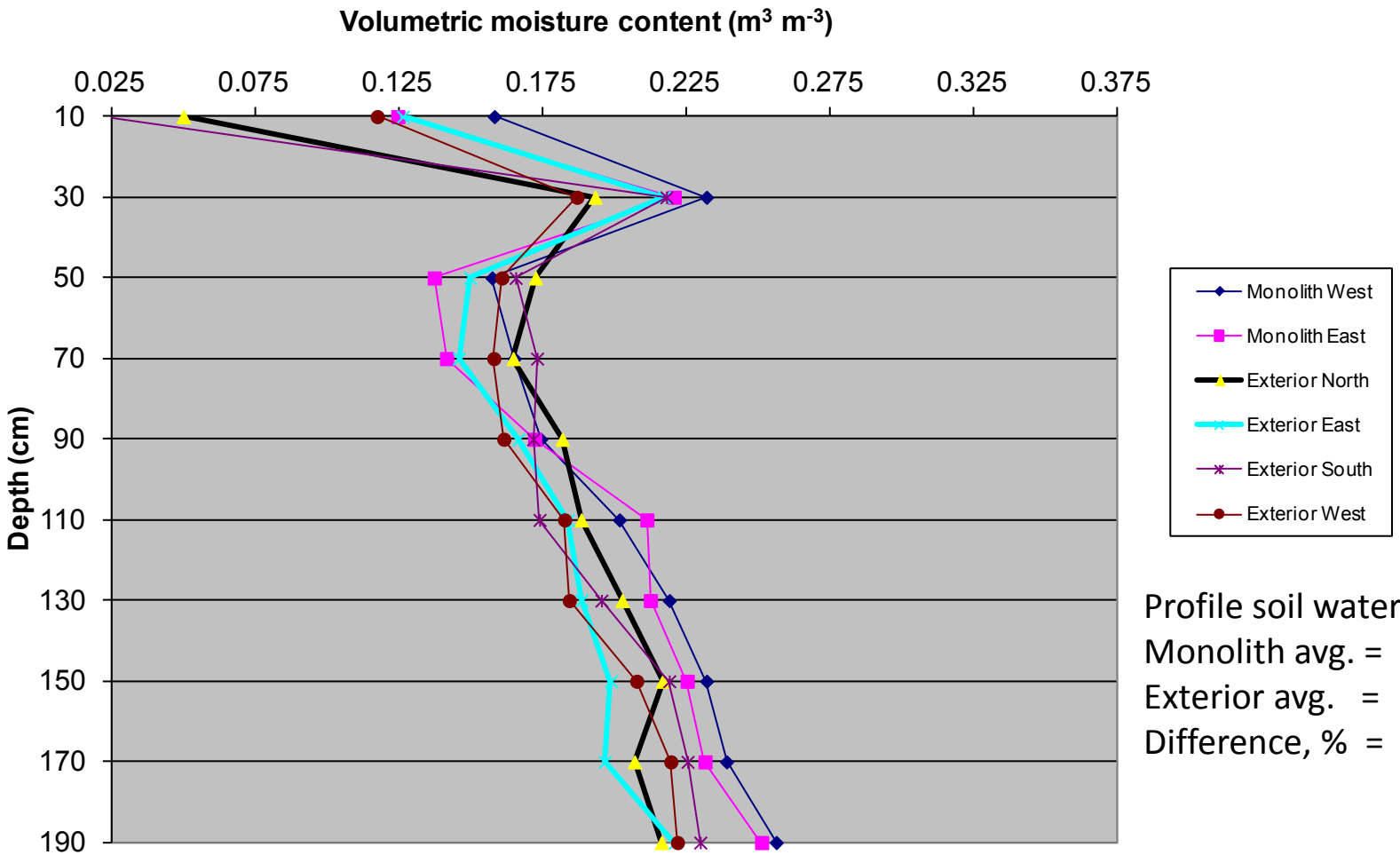
Periods: 4/1/'08 – 11/5/'08; 3/24/'09 – 10/5/'09; 3/31/'10 – 10/28/'10; 4/6/'11 – 11/30/'11
(218 days) (195 days) (211 days) (238 days)

Getting daily crop coefficient (K_c) values



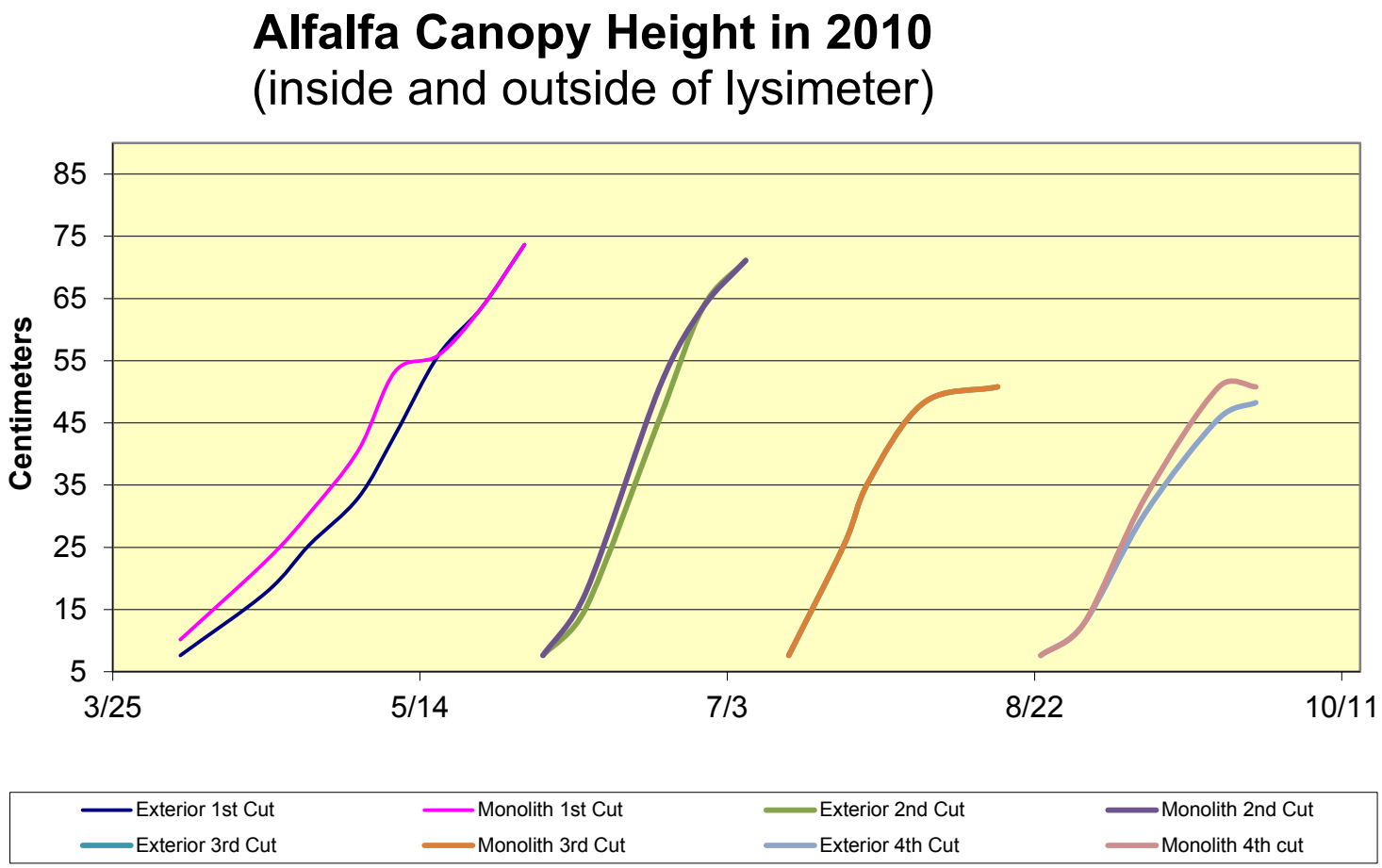
Uniformity of soil moisture in lysimeter and surrounding field

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



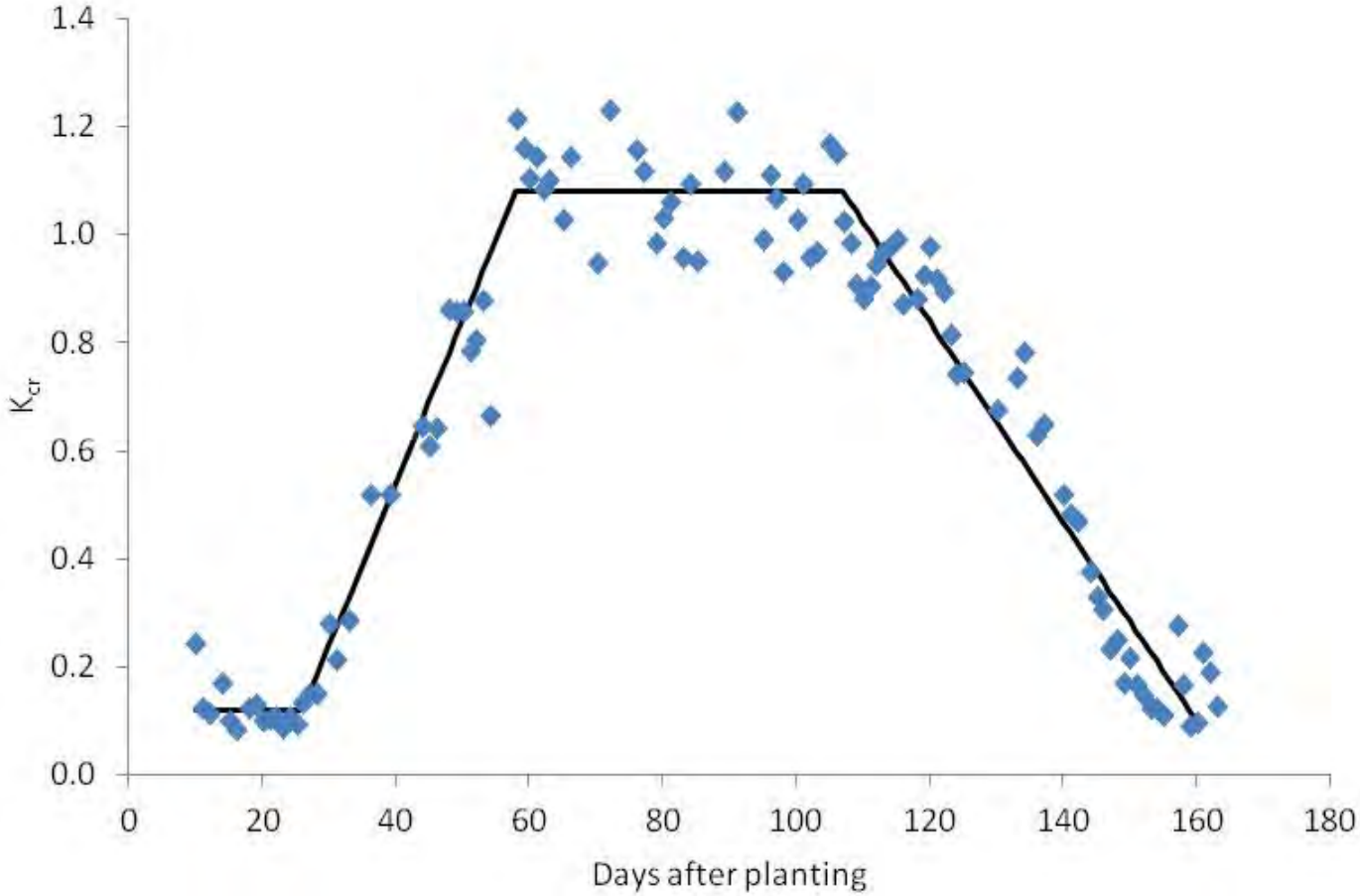
Profile soil water (cm)
Monolith avg. = 39.6
Exterior avg. = 35.9
Difference, % = 10.4 %

Uniformity of canopy height on lysimeter and surrounding field

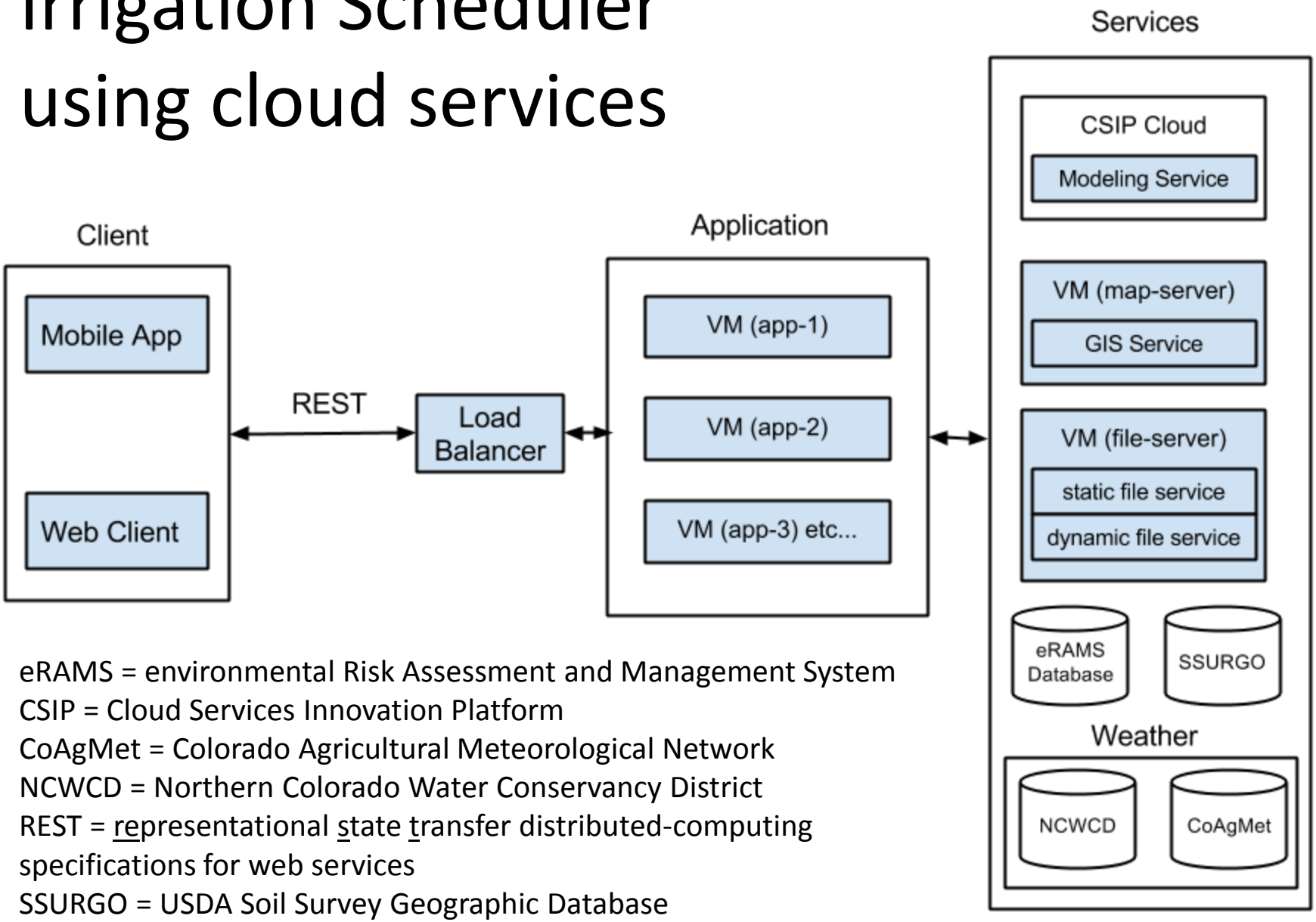


Corn on the large lysimeter (12 June 2013)

Seasonal corn crop coefficient (K_{cr}) curve for 2013 at Rocky Ford, CO



Irrigation Scheduler using cloud services

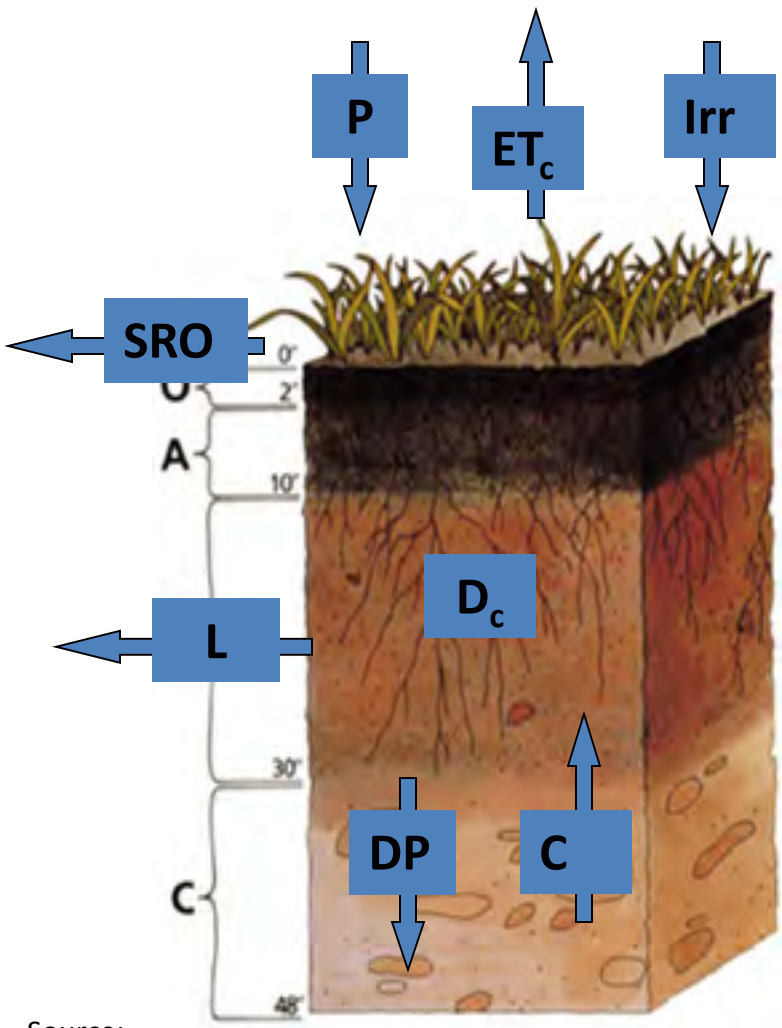


eRAMS = environmental Risk Assessment and Management System
CSIP = Cloud Services Innovation Platform
CoAgMet = Colorado Agricultural Meteorological Network
NCWCD = Northern Colorado Water Conservancy District
REST = representational state transfer distributed-computing specifications for web services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

Daily Water Balance of the Soil Profile:

$$D_c = D_p + ET_c - P - Irr + SRO$$

(if $D_c < 0$, then $D_c = 0$)



P = precipitation

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/

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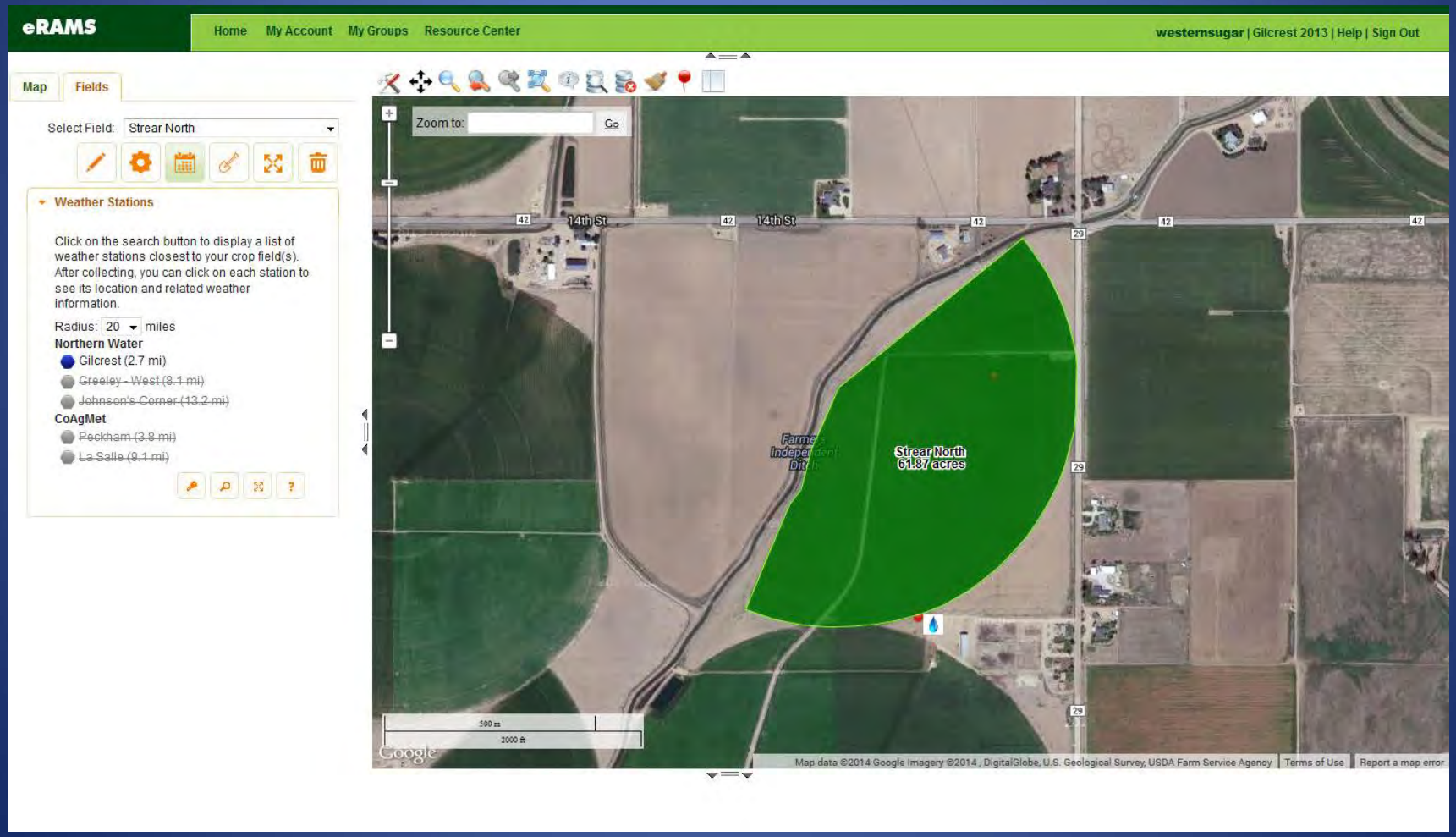
WISE



Irrigation Schedule - Graph

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

Water balance component	With actual irrigations (mm)	With recommended irrigations (mm)
ET_c (mm)	501	501
Gross Irr (mm)	511	372
P (mm)	125	125
DP + SRO (mm)	146	37
ΔS (mm)	12	42

ΔS = 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)

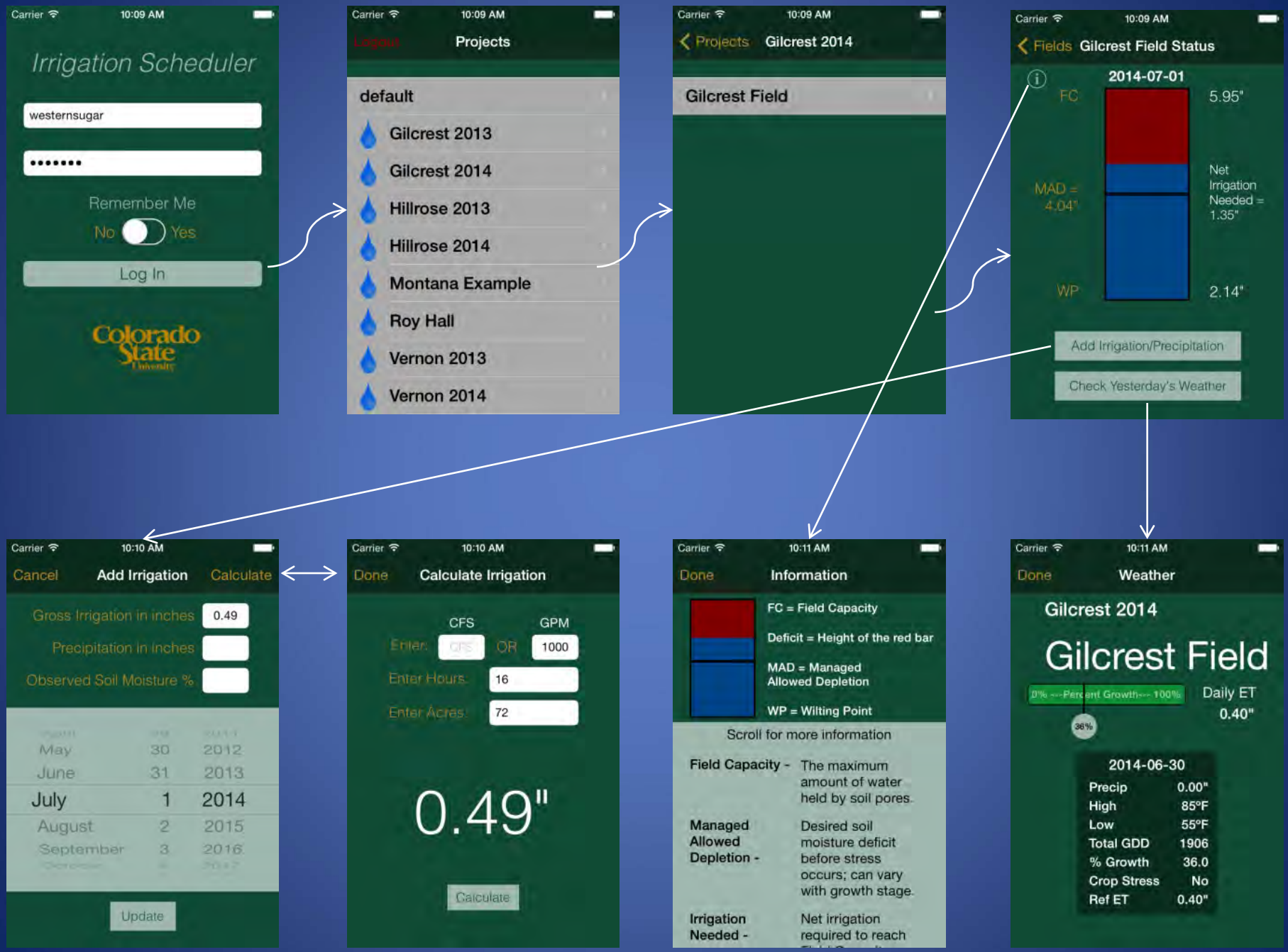
WISE Smart phone Apps

Download on the App Store

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

android

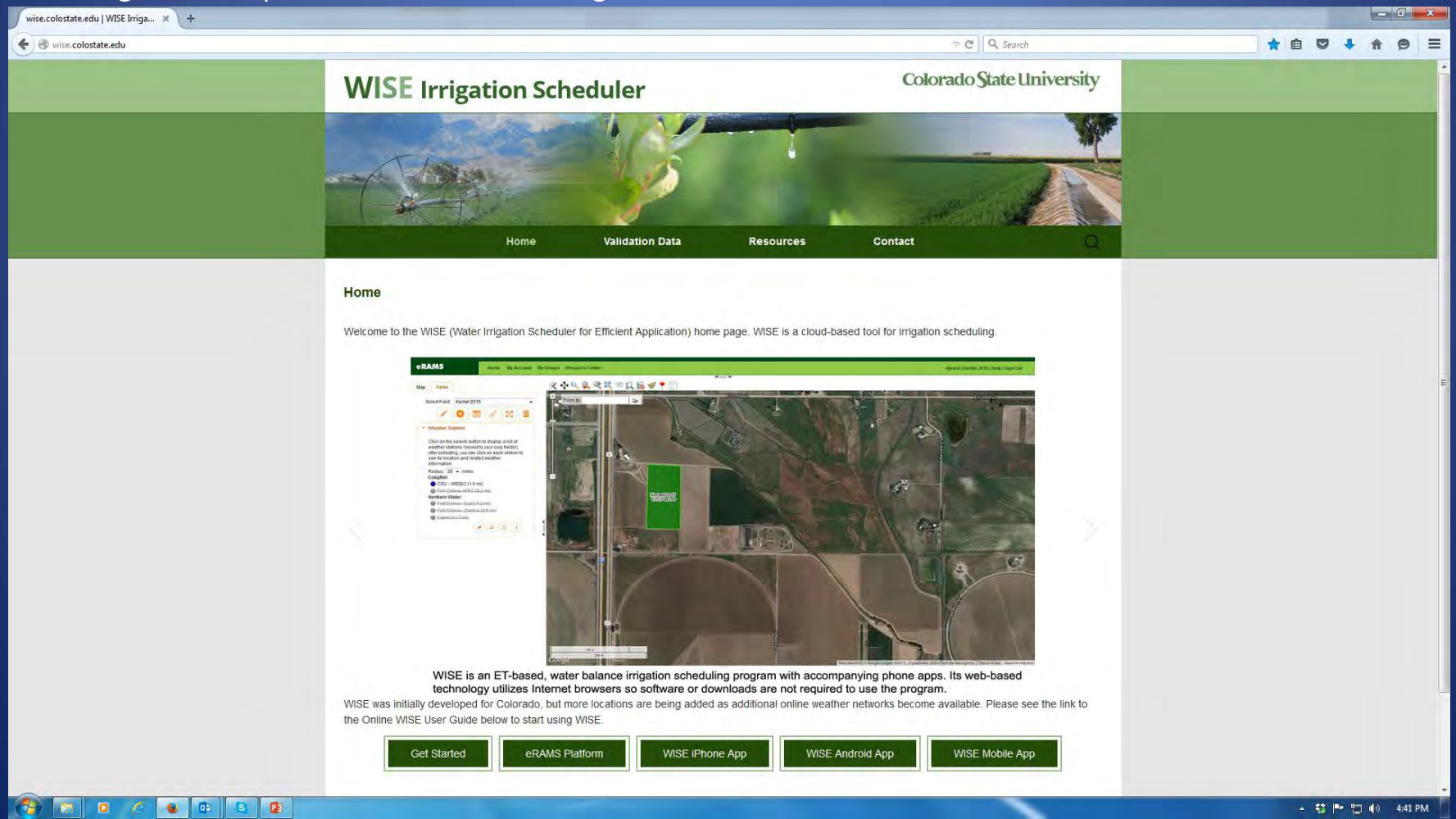
https://play.google.com/store/apps/details?id=com.erams.wise


Carrier 10:09 AM
Irrigation Scheduler
westernsugar
•••••••
Remember Me
No Yes
Log In
Colorado State University
Carrier 10:09 AM
Logout
Projects
default
Gilcrest 2013
Gilcrest 2014
Hillrose 2013
Hillrose 2014
Montana Example
Roy Hall
Vernon 2013
Vernon 2014
Carrier 10:09 AM
Projects
Gilcrest 2014
Gilcrest Field
Carrier 10:09 AM
Fields
Gilcrest Field Status
2014-07-01
FC
5.95"
MAD = 4.04"
Net Irrigation Needed = 1.35"
WP
2.14"
Add Irrigation/Precipitation
Check Yesterday's Weather
Carrier 10:10 AM
Cancel
Add Irrigation
Calculate
Gross Irrigation in inches
0.49
Precipitation in inches
Observed Soil Moisture %
May 30 2012
June 31 2013
July 1 2014
August 2 2015
September 3 2016
Update
Carrier 10:10 AM
Done
Calculate Irrigation
CFS
GPM
Enter:
OR
1000
Enter Hours:
16
Enter Acres:
72
0.49"
Calculate
Carrier 10:11 AM
Done
Information
FC = Field Capacity
Deficit = Height of the red bar
MAD = Managed Allowed Depletion
WP = Wilting Point
Scroll for more information
Field Capacity - The maximum amount of water held by soil pores.
Managed Allowed Depletion - Desired soil moisture deficit before stress occurs; can vary with growth stage.
Irrigation Needed - Net irrigation required to reach
Carrier 10:11 AM
Done
Weather
Gilcrest 2014
Gilcrest Field
0% ---Percent Growth--- 100%
36%
Daily ET
0.40"
2014-06-30
Precip 0.00"
High 85°F
Low 55°F
Total GDD 1906
% Growth 36.0
Crop Stress No
Ref ET 0.40"

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

Andales, A.A., Bauder, T.A., and Arabi, M. 2014. A Mobile Irrigation Water Management System Using a Collaborative GIS and Weather Station Networks. In: Practical Applications of Agricultural System Models to Optimize the Use of Limited Water (Ahuja, L.R., Ma, L., Lascano, R.; Eds.), Advances in Agricultural Systems Modeling, Volume 5. ASA-CSSA-SSSA, Madison, Wisconsin, pp. 53-84.

Bartlett, A.C., Andales A.A., Arabi, M., Bauder, T.A. 2015. A Smartphone App to Extend Use of a Cloud-based Irrigation Scheduling Tool. Computers and Electronics in Agriculture 111:127-130.



WISE Project Team

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Funding provided by:

- USDA-NIFA
- Colorado Water Conservation Board
- Colorado Agricultural Experiment Station
- Western Sugar Cooperative
- Coca Cola

Acknowledgements

- Research team mates: Lane Simmons, Mike Bartolo, Jose Chavez, Abdel Berrada, Lee Sommers, Reagan Waskom, Frank Johnson, Dale Straw, Tom Ley, Hamdan AlWahaibi
- Funding provided by the Colorado Water Conservation Board, the Colorado Agricultural Experiment Station, Colorado Water Institute, and the Colorado Division of Water Resources
- Technical assistance provided by USDA-ARS (Fort Collins, CO and Bushland, TX)