Measurement, Interpretation, and Use of Water Productivity Data

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Fort Collins, CO

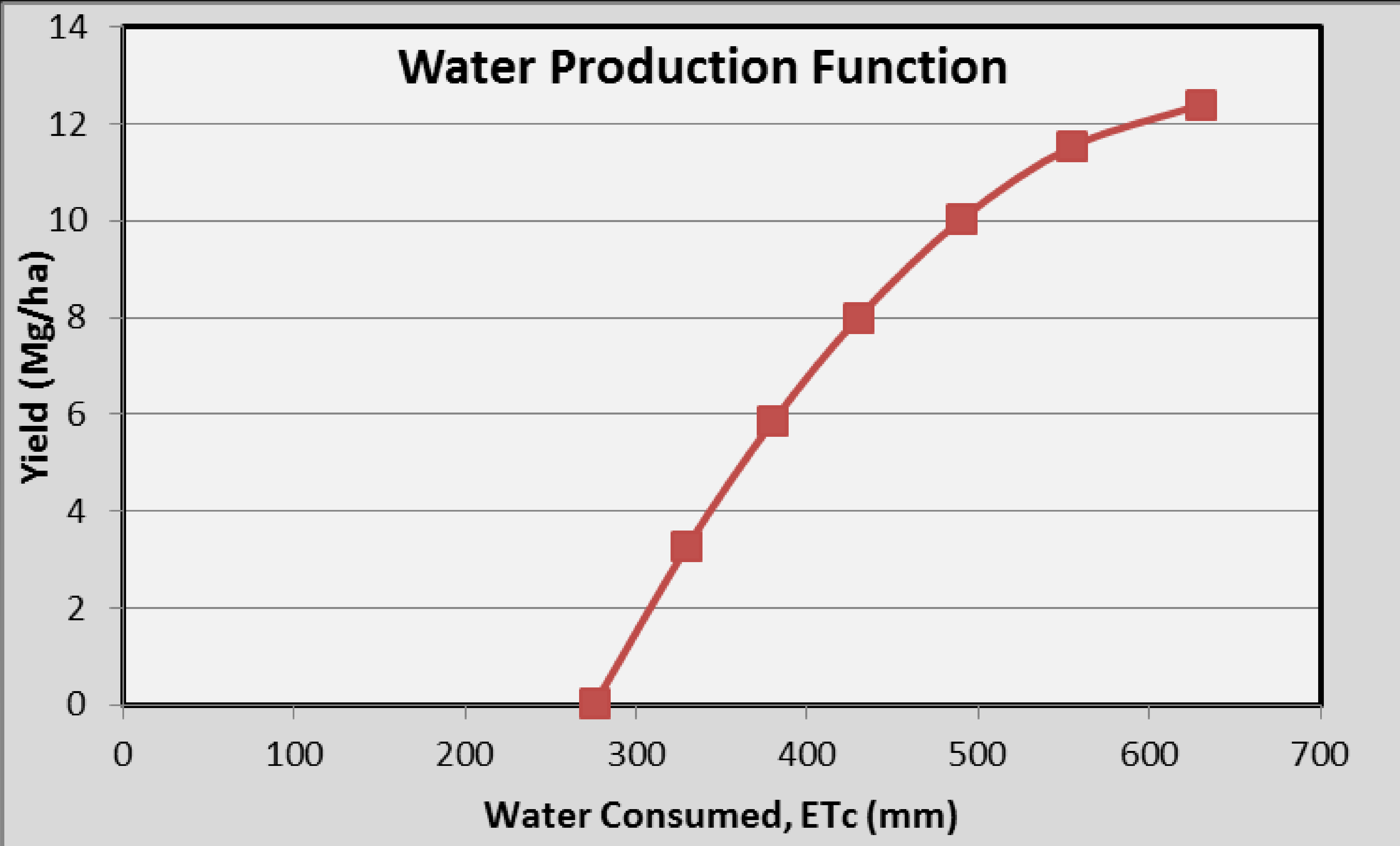
Innovations in Irrigation Water Management since 1911

USDA ars
United States Department of Agriculture
Agricultural Research Service

Use of Water Productivity Data

- Predict yield loss due to water stress
- Improve allocation of limited water supplies
  - Among crops
  - Among growth stages
  - Among farmers
- Predict the yield and economic benefits of supplemental irrigation.

Models

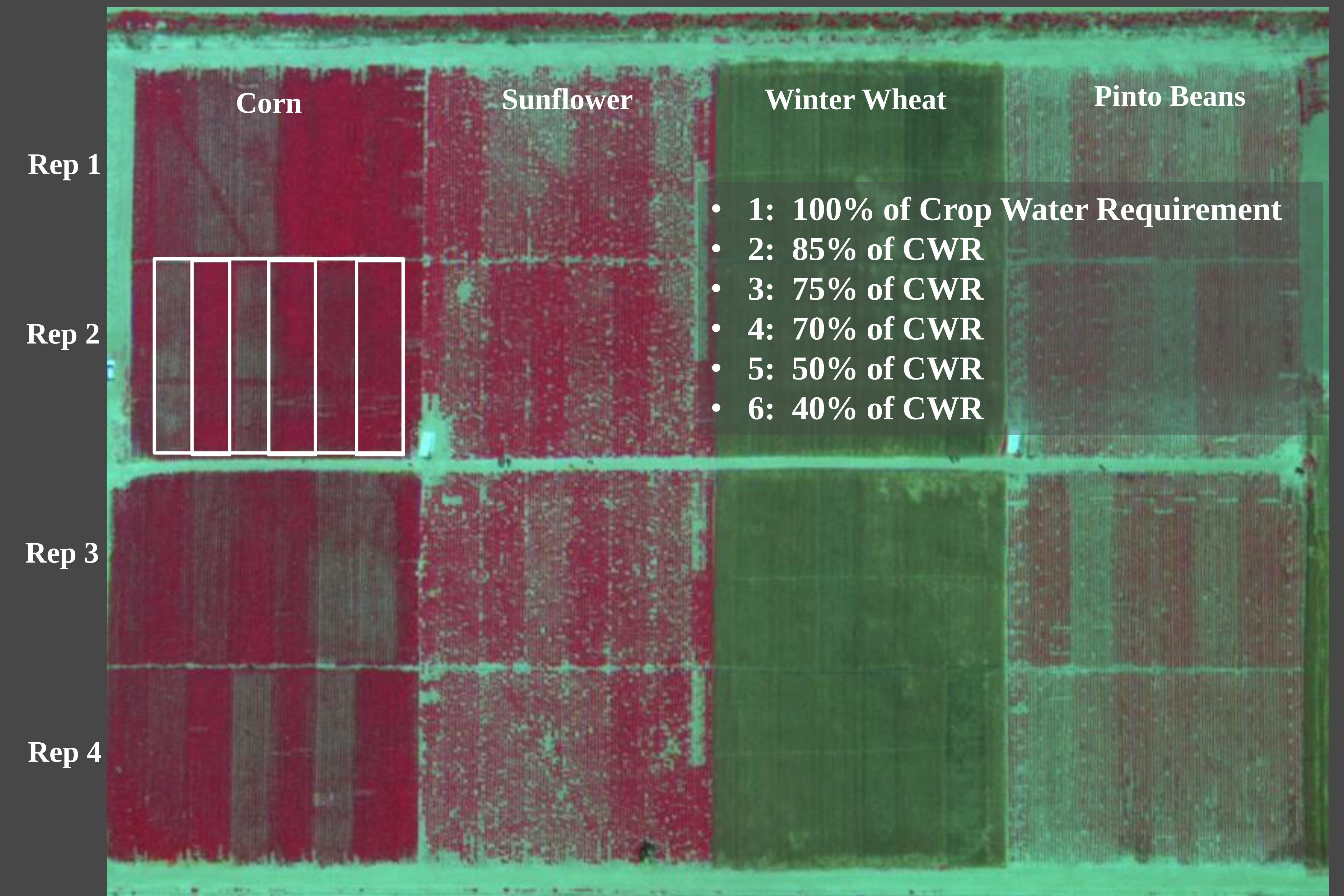

Water Production Function
Yield (Mg/ha)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
Water Consumed, ETc (mm)

Water Use?

- Precipitation
- Supplemental Irrigation
- Precipitation + Irrigation
- Evapotranspiration, ET_c
  - Precipitation + Irrigation – Lost water
- Transpiration
  - ET_c – soil evaporation

WPF Data:
yield and water use

- Many fields, grower conditions
  - Farm plots – with measured precip and irrigation
  - Farmer surveys
  - Ag Statistics Data (USA – NASS) plus climatic and irrigation supply data
- Replicated research plots


Corn
Sunflower
Winter Wheat
Pinto Beans
Rep 1
Rep 2
Rep 3
Rep 4
• 1: 100% of Crop Water Requirement
• 2: 85% of CWR
• 3: 75% of CWR
• 4: 70% of CWR
• 5: 50% of CWR
• 6: 40% of CWR

Representative Agronomy Representative Yields

- Variety selection
- Population
- Fertilization
- Weed/Pest control
- Tillage

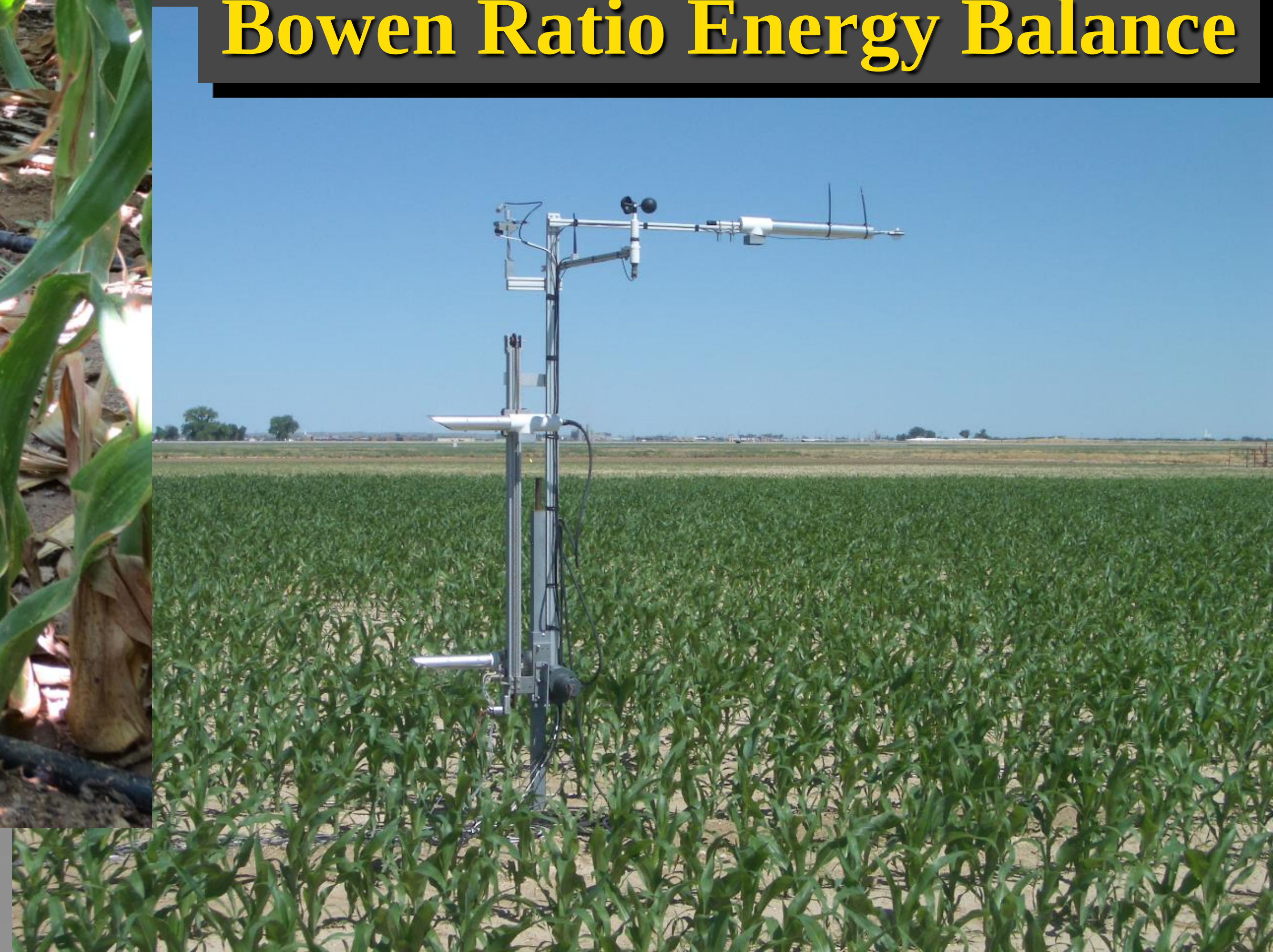
Sprinkler for Germination/Incorporation

Nelson Poly 2000 system
with R-10 rotators

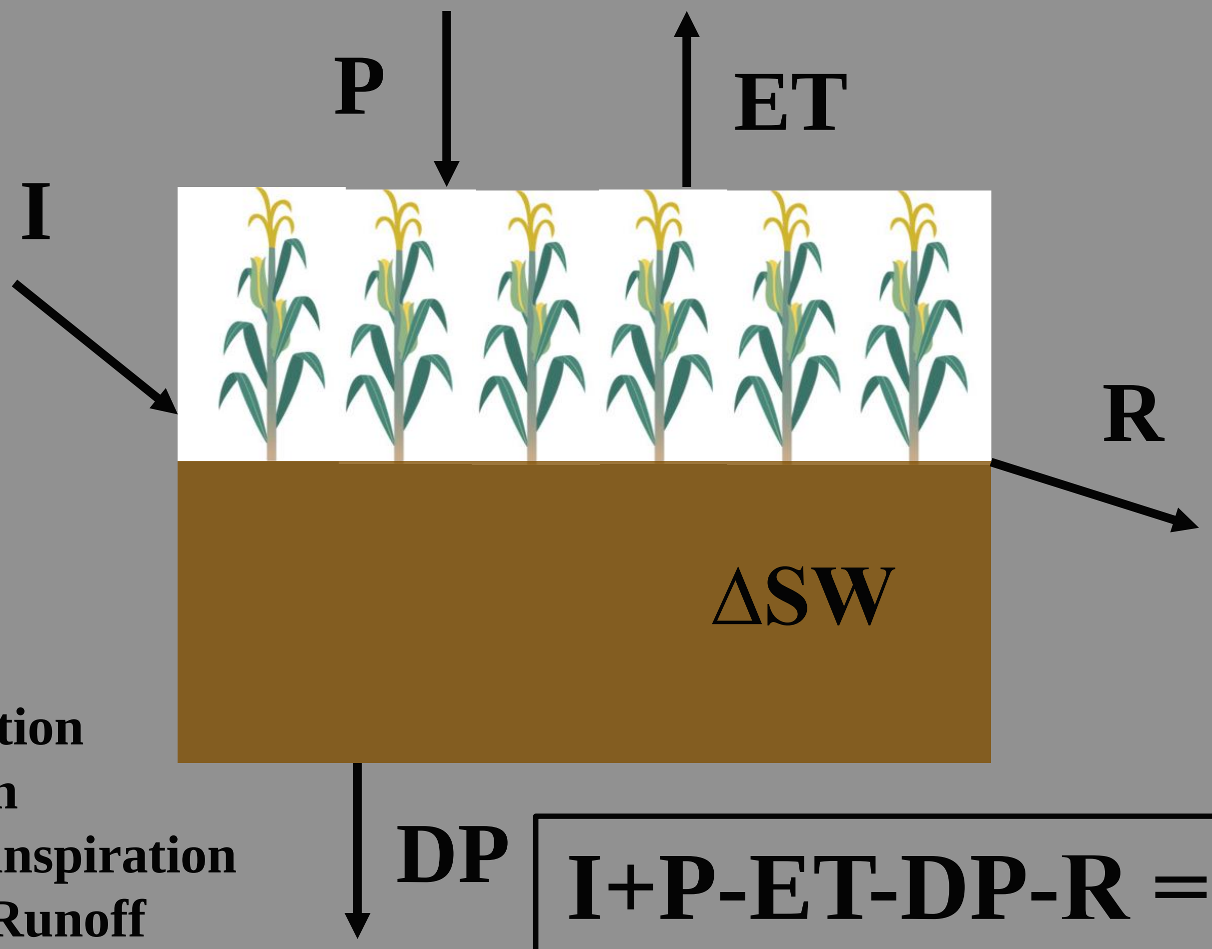
Crop Water Use (ET_c) Measurement

Sap Flow

Bowen Ratio Energy Balance



Water Balance

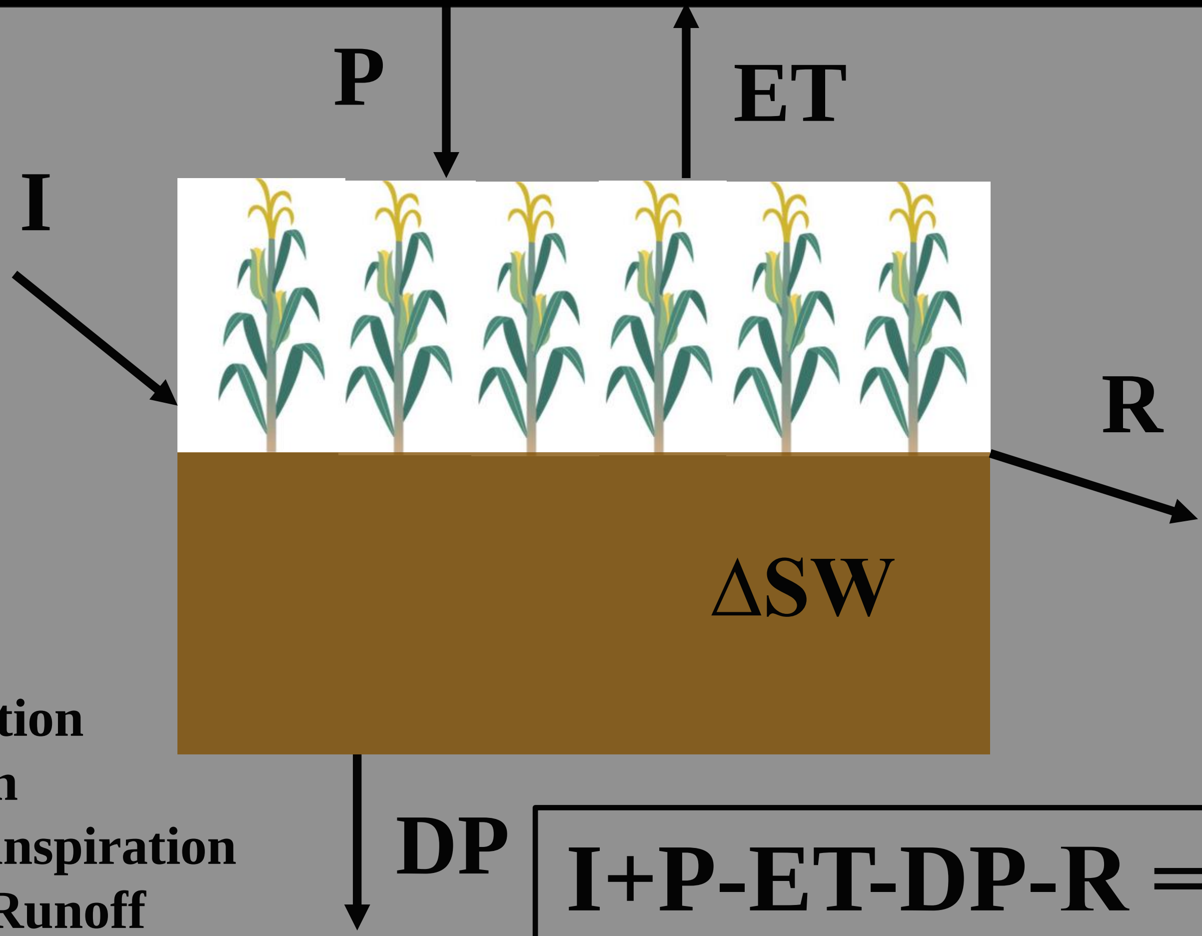


P Precipitation
I Irrigation
ET Evapotranspiration
R Surface Runoff
DP Deep Percolation
ΔSW Change in Soil Water Storage

$$I+P-ET-DP-R = \Delta SW$$

$$ET = I+P-\Delta SW-DP-R$$

If Precipitation > 50% of potential ET (CWR), Difficult to estimate losses



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I Irrigation
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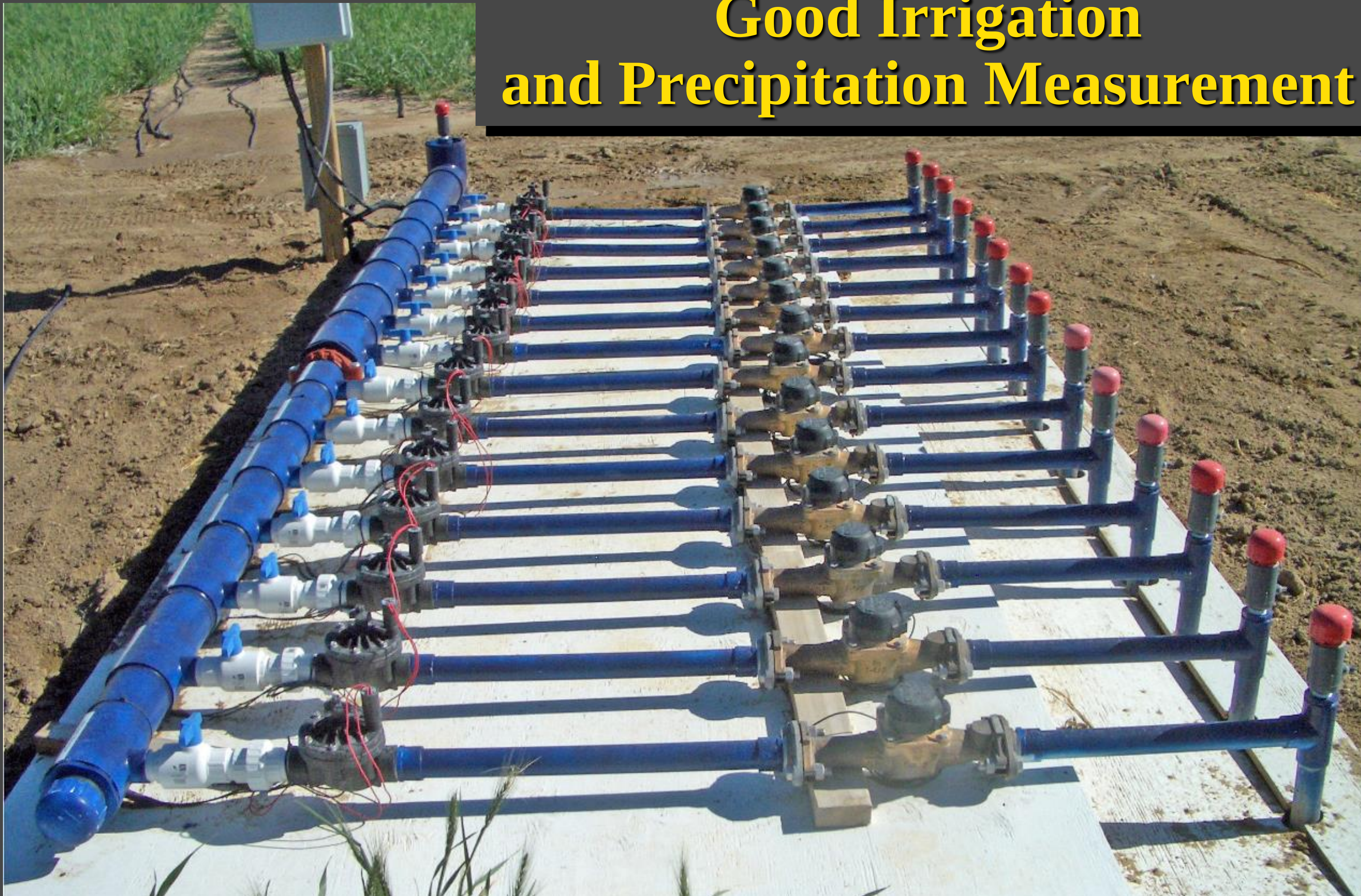
$$ET = I + P - \Delta SW - DP - R$$

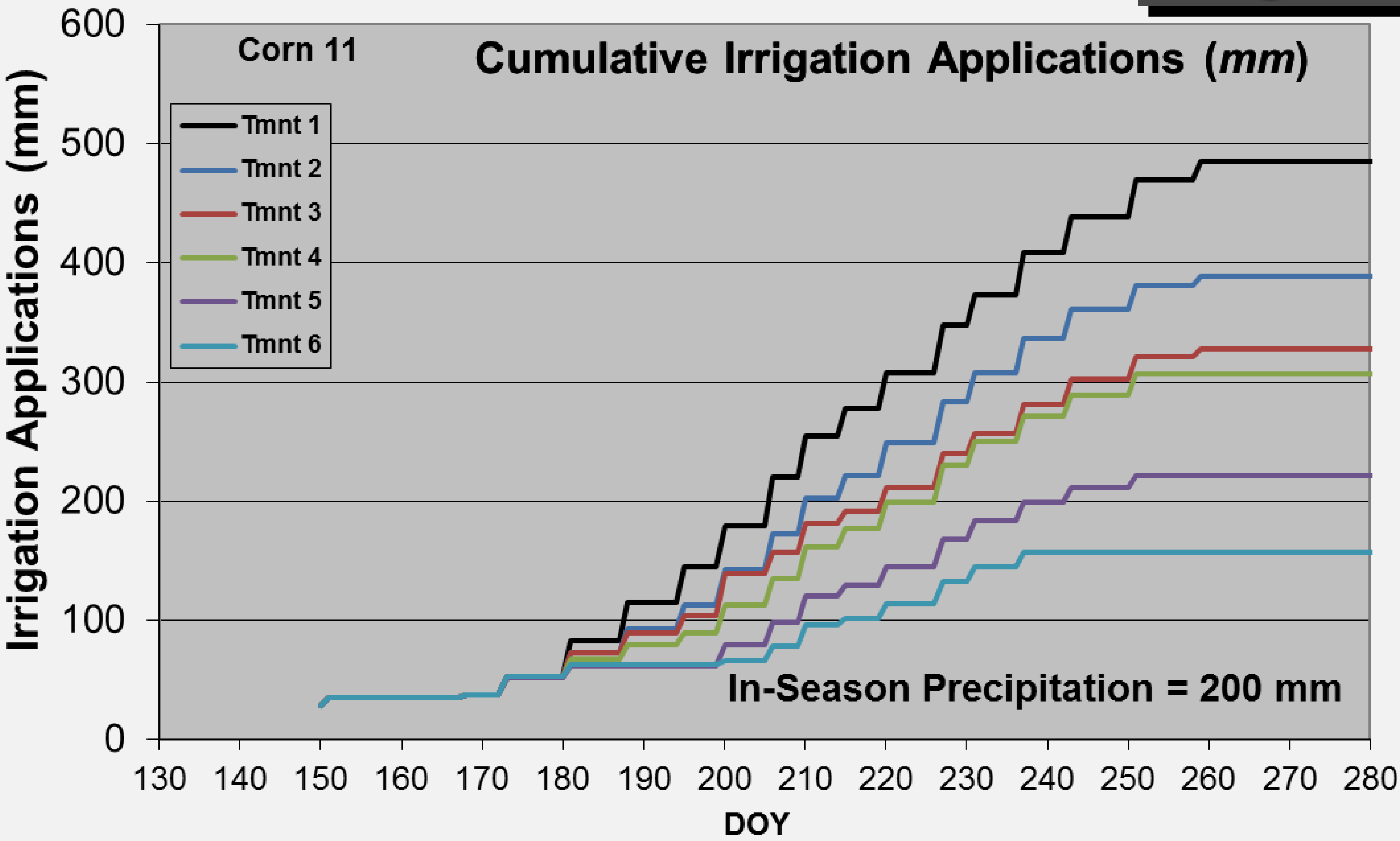
Good Irrigation and Precipitation Measurement



Uniform, Efficient Irrigation

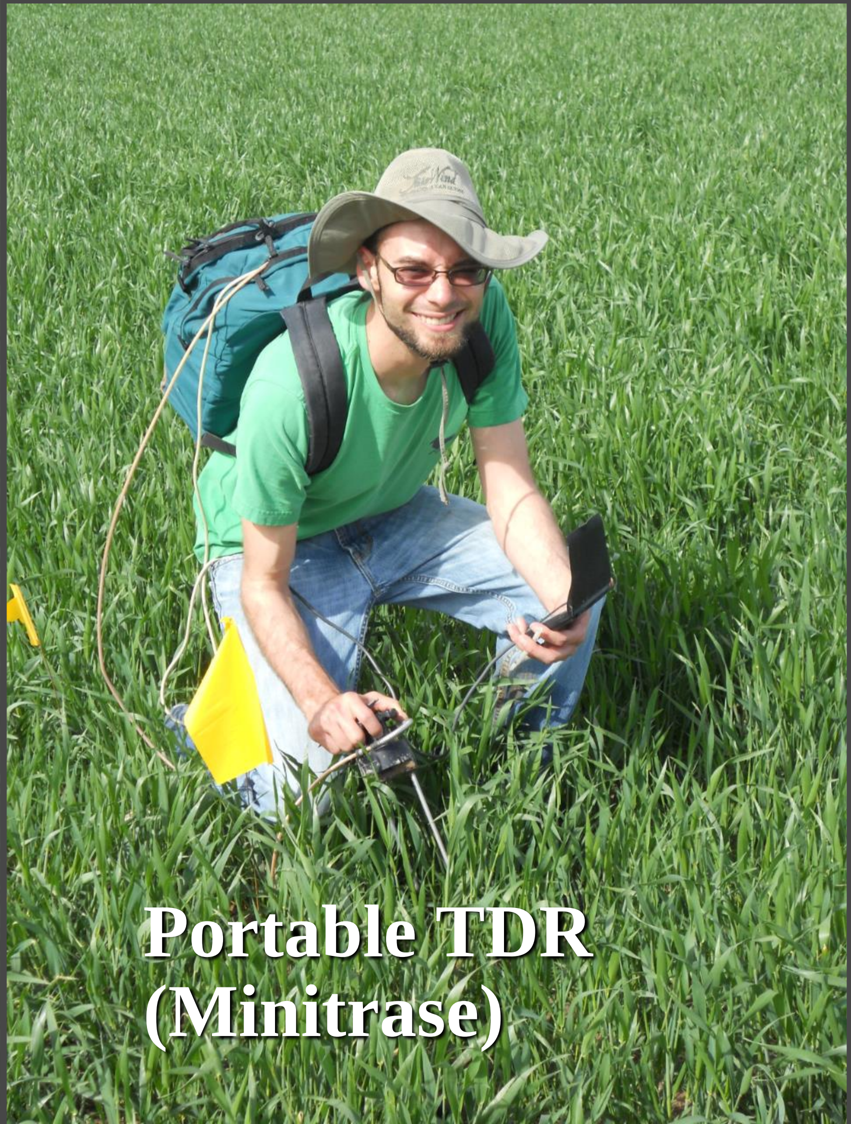
Drip hose to individual rows

Irrigation

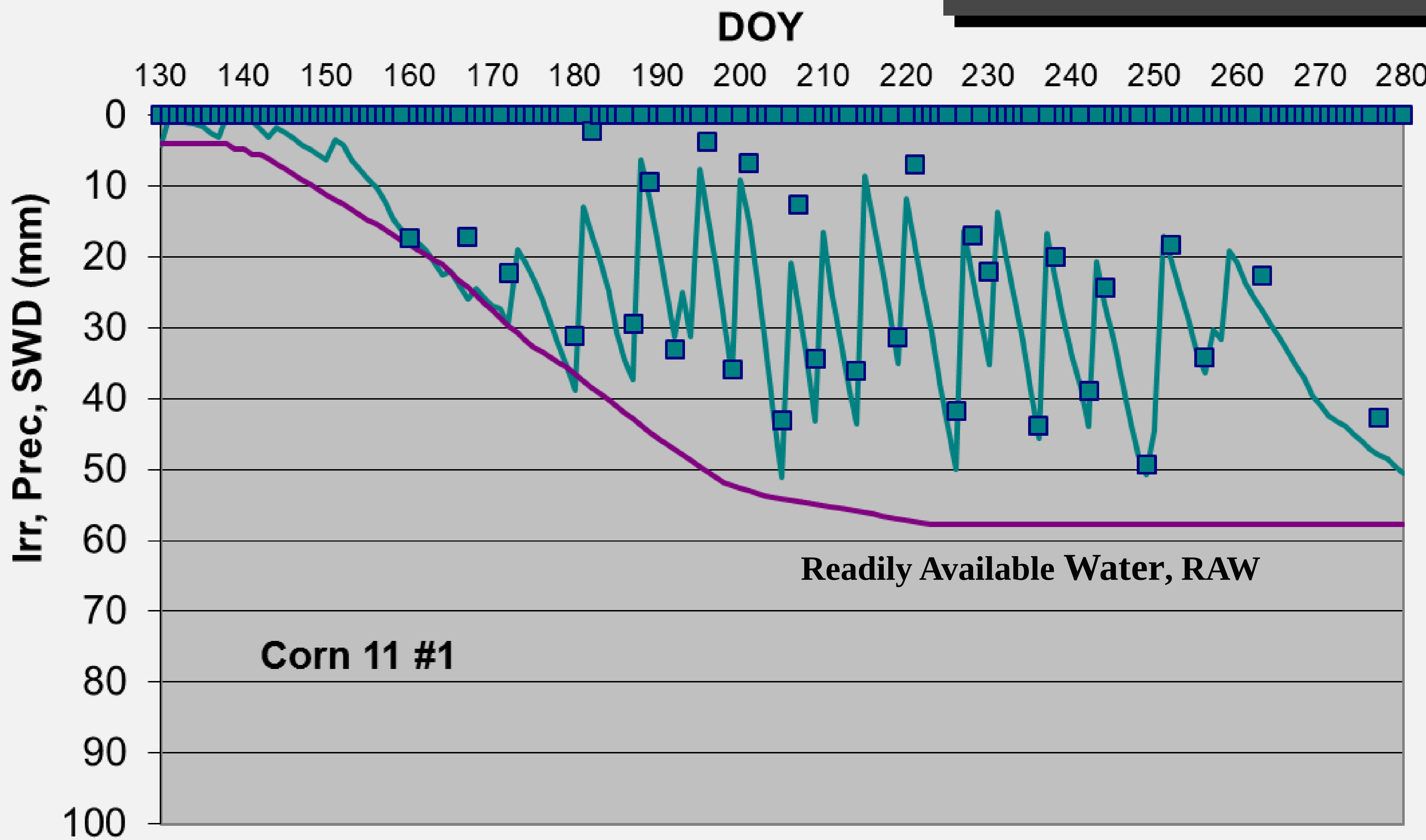


Corn 11
Cumulative Irrigation Applications (*mm*)
Tmnt 1
Tmnt 2
Tmnt 3
Tmnt 4
Tmnt 5
Tmnt 6
In-Season Precipitation = 200 mm
Irrigation Applications (mm)
0
100
200
300
400
500
600
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
DOY

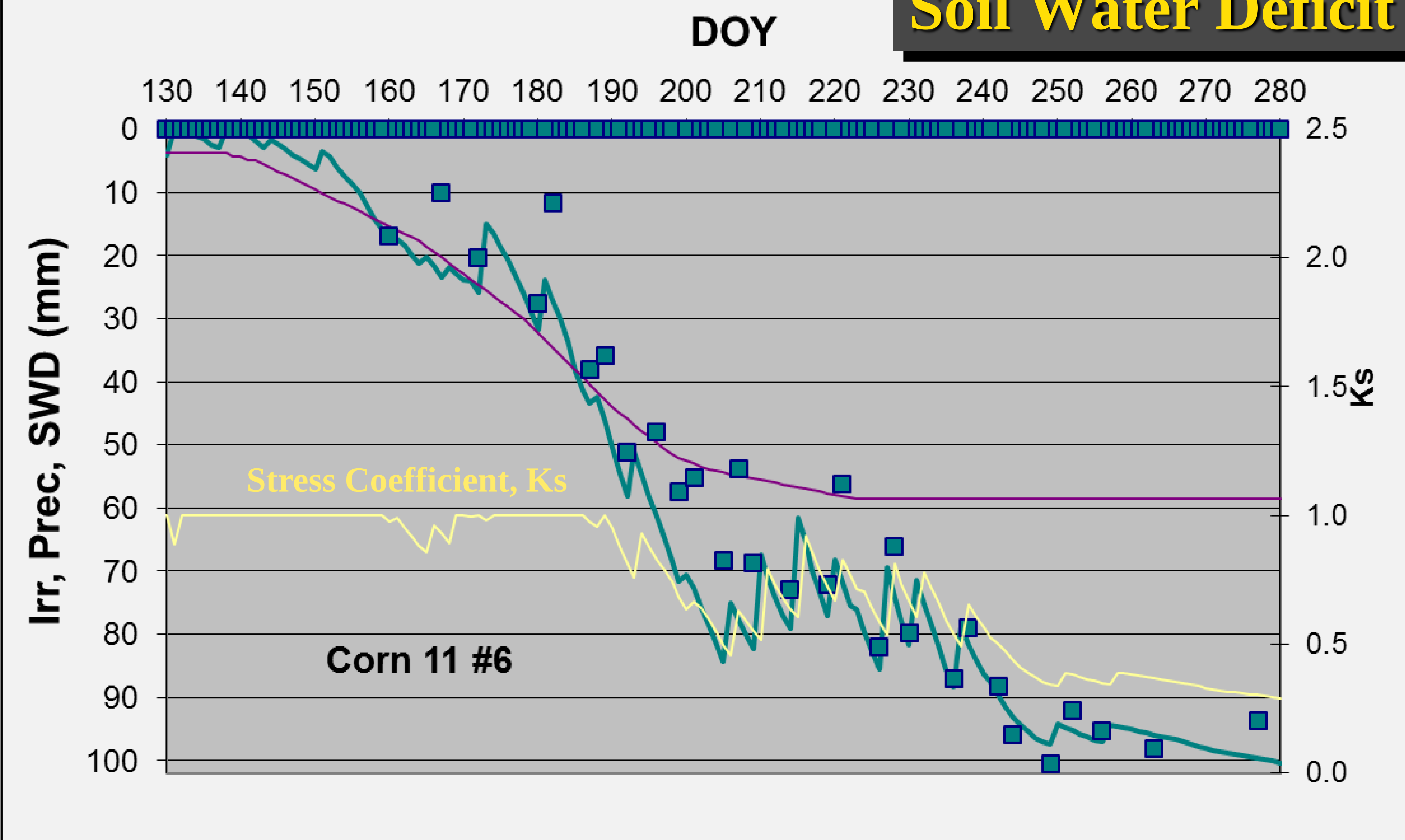
Soil Water Content



Soil Water Deficit



Soil Water Deficit



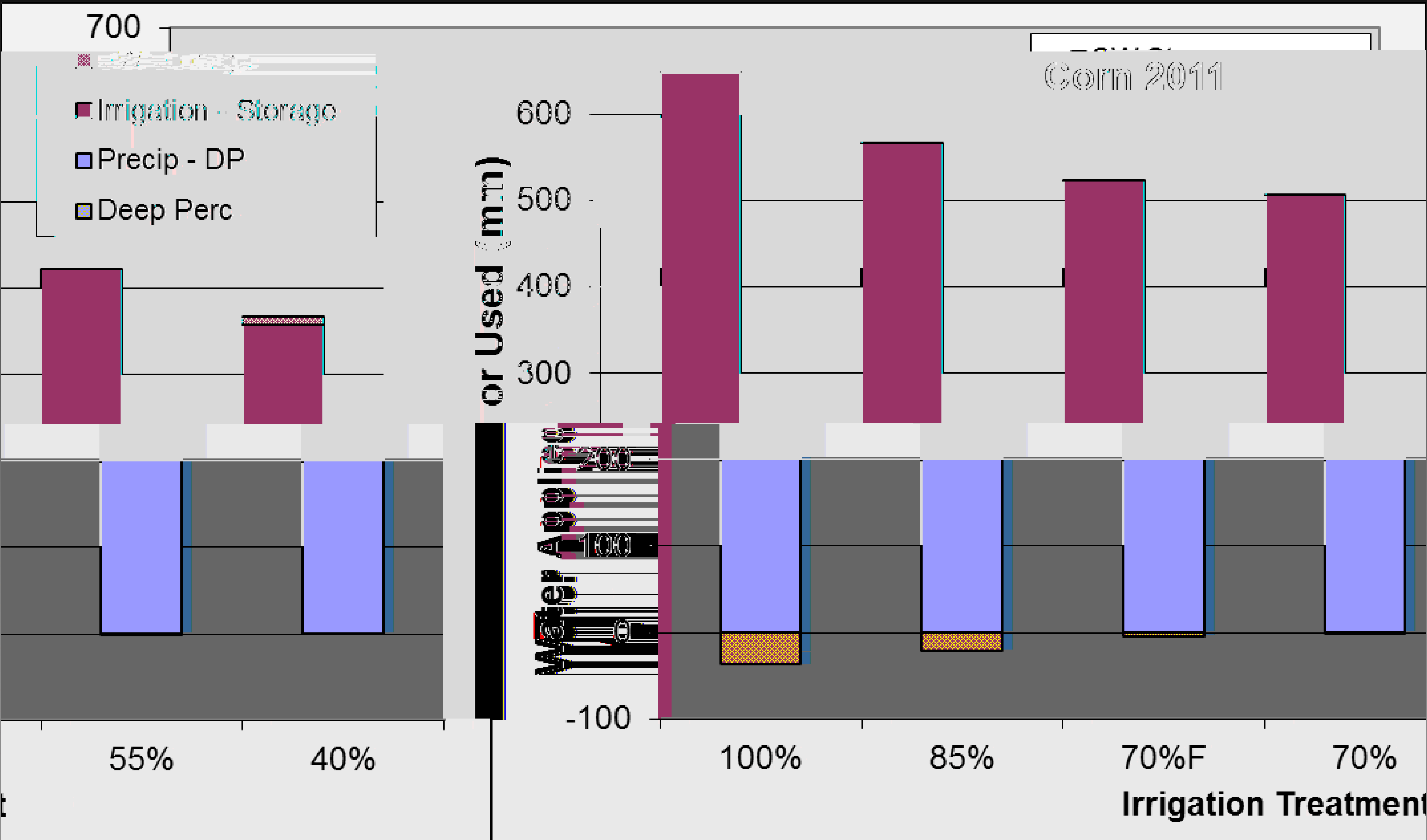
Reference ET
(to extrapolate results to other years and sites)

Water Balance Spreadsheet

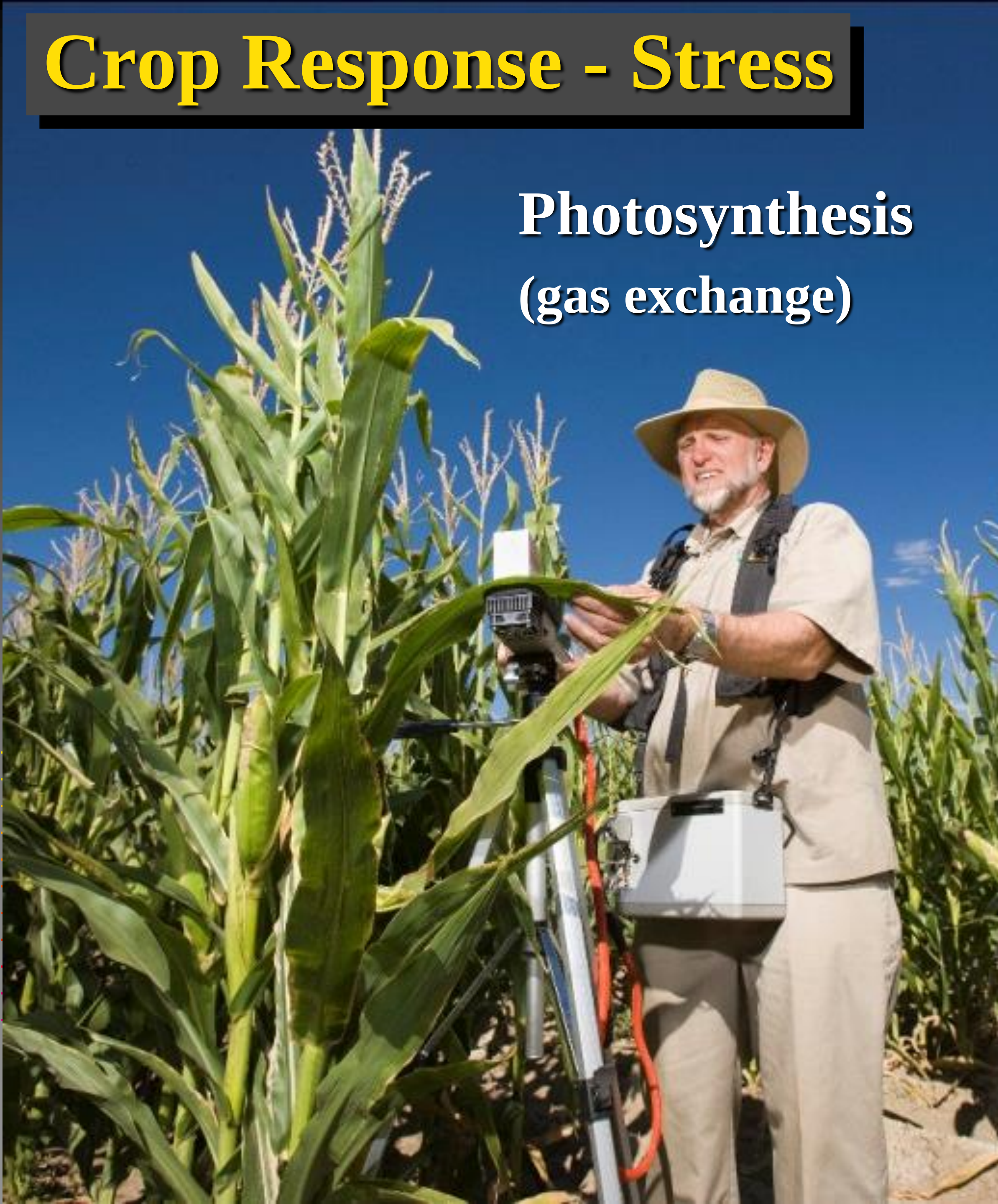
FAO 56

Irrigation Schedule | **Corn** | **Tmnt 1** | **100** %

Date		1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May	9-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	18-May
DOY		121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138
Stage of Growth				Planting															
Root Zone Depth	mm	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Canopy Cover	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kcb (Table)		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Kcb (CC)		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Kcb (selection)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kcb (Select)		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Ks		1.00	0.36	0.30	0.23	0.19	0.14	0.10	1.00	1.00	1.00	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Kcb (Select) * Ks		0.15	0.05	0.04	0.04	0.03	0.02	0.01	0.15	0.15	0.15	0.13	0.15	0.15	0.15	0.15	0.15	0.15	0.15
ETr (LIRF)	mm/d	4.11	4.15	5.16	5.10	6.63	6.46	8.06	8.30	10.79	7.94	0.59	1.19	5.74	1.93	2.55	5.81	3.10	1.09
Tc (Kcb Select)	mm/d	0.6	0.2	0.2	0.2	0.2	0.1	0.1	1.2	1.6	1.2	0.1	0.2	0.9	0.3	0.4	0.9	0.5	0.2
Cum Tc (Kcb select)	mm	0.0	0.2	0.5	0.6	0.8	0.9	1.1	2.3	3.9	5.1	5.2	5.4	6.2	6.5	6.9	7.8	8.3	8.4
Cum ETc (Kcb Select	mm	1	1	1	1	1	2	6	7	9	10	19	20	21	21	22	22	23	32
ETc (BR)	mm/d	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Kc Cal (BR/ETr)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.01
Cum ETc (BR)	mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Precip	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.0	16.0	0.0	0.0	0.0	0.0	0.0	15.0
Eff Precip	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.6	14.8	0.0	0.0	0.0	0.0	0.0	6.6
Cum Eff Prec	mm	0	0	0	0	0	0	0	0	0	0	23.6	38.4096	38.4096	38.4096	38.4096	38.4096	38.4096	45.0096
Proj SWD - 1050 mm	mm	75	75.2	75.5	75.6	75.8	75.9	51.9	53.1	54.7	55.9	32.4	17.8	18.6	18.9	19.3	20.2	20.6	14.2
Meas. SWD - 1050 m	mm																		
Proj SWD - RZ	mm	6.0	6.2	6.5	6.6	6.8	6.9	0.0	1.2	2.9	4.1	0.0	0.0	0.9	1.1	1.5	2.4	2.9	0.0
Measured SWD - RZ	mm																		
Target Irrigation	mm																		
Actual Irrigation	mm	0.0	0.0	0.0	0.0	0.0	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Effect. Irrig	mm	0.0	0.0	0.0	0.0	0.0	0.0	24.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proj Deep Perc	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cumulative Irr	mm	0	0	0	0	0	0	29	29	29	29	29	29	29	29	29	29	29	29
Cumulative Eff Irr	mm	0	0	0	0	0	0	24	24	24	24	24	24	24	24	24	24	24	24
Cum Irr + Prec	mm	0	0	0	0	0	0	29	29	29	29	61	77	77	77	77	77	77	92
Cum Eff Irr + Prec	mm	0	0	0	0	0	0	24	24	24	24	48	63	63	63	63	63	63	69
Cum Deep Perc	mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWD (15)	%	0.0																	
SWD (30)	%																		
SWD (60)	%																		
SWD (90)	%																		
FC (RZ)	mm	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6


Corn 2011
Irrigation - Storage
Precip - DP
Deep Perc
700
600
500
400
300
200
100
0
-100
or Used (mm)
55%
40%
100%
85%
70%F
70%
Irrigation Treatment

Crop Response - Stress



Crop Response - Stress

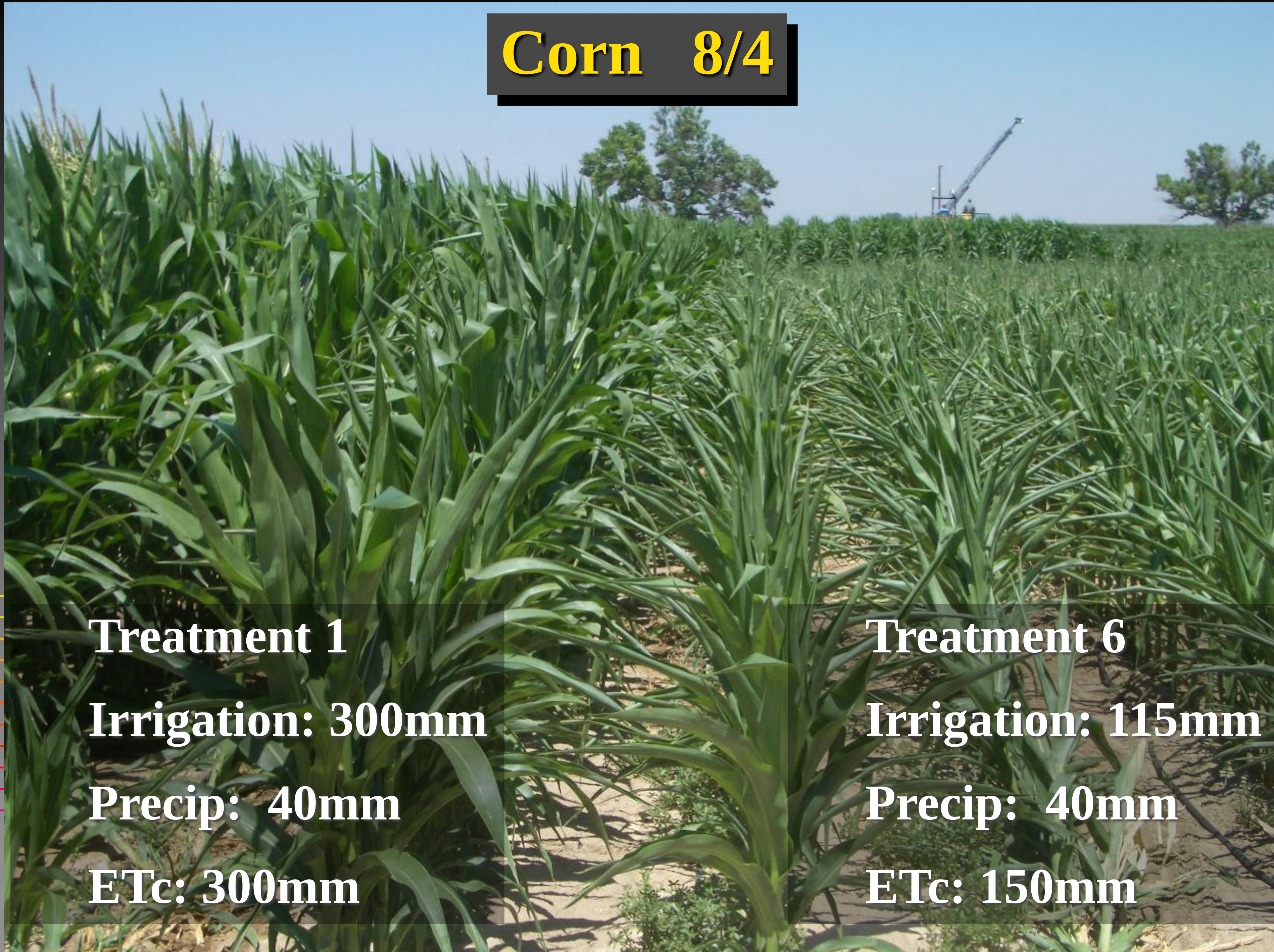
- Fractional Ground Cover
- Reflectance
- Canopy Temperature
- PAR Absorption

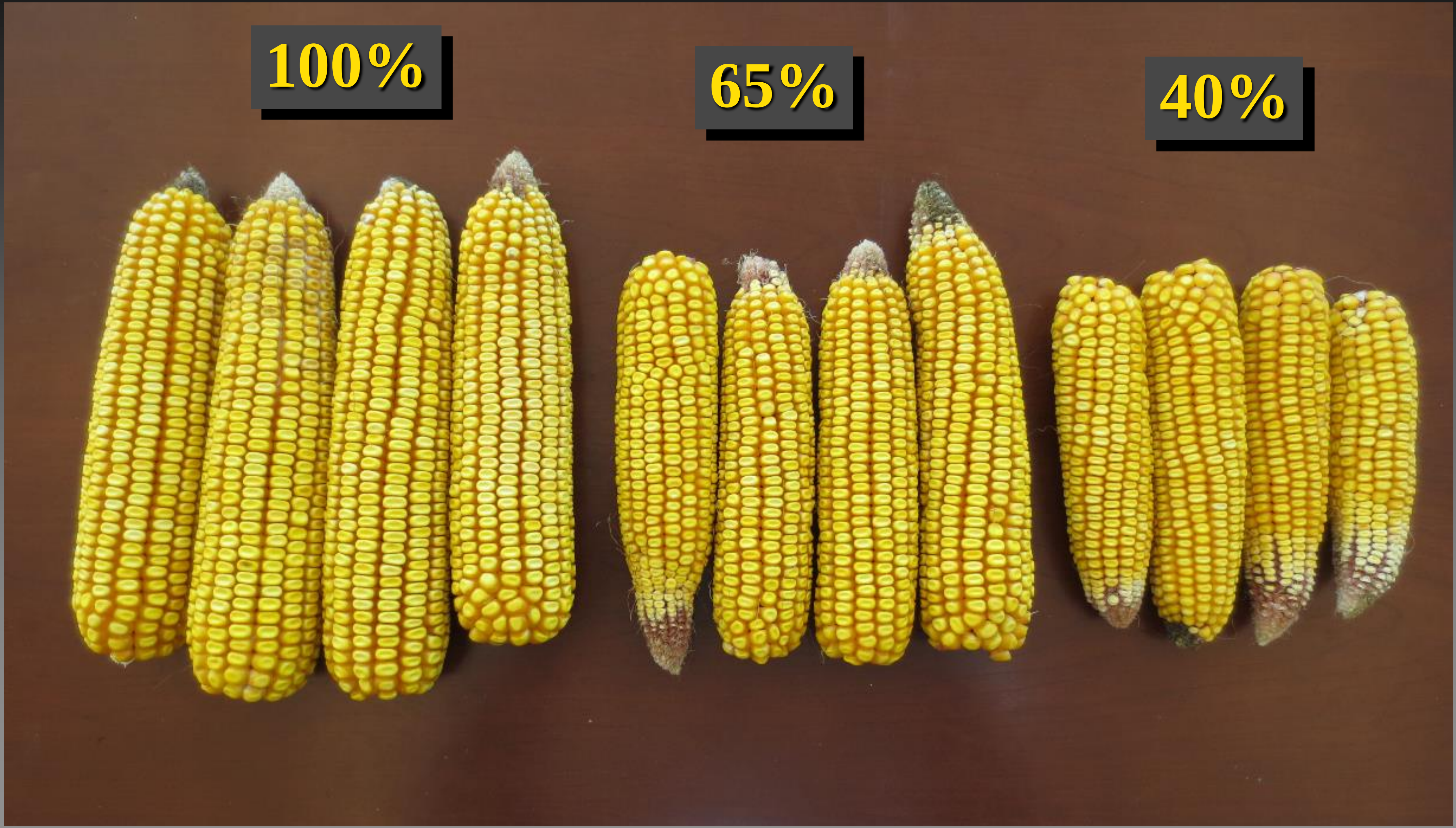
High-clearance
Reflectance Tractor

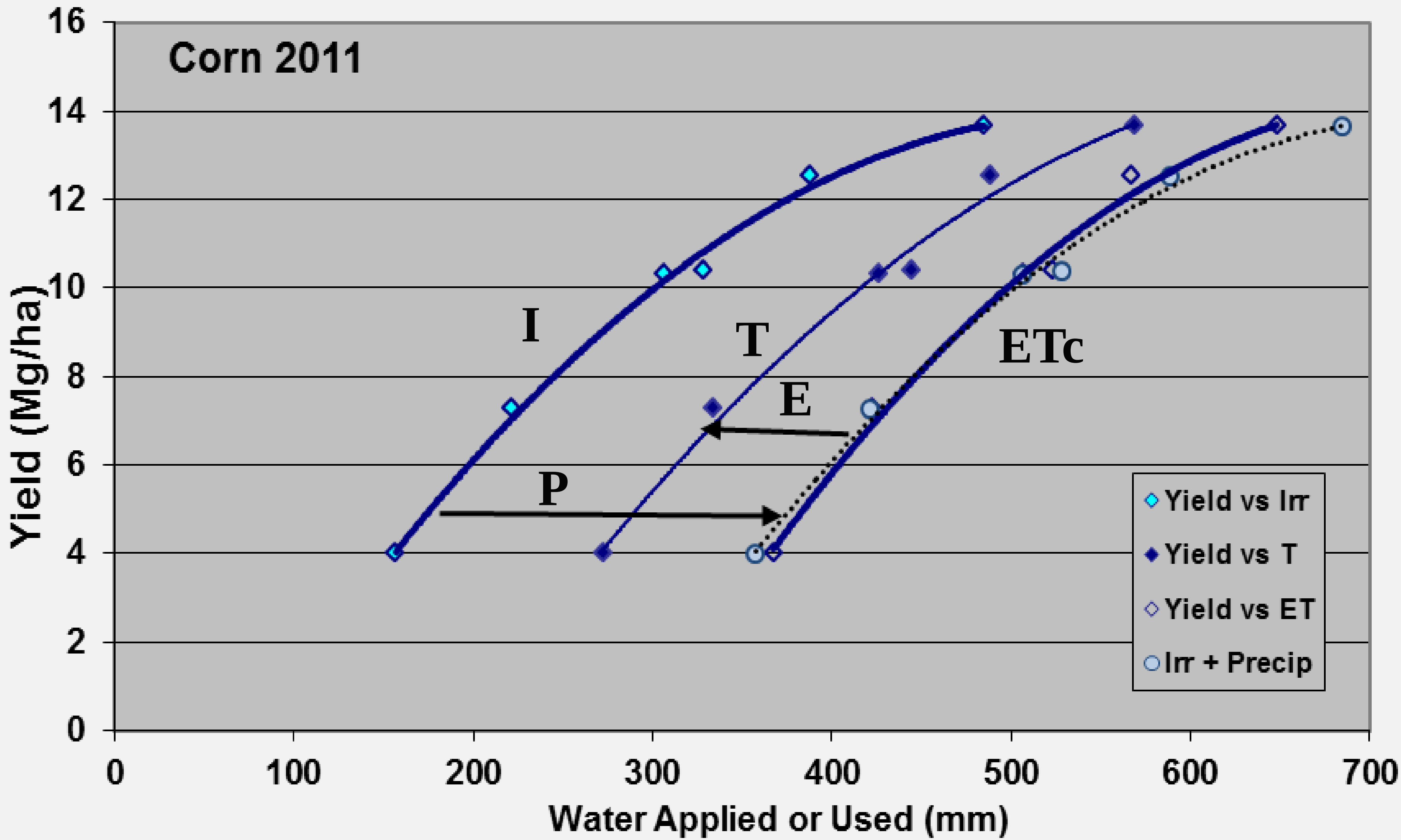
Spectroradiometers
Thermal Camera, IRT

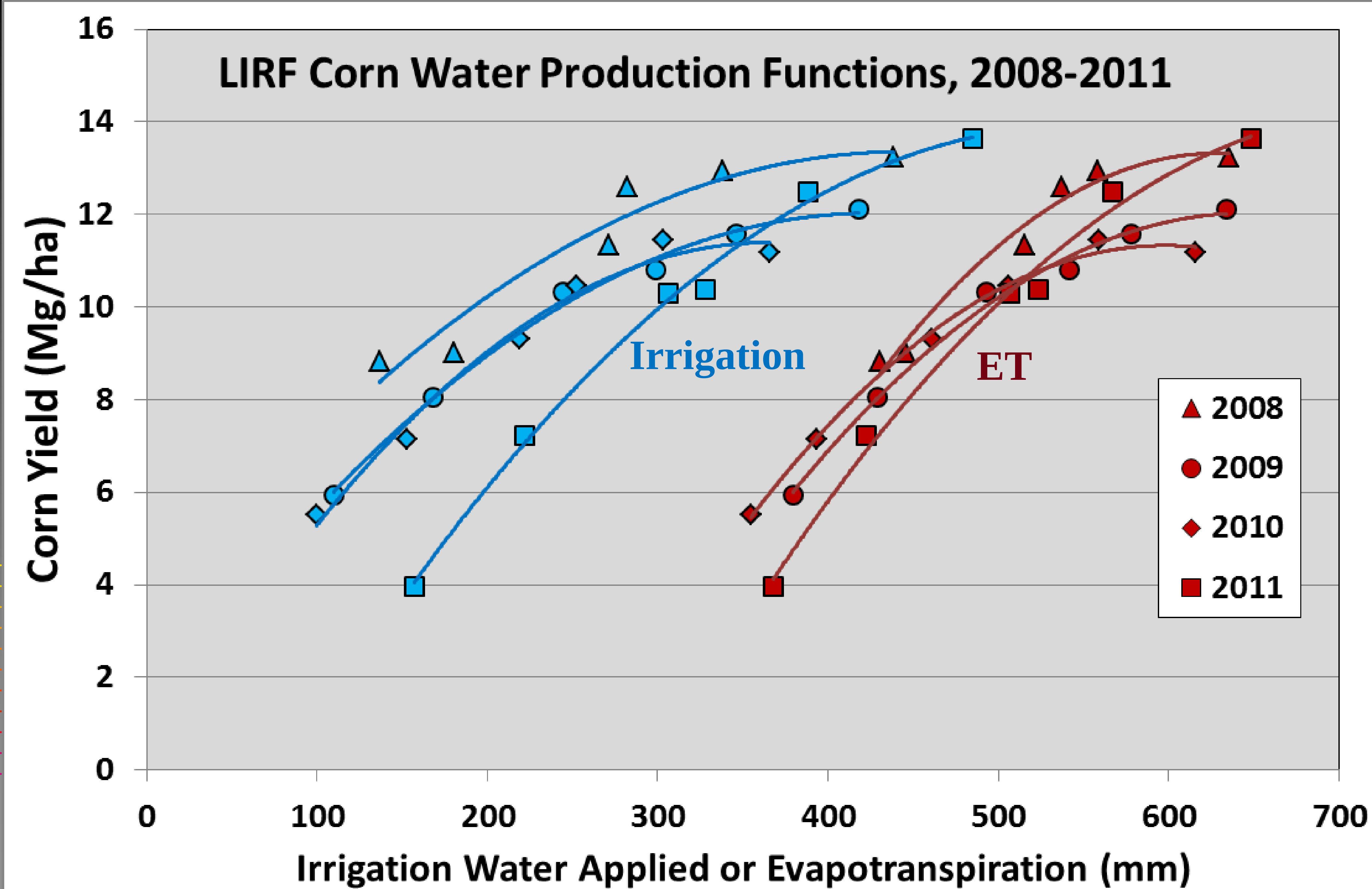
Fixed IRTs


LIRF 2008

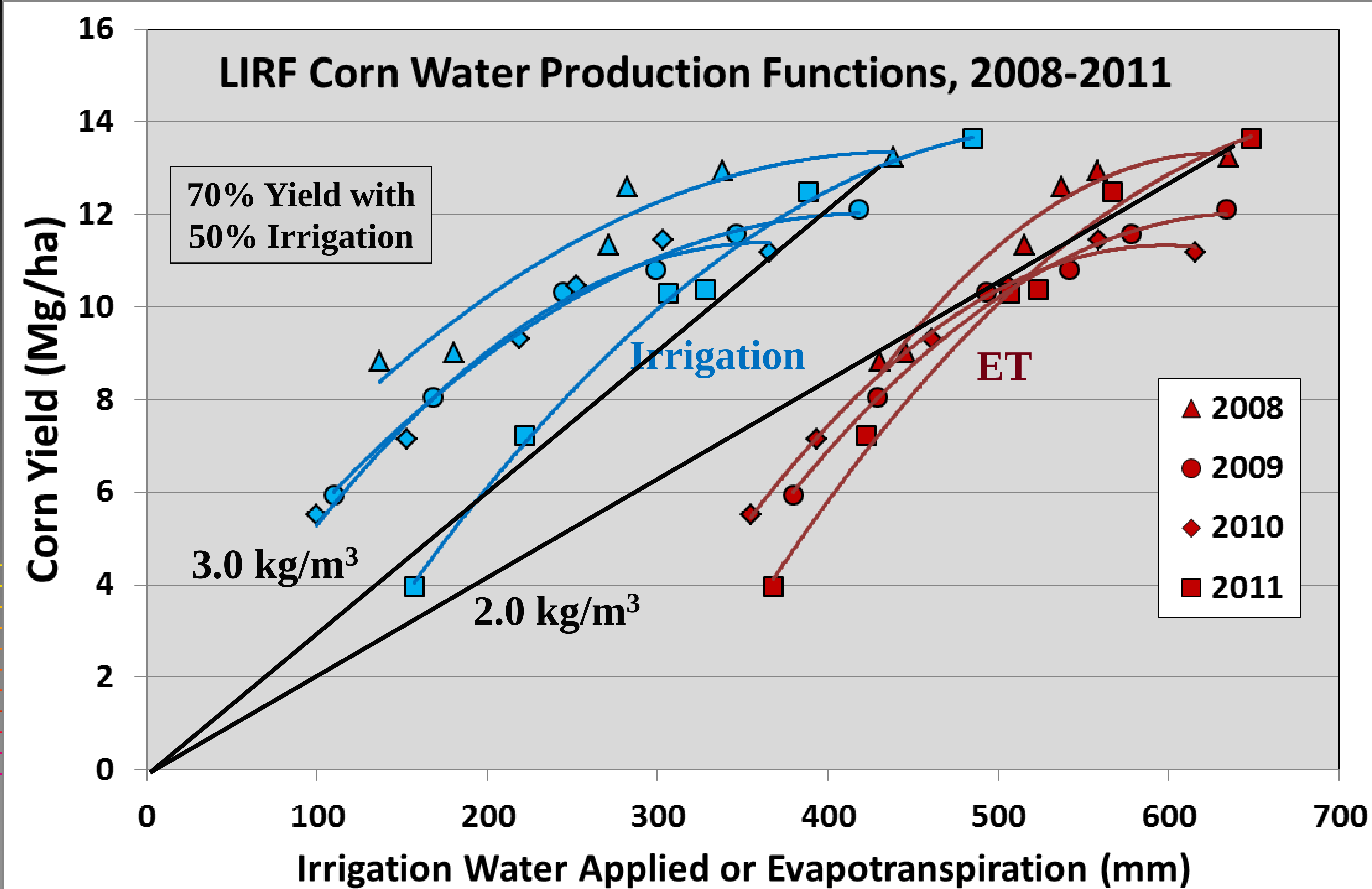

Corn 8/4
Treatment 1
Irrigation: 300mm
Precip: 40mm
ETc: 300mm
Treatment 6
Irrigation: 115mm
Precip: 40mm
ETc: 150mm

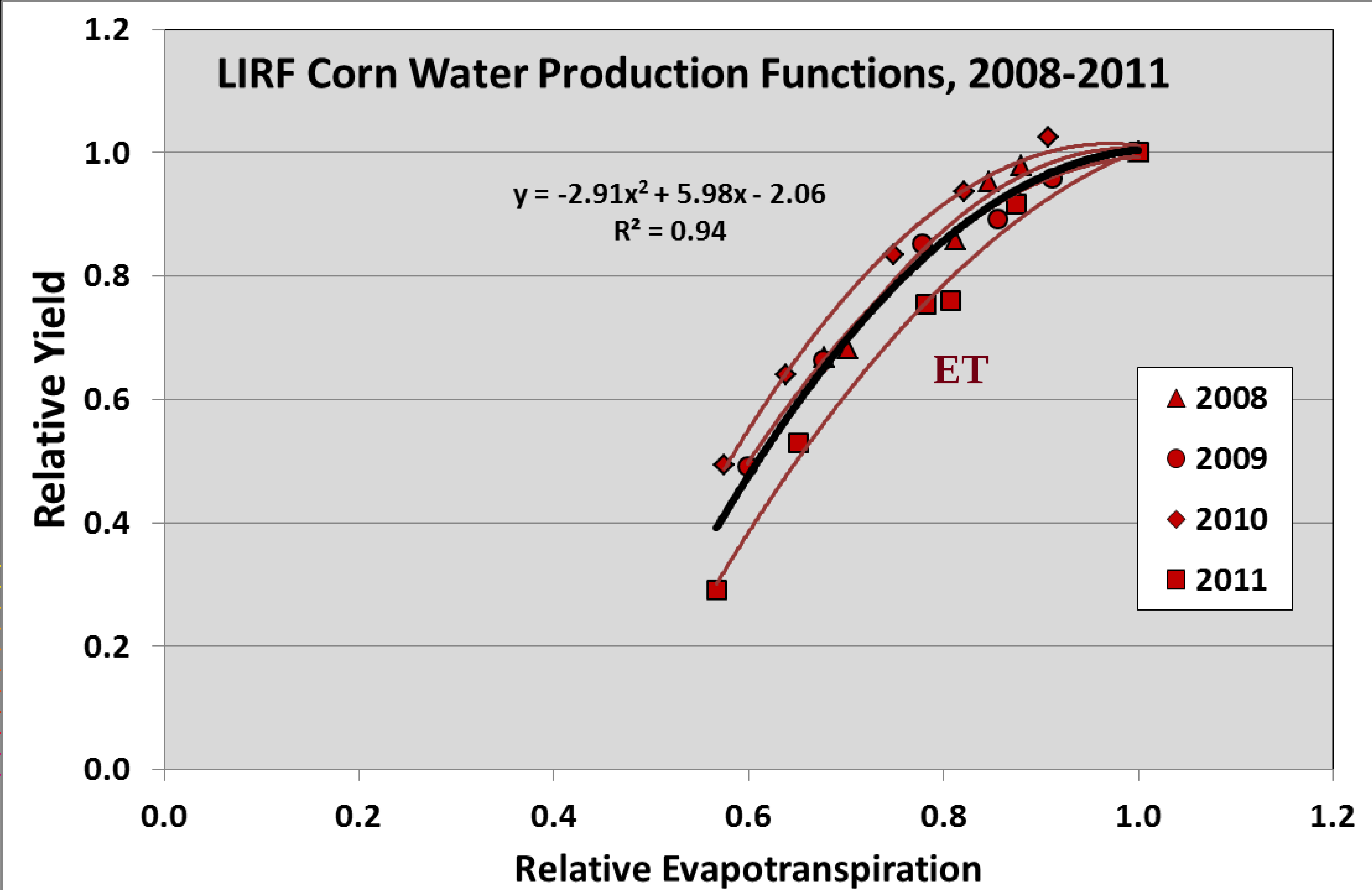

100%
65%
40%


Corn 2011
16
14
12
10
8
6
4
2
0
Yield (Mg/ha)
0
100
200
300
400
500
600
700
Water Applied or Used (mm)
I
T
ETc
E
P
Yield vs Irr
Yield vs T
Yield vs ET
Irr + Precip

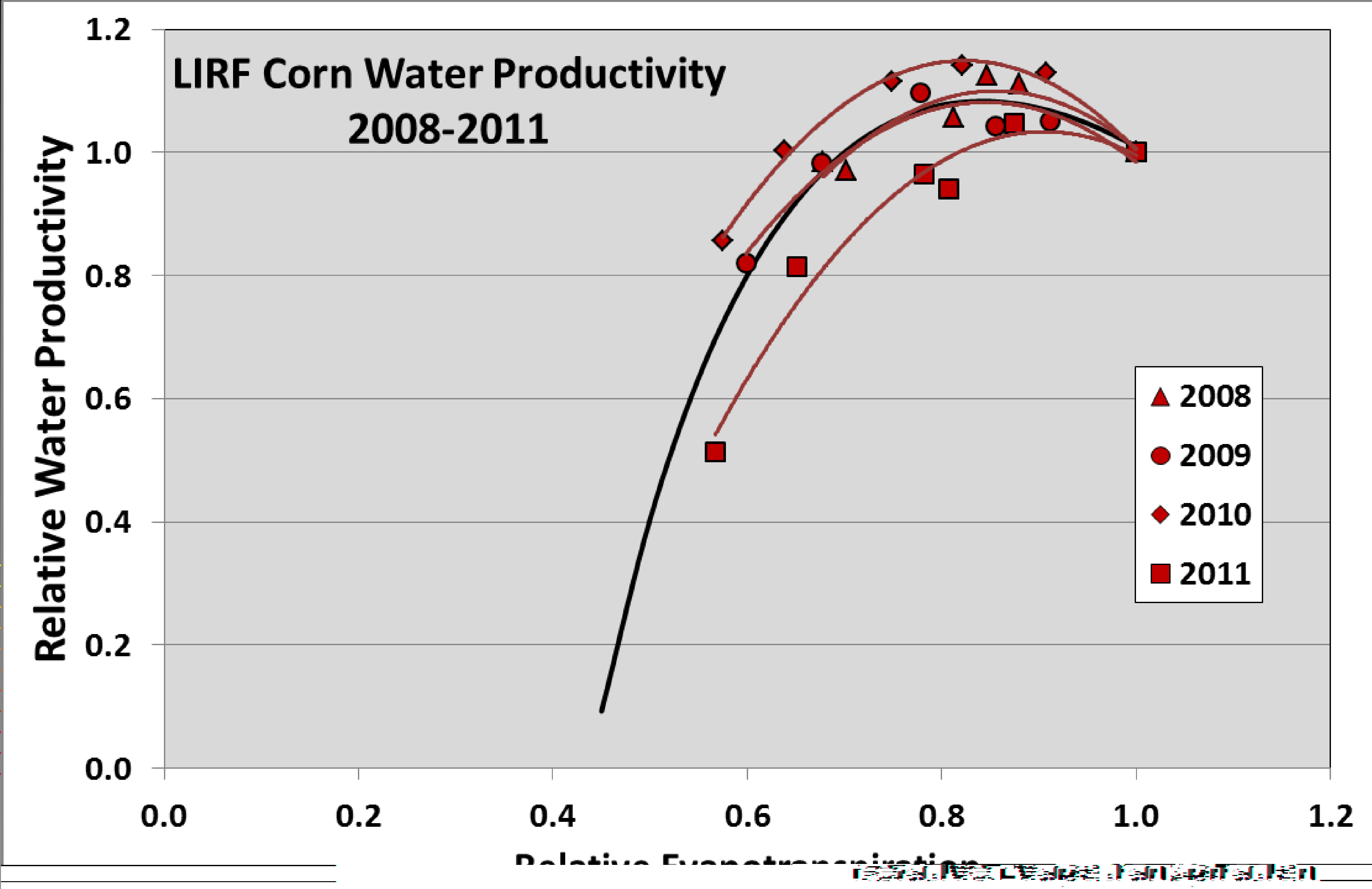


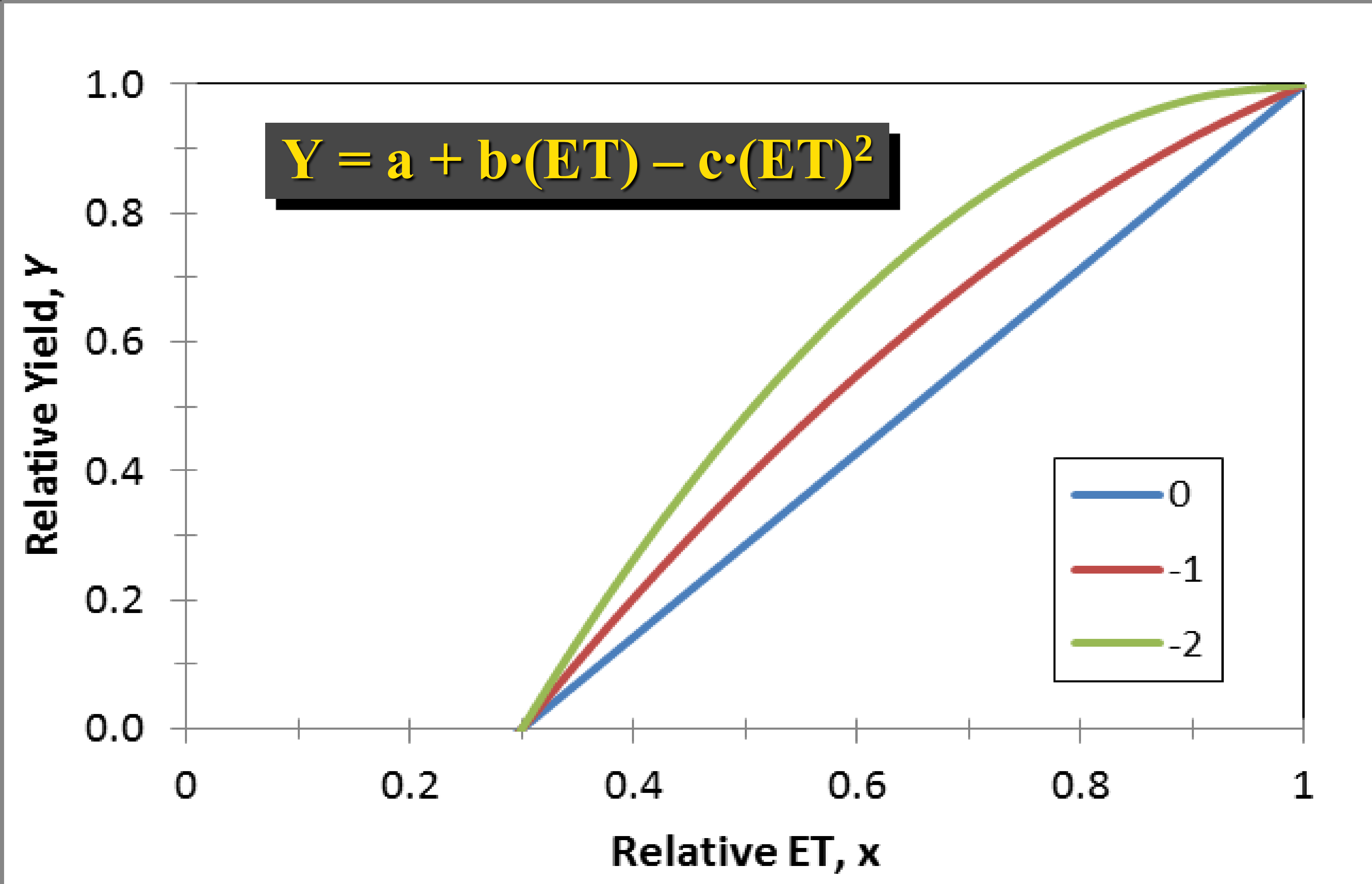
LIRF Corn Water Production Functions, 2008-2011
Corn Yield (Mg/ha)
Irrigation Water Applied or Evapotranspiration (mm)
Irrigation
ET
2008
2009
2010
2011
0
2
4
6
8
10
12
14
16
0
100
200
300
400
500
600
700


LIRF Corn Water Production Functions, 2008-2011
70% Yield with
50% Irrigation
Irrigation
ET
3.0 kg/m³
2.0 kg/m³
2008
2009
2010
2011
Corn Yield (Mg/ha)
Irrigation Water Applied or Evapotranspiration (mm)
0
2
4
6
8
10
12
14
16
0
100
200
300
400
500
600
700



LIRF Corn Water Production Functions, 2008-2011
y = -2.91x² + 5.98x - 2.06
R² = 0.94
ET
2008
2009
2010
2011
Relative Yield
Relative Evapotranspiration
0.0
0.2
0.4
0.6
0.8
1.0
1.2


LIRF Corn Water Productivity
2008-2011
Relative Water Productivity
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2008
2009
2010
2011



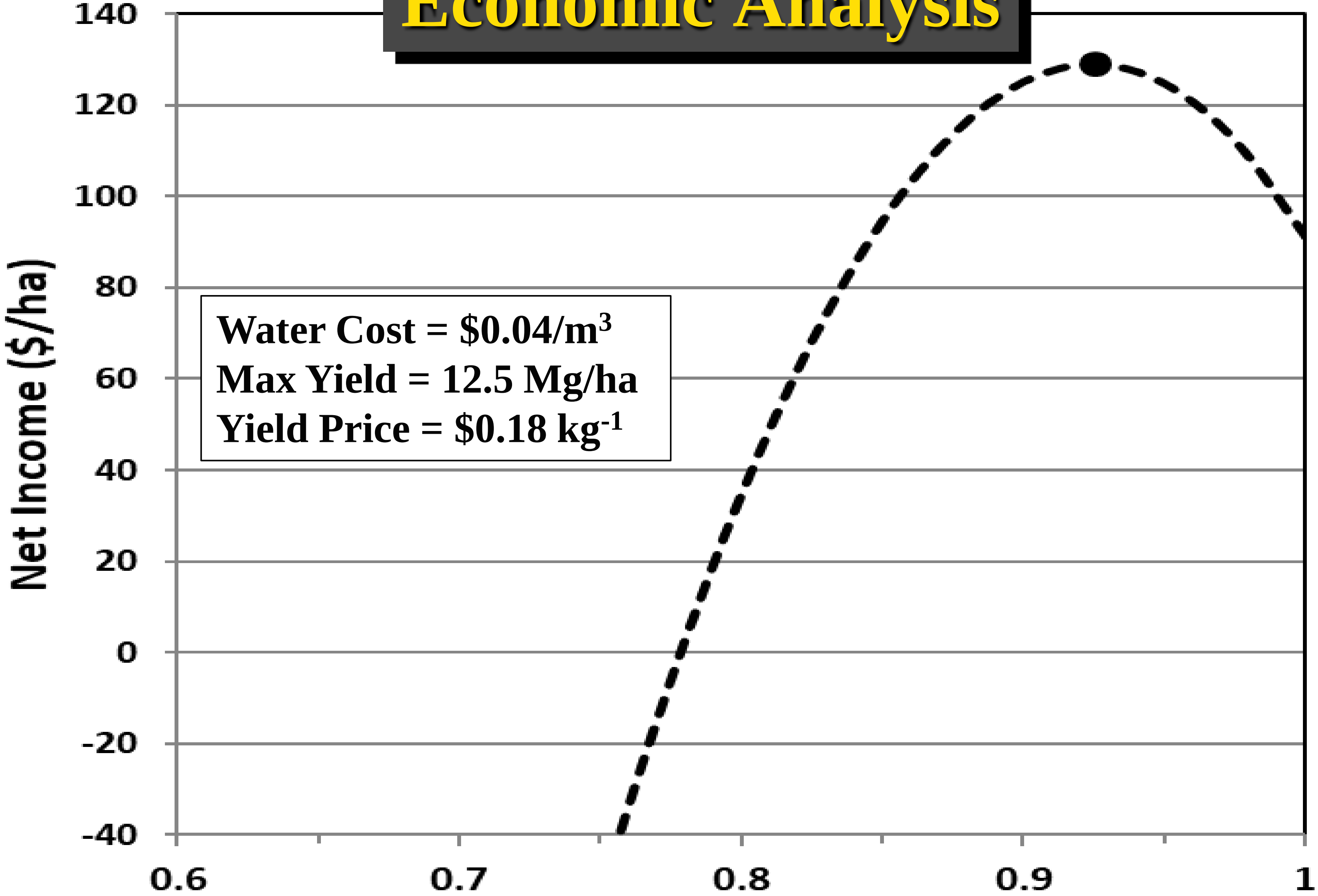
Y = a + b·(ET) – c·(ET)²
1.0
0.8
0.6
0.4
0.2
0.0
Relative Yield, Y
0
0.2
0.4
0.6
0.8
1
Relative ET, x
0
-1
-2

Economic Model

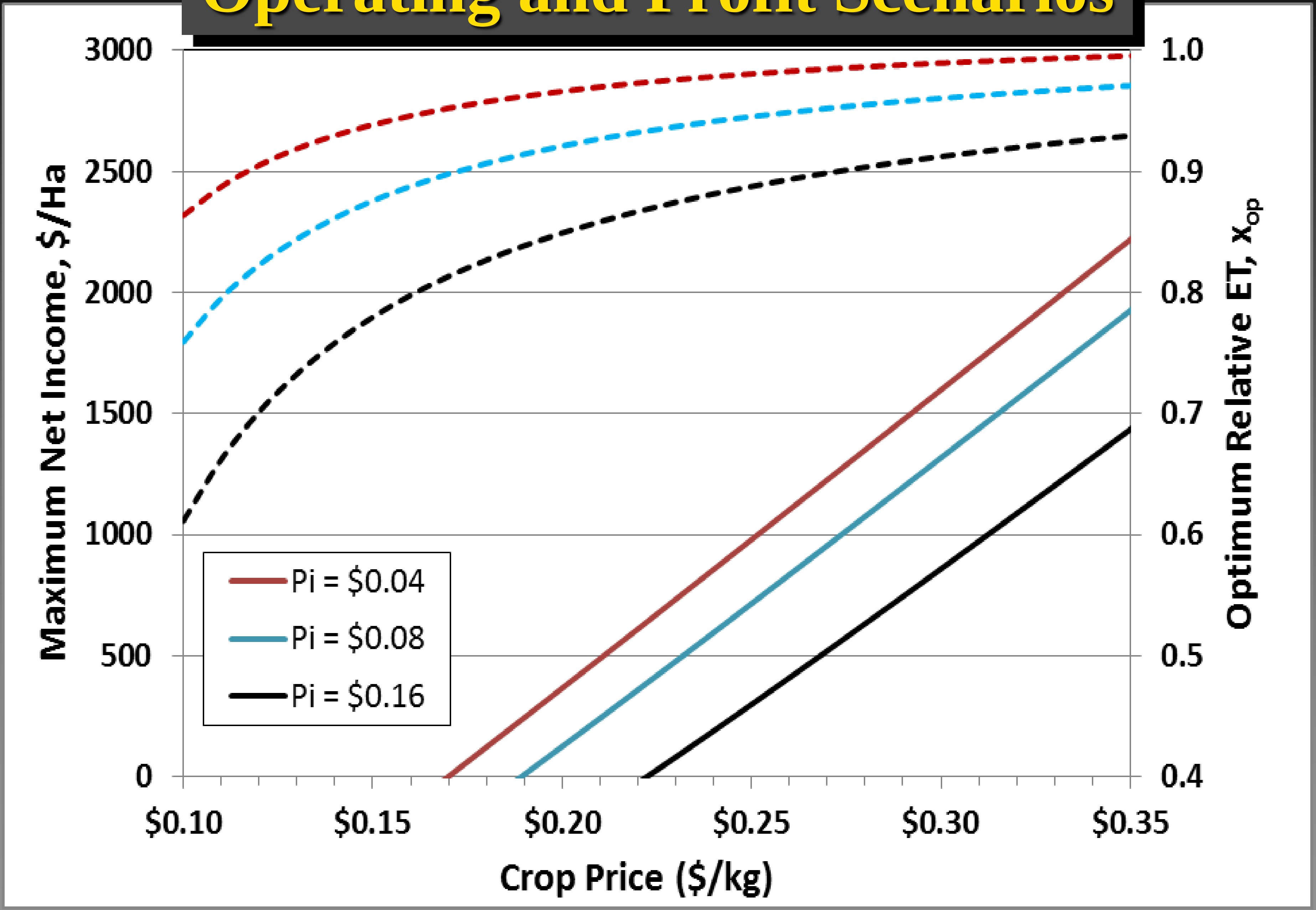
$$NI = Py * Y - Pps - Pp * Y - Pi*I_S$$

NI = the net income from irrigated crop production ($\$ ha^{-1}$)
Py = the unit price of crop yield ($/kg)
Pp = the variable cost of production, not including irrigation ($\$ kg^{-1} ha^{-1}$)
Pps = the fixed cost of production ($\$ ha^{-1}$)
Pi = the variable cost of applied irrigation water ($\$ m^{-3}$)
Y = projected crop yield for the ET target ($kg\ ha^{-1}$)
I_S = the amount of irrigation water applied ($m^3\ ha^{-1}$)

Economic Analysis



Operating and Profit Scenarios



Summary: Methodology

- Use “Representative” agronomy
- Carefully control and measure water inputs and losses, and crop water status
- Measure (estimate) crop ET

Summary: Interpretation

- Develop WPF based on ET
- For our maize, ET WPFs were curviliner.
- Include economic analysis (WP is not the answer)
- Publish datasets

Water Management Research Unit

Fort Collins, CO

USDA ARS United States Department of Agriculture Agricultural Research Service

Thank you

Limited Irrigation Research Farm (LIRF)

A Field Laboratory for Water Management Research