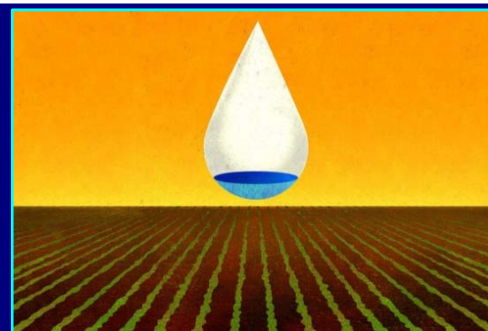

Resource-Efficient Irrigation of Field Crops: from Principles to Field Practice

2018 Agricultural Growers Meeting

Susanville, CA – March 1st, 2018

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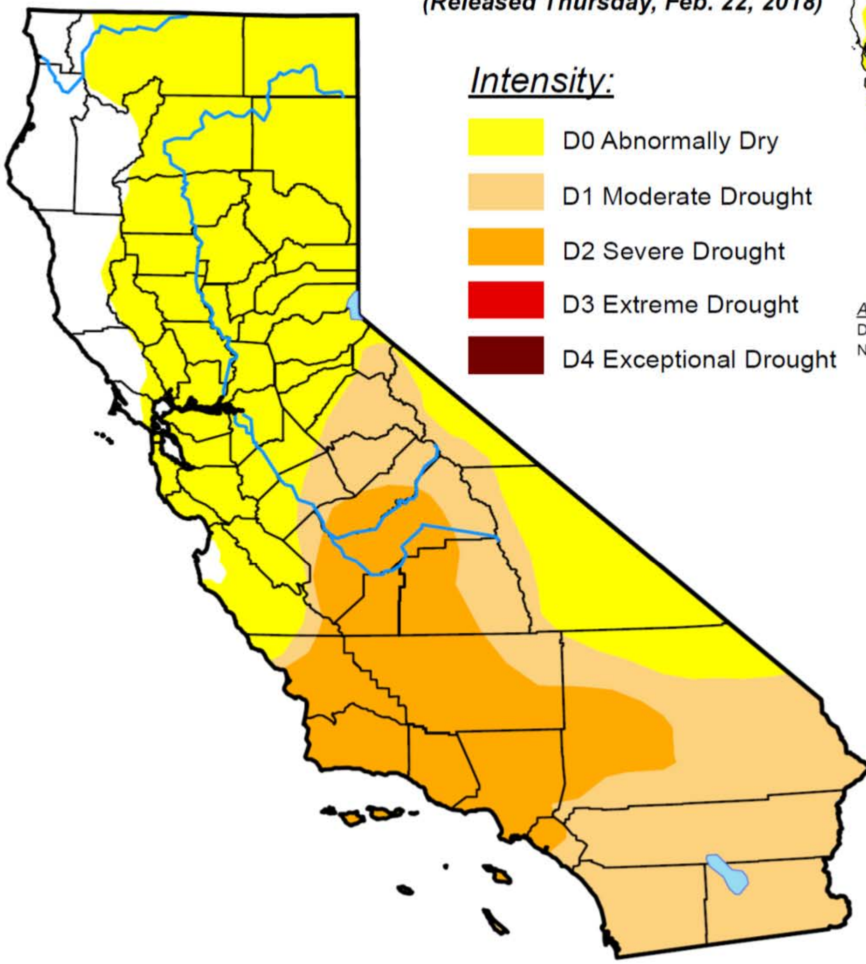
OBJECTIVES

1) Give a Snapshot on Water Supply and Drought
2) Review the Principles of Efficient Irrigation
3) Field Practice: What it takes to be efficient?
4) Provide Information on Water & Energy Requirements
5) Indicate How Technology Can Help

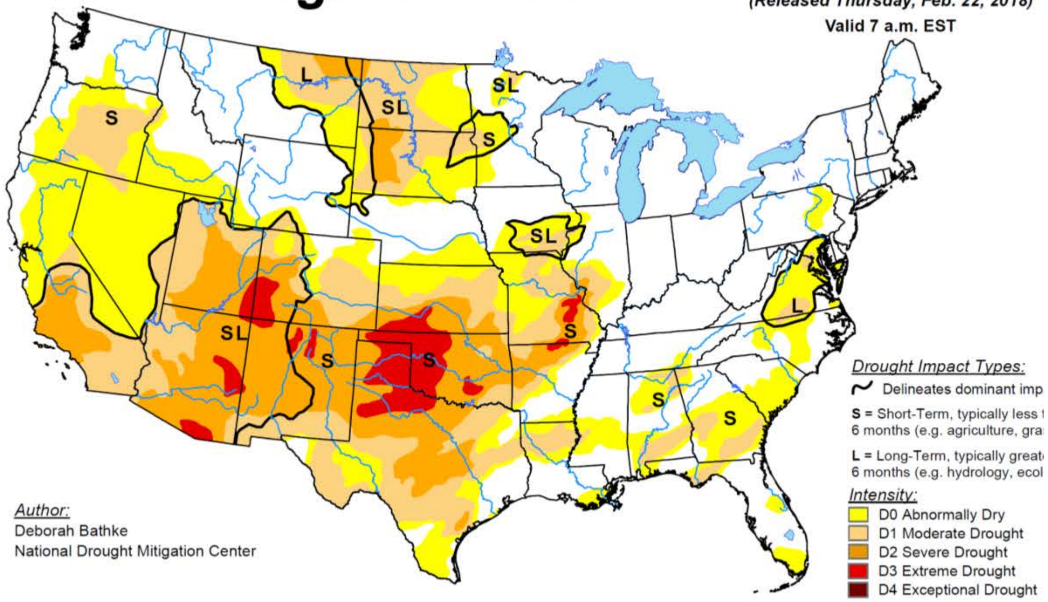
U.S. Drought Monitor
California

February 20, 2018
(Released Thursday, Feb. 22, 2018)

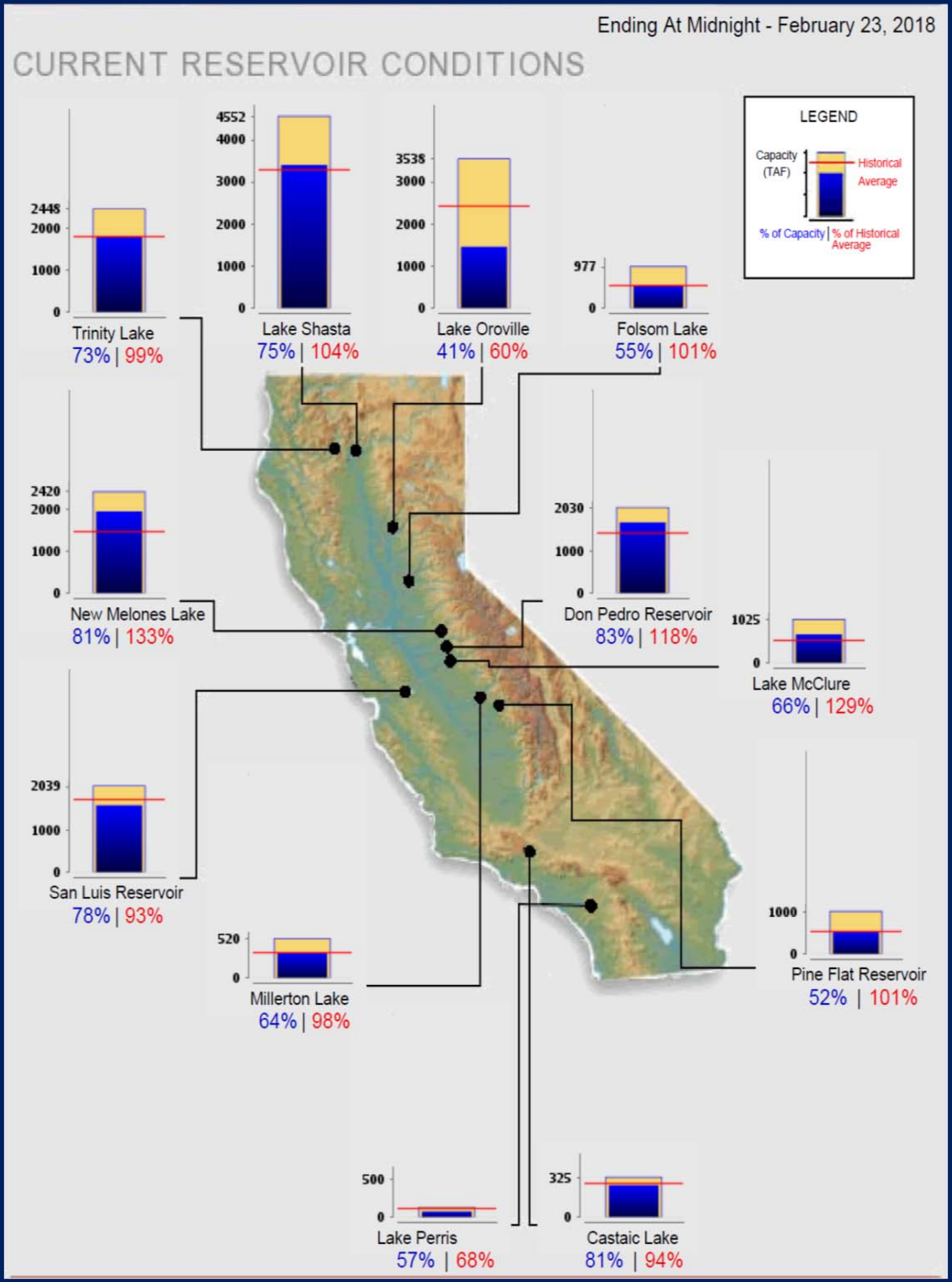


U.S. Drought Monitor

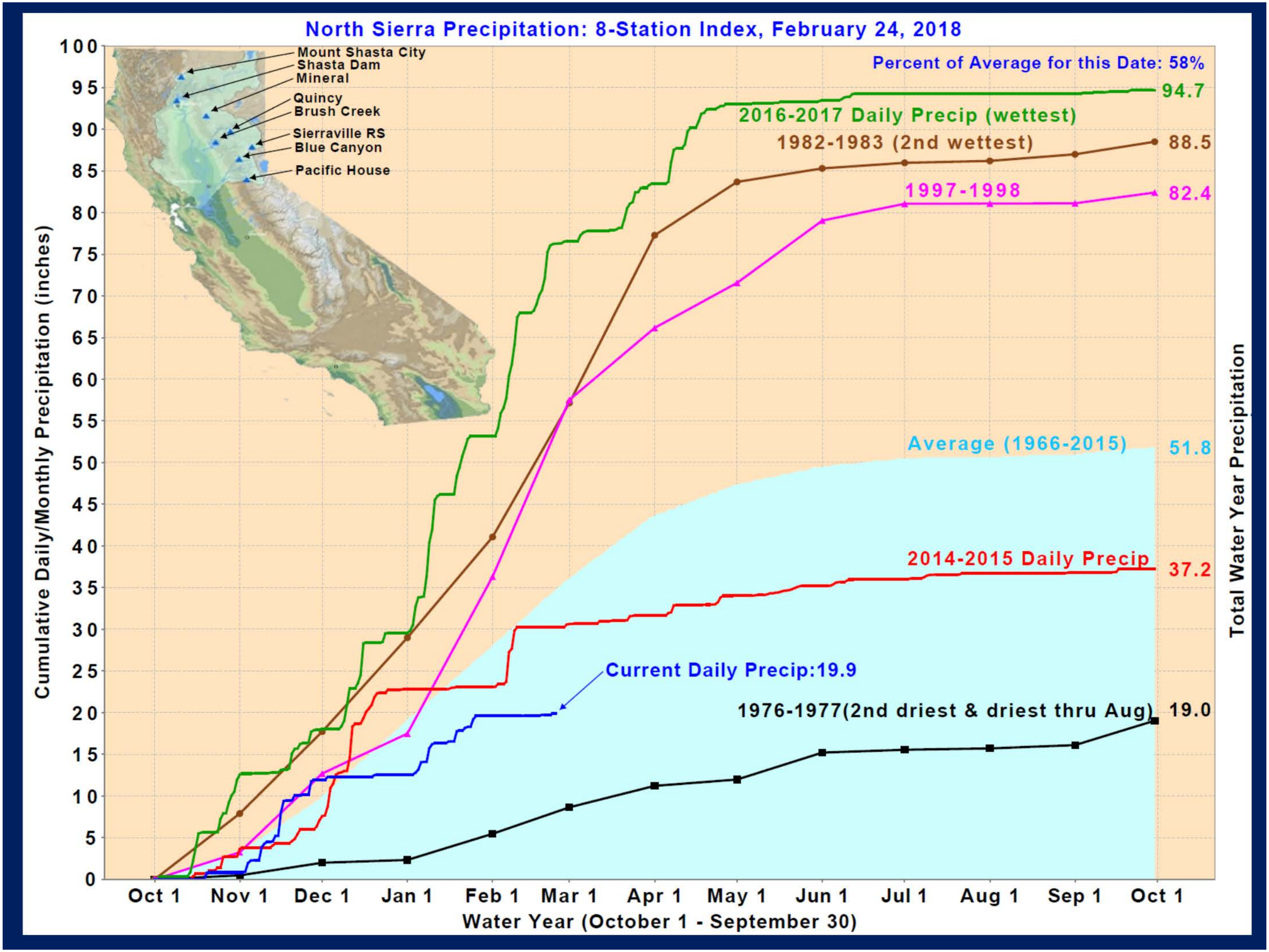
February 20, 2018
(Released Thursday, Feb. 22, 2018)
Valid 7 a.m. EST



Author:
Deborah Bathke
National Drought Mitigation Center



Ending At Midnight - February 23, 2018
CURRENT RESERVOIR CONDITIONS
LEGEND
Capacity (TAF)
Historical Average
% of Capacity | % of Historical Average
Trinity Lake
73% | 99%
Lake Shasta
75% | 104%
Lake Oroville
41% | 60%
Folsom Lake
55% | 101%
New Melones Lake
81% | 133%
Don Pedro Reservoir
83% | 118%
Lake McClure
66% | 129%
San Luis Reservoir
78% | 93%
Millerton Lake
64% | 98%
Pine Flat Reservoir
52% | 101%
Lake Perris
57% | 68%
Castaic Lake
81% | 94%



North Sierra Precipitation: 8-Station Index, February 24, 2018
Percent of Average for this Date: 58%
Mount Shasta City
Shasta Dam
Mineral
Quincy
Brush Creek
Sierraville RS
Blue Canyon
Pacific House
2016-2017 Daily Precip (wettest)
94.7
1982-1983 (2nd wettest)
88.5
1997-1998
82.4
Average (1966-2015)
51.8
2014-2015 Daily Precip
37.2
Current Daily Precip:19.9
1976-1977(2nd driest & driest thru Aug)
19.0
Cumulative Daily/Monthly Precipitation (inches)
Total Water Year Precipitation
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Oct 1
Nov 1
Dec 1
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Water Year (October 1 - September 30)

Beneficial is the water used for crop production & health

- ✓Transpiration (T) of water through the canopy
- ✓Application of fertilizers & nutrients, chemicals for pest & weeds control
- ✓Frost Protection & Canopy Cooling
- ✓Leaching salts + applic. of amendments (gypsum, humic/fulvic acids etc.)

$$Irr.Eff. = \frac{Water\ used\ by\ the\ crop\ for\ ET + Other\ Beneficial\ Uses}{Total\ water\ applied\ onto\ the\ field}$$

Water Applied to the field

- ✓Replenish Soil Moisture Depleted since the last irrigation
- ✓Soil Evaporation + Deep Percolation + Surface Runoff + Wind Drift
- ✓Leakages from pipes, canal, ditches + valves/gates stuck-open, wrong commands, operational losses, irrigation over-run, etc.
- ✓Pipe flushing + Screen cleaning & Filters back-flush
- ✓Pipe & hose chemical injection (keep the pipe system clean and functional)
- ✓Water draining out of pipes and hoses after irrigation shut-off (pulsing on-off)

Distribution Uniformity (D.U.) vs. Irrigation Efficiency (I.E.)

Distribution Uniformity:

is a number (%) describing how evenly water is distributed across the field/plants

Irrigation Efficiency:

is the fraction of the applied water that is beneficially used by the crop

EXAMPLE

2 gallons per tree in July

The trees will use every drop of the applied water

D.U. = 100%; I.E. = ~100%

200 gallons per tree in July

Trees will use only a fraction of the applied water

D.U. = 100%; I.E. << 100%

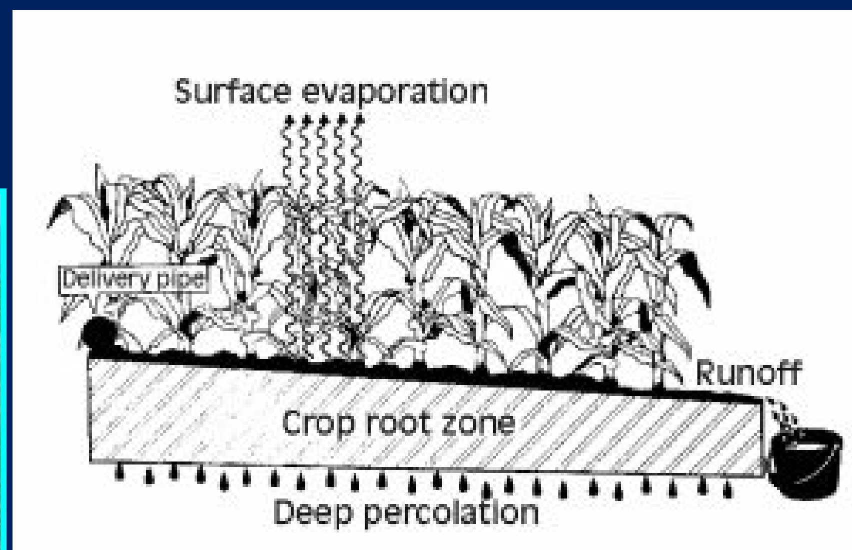
Irrigation Efficiency Components

Irrigation Application

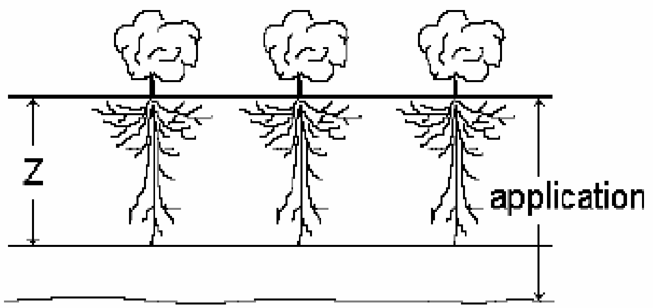
- ✓Adequacy of application (depth or volume infiltrated & stored)
- ✓Application Uniformity (DU)

Irrigation Losses

- ✓Soil Evaporation
- ✓Deep percolation
- ✓Runoff
- ✓Wind drift (sprinkler)



<u>Adequacy of application</u> refers to the depth or volume of water that infiltrates and gets stored in the root zone and is available for plant use



Uniform, but average depth applied exceeds the soil water deficit (too much deep percolation)

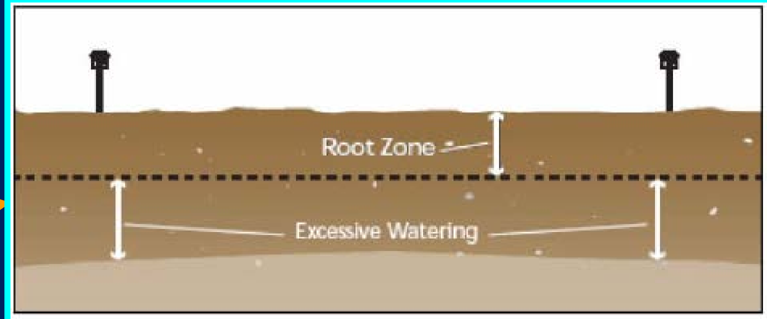


FIGURE 3: Depiction of irrigation resulting in good DU but poor irrigation efficiency

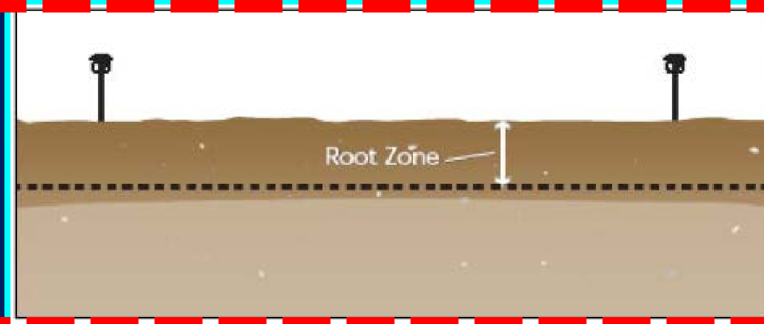
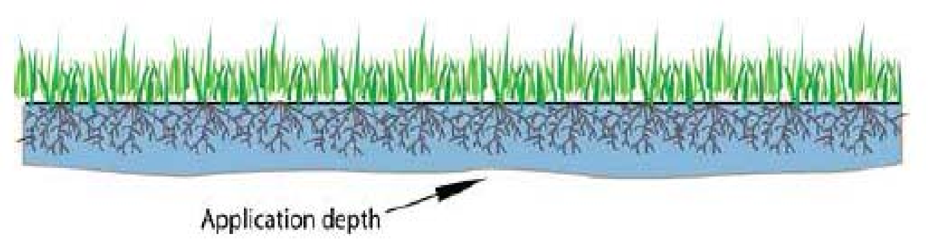


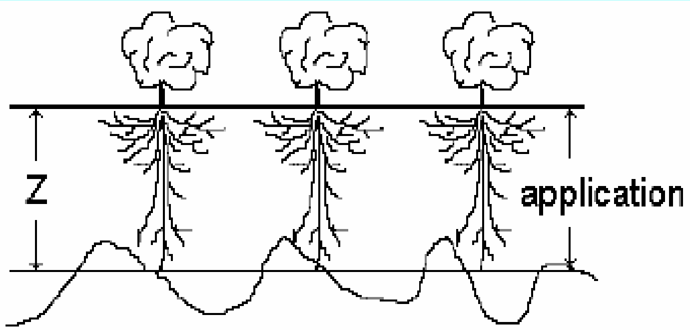
FIGURE 4: Depiction of irrigation sufficiently watering the entire field with good DU and irrigation efficiency



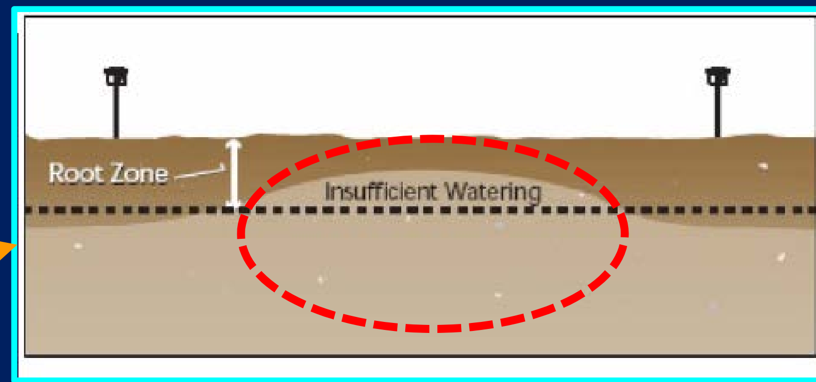
Whether an irrigation is adequate or not depends on the irrigation set-time, application rate, & soil moisture status/depletion @ irrigation start

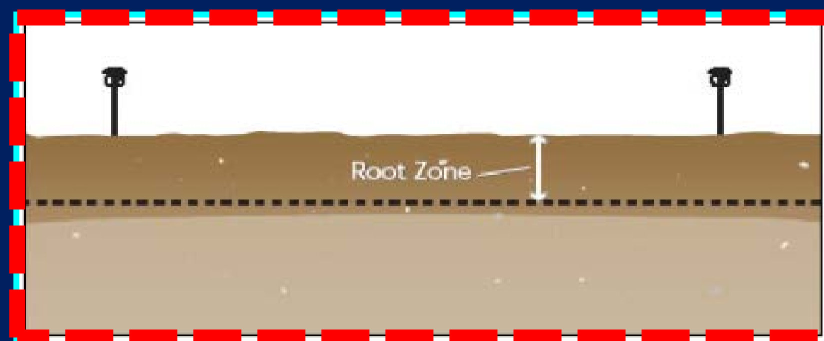
Whether water is distributed evenly among plants (D.U.) mainly depends on proper system design, operation & maintenance

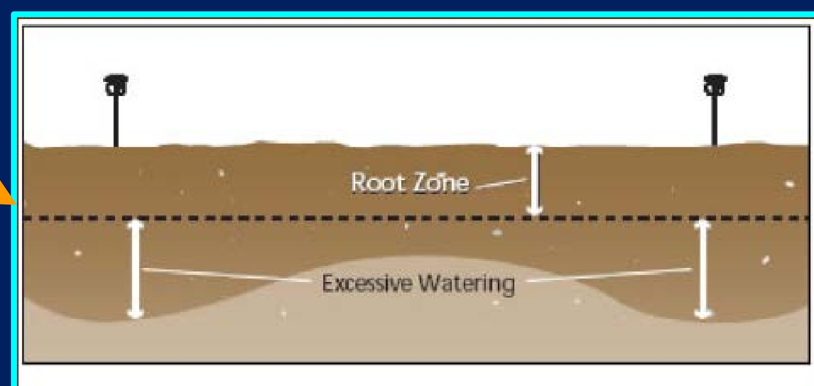
UNIFORMITY OF APPLICATION



Average depth is correct, but application is highly nonuniform, with underirrigation and DP







Why should we care about being efficient irrigators?

✓**REDUCE WATER AND ENERGY BILLS FOR PRODUCING CROPS** (Groundwater pumping)

✓**GROW MORE ACREAGE WITH SAME WATER/ENERGY OR OBTAIN HIGHER YIELD**

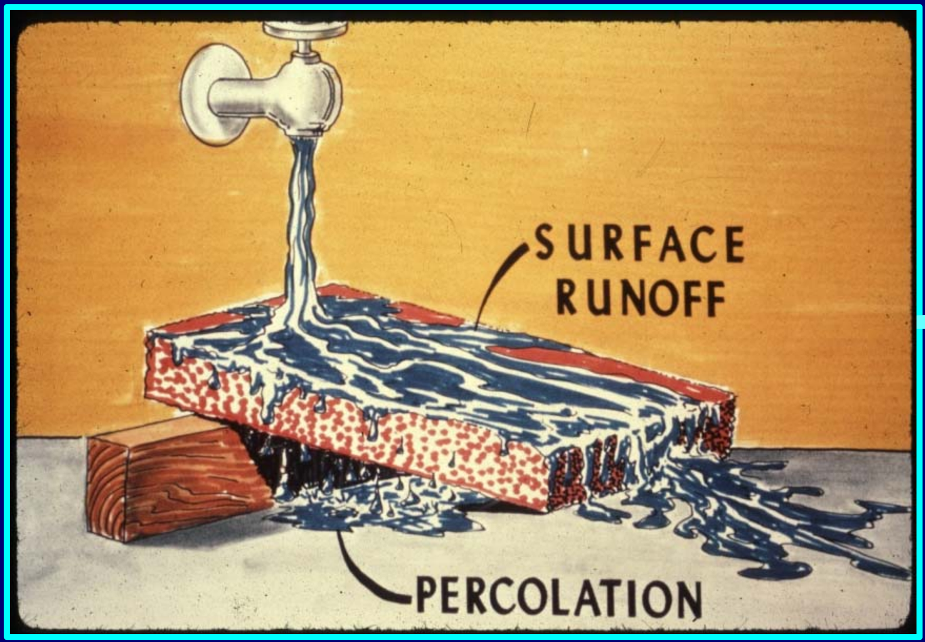
✓**HEALTHY CROP => LESS WATER-RELATED PROBLEMS** (water stress, hypoxia, phytophtora, weeds growth, etc.)

✓**BETTER CONTROL ON WATER & NUTRIENTS AVAILABLE IN THE SOIL TO PLANTS**

✓**COMPLIANCE WITH EXISTING ENVIRONMENTAL REGULATIONS** (ILRP, SGMA, AB 589, BILL32)

INEFFICIENT IRRIGATION OFTEN LEADS TO:

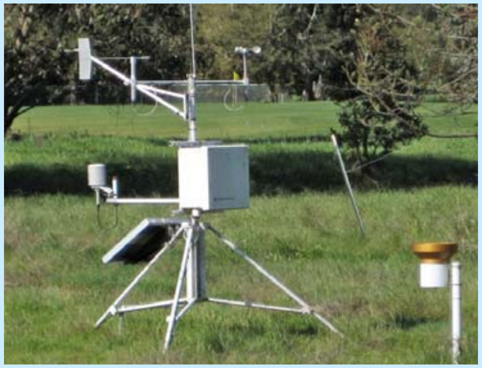
- ✓ **Higher costs (labor, water, nutrients, pumping)**
- ✓ **Crop yield lower than the max potential**
- ✓ **Uneven plants development & production**
- ✓ **Leaching nutrients, fertilizers and pesticides**



<u>Basic criterion</u> for Irrigation Management: replenish the amount of water used by the crop (ET_C) since the last irrigation, avoiding ponding & losses

Crop ET = Reference ET x Crop Coefficient

$$ET_C = ET_O \times k_C$$



ET of a grass surface

✓Use historical ETc averages

✓Use historical ET_O or real-time ET_O and K_c values

CIMIS and Spatial CIMIS provide daily **ETo** data: **http://wwwcimis.water.ca.gov/**

Table 2. Historical alfalfa crop evapotranspiration (inches per day).

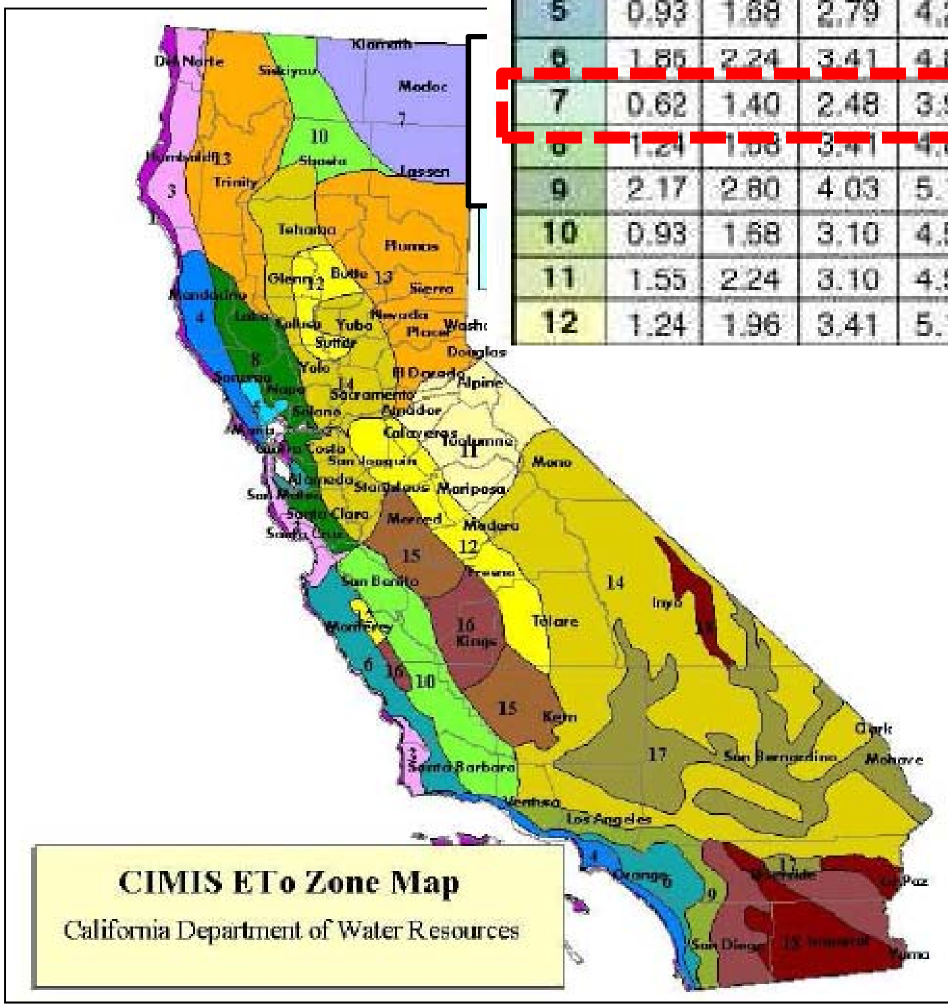
		Shafter	Five Points	Parlier	Davis	Nicolaus	Durham	McArthur	Brawley
Jan	1-15	0.03	0.04	0.03	0.03	0.03	0.03	0.02	0.07
	16-31	0.05	0.05	0.04	0.05	0.04	0.05	0.03	0.09
Feb	1-15	0.07	0.06	0.06	0.06	0.06	0.06	0.04	0.10
	16-30	0.09	0.09	0.08	0.09	0.09	0.09	0.07	0.13
Mar	1-15	0.11	0.11	0.10	0.09	0.09	0.09	0.08	0.16
	16-31	0.14	0.15	0.13	0.14	0.12	0.12	0.11	0.19
Apr	1-15	0.19	0.20	0.17	0.18	0.15	0.16	0.14	0.22
	16-30	0.20	0.22	0.19	0.20	0.18	0.17	0.14	0.25
May	1-15	0.24	0.26	0.22	0.23	0.21	0.21	0.18	0.28
	16-31	0.26	0.27	0.24	0.24	0.21	0.22	0.19	0.29
Jun	1-15	0.27	0.29	0.26	0.28	0.24	0.25	0.22	0.31
	16-30	0.28	0.30	0.27	0.29	0.26	0.26	0.25	0.32
Jul	1-15	0.28	0.30	0.27	0.29	0.26	0.27	0.27	0.31
	16-31	0.26	0.28	0.25	0.27	0.25	0.25	0.25	0.29
Aug	1-15	0.25	0.28	0.24	0.26	0.24	0.24	0.25	0.29
	16-31	0.23	0.25	0.22	0.24	0.21	0.21	0.22	0.28
Sep	1-15	0.21	0.23	0.19	0.21	0.19	0.19	0.18	0.26
	16-30	0.18	0.20	0.15	0.18	0.16	0.16	0.14	0.22
Oct	1-15	0.16	0.17	0.13	0.16	0.13	0.14	0.12	0.19
	16-31	0.12	0.13	0.09	0.12	0.09	0.10	0.08	0.15
Nov	1-15	0.08	0.10	0.07	0.09	0.07	0.07	0.05	0.12
	16-30	0.06	0.07	0.04	0.06	0.05	0.05	0.03	0.10
Dec	1-15	0.05	0.05	0.03	0.05	0.03	0.04	0.02	0.07
	16-31	0.03	0.03	0.02	0.04	0.04	0.03	0.02	0.07

Historical ET_o average estimates: http://wwwcimis.water.ca.gov/cimis

CIMIS

Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	33.0
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.4
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.0
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.3



APPLICATION RATE << SOIL INTAKE RATE (inch/hr)

System	Appl. Rate (in./hr)	$Eff._A$
Surface Irr.	0.40 – 0.45	0.75
Drip	0.03	0.85
Micro-sprinkler	0.05	0.80
Sprinkler	0.12	0.75

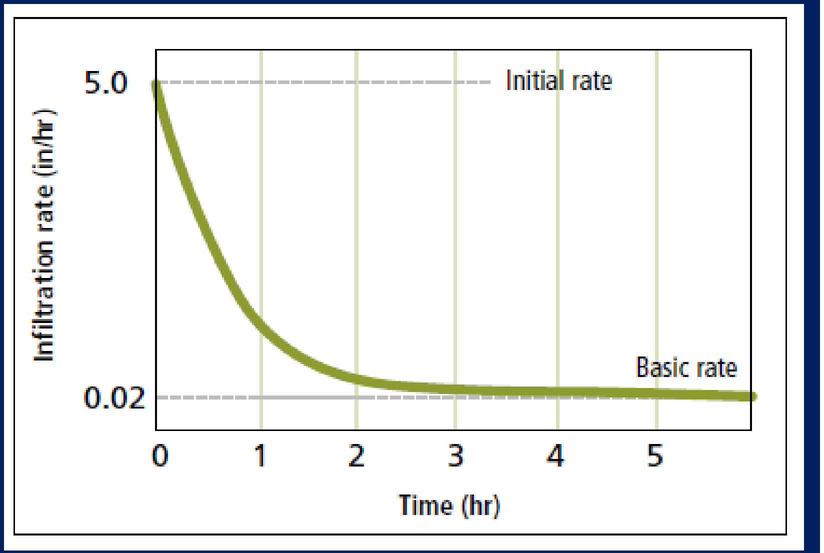


Table 1. Recommended maximum application rates for soils of various textures

Soil type	Maximum application rate (in/hr) at slope		
	0–5%	5–8%	8–12%
coarse sandy soil	1.5–2.0	1.0–1.5	0.75–1.0
light sandy soil	0.75–1.0	0.5–0.8	0.4–0.6
silt loam	0.3–0.5	0.25–0.4	0.15–0.3
clay loam, clay	0.15	0.10	0.08

Source: NRCS 1984.

Range of available water-holding capacity in different soils (inches of water per foot of soil)

Soil texture	Water-holding capacity Range In./ft	Water-holding capacity Average In./ft
1. Very coarse texture—very coarse sands	0.38-0.75	0.50
2. Coarse texture—coarse sands, fine sands, and loamy sands	0.75-1.25	1.00
3. Moderately coarse texture—sandy loams	1.25-1.75	1.50
4. Medium texture—very fine sandy loams, loams, and silt loams	1.50-2.30	2.00
5. Moderately fine texture—clay loams, silty clay loams, and sandy clay loams	1.75-2.50	2.20
6. Fine texture—sandy clays, silty clays, and clays	1.60-2.50	2.30
7. Peats and mucks	2.00-3.00	2.50

NOTE: 1 mm/m = 0.012 in./ft.

Source: Keller & Bliesner, 2000

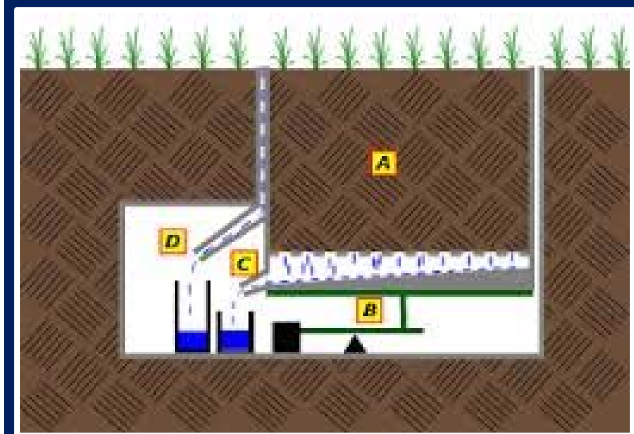
HOW MUCH WATER DOES ALFALFA USES IN CALIFORNIA ON AVERAGE OVER THE CROP SEASON?

SITE	SEASONAL ETc (inches)
Intermountain	33-36
Sacramento Valley	44-46
Central Valley	48-52
Desert Areas	58-66

System	$Eff._{APPL.}$
Surface Irrigation	**0.70**
Sprinkler	**0.75**
Micro-sprinkler	**0.80**
Drip	**0.85**

Updating information on alfalfa ET under no water limitations

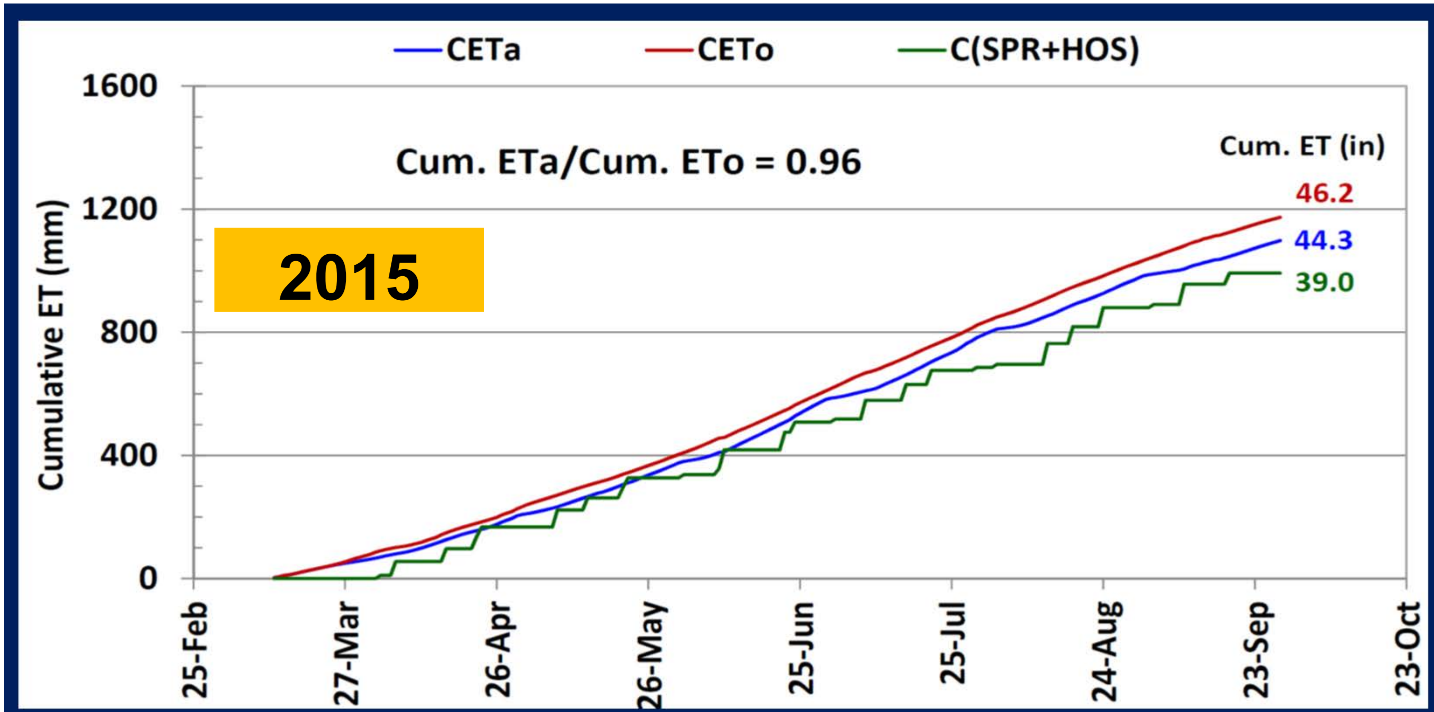
DWR-Funded Project (2014-2017)



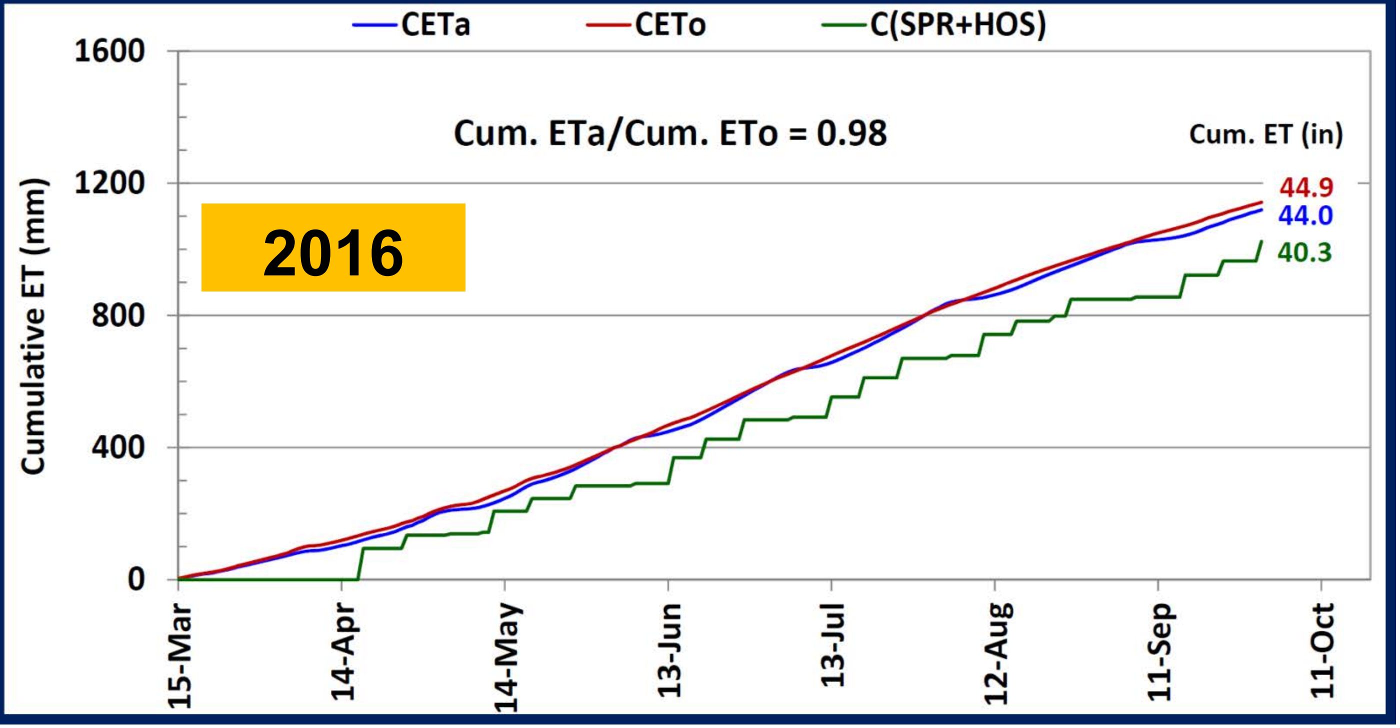
1. Measure alfalfa ET under the typical growing conditions of the Sacramento Valley

2. Determine the K_c values along the entire crop season, and within individual cutting cycles

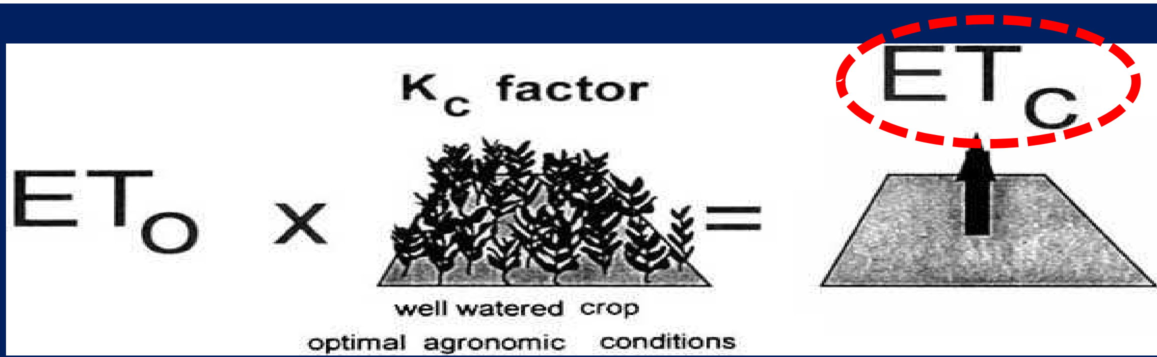
3. Provide information and tools to improve irrigation scheduling



CETa
CETo
C(SPR+HOS)
1600
1200
800
400
0
Cumulative ET (mm)
Cum. ETa/Cum. ETo = 0.96
Cum. ET (in)
46.2
44.3
39.0
2015
25-Feb
27-Mar
26-Apr
26-May
25-Jun
25-Jul
24-Aug
23-Sep
23-Oct



CETa
CETo
C(SPR+HOS)
1600
1200
800
400
0
Cumulative ET (mm)
Cum. ETa/Cum. ETo = 0.98
Cum. ET (in)
44.9
44.0
40.3
2016
15-Mar
14-Apr
14-May
13-Jun
13-Jul
12-Aug
11-Sep
11-Oct



Amount of water lost by alfalfa for ET

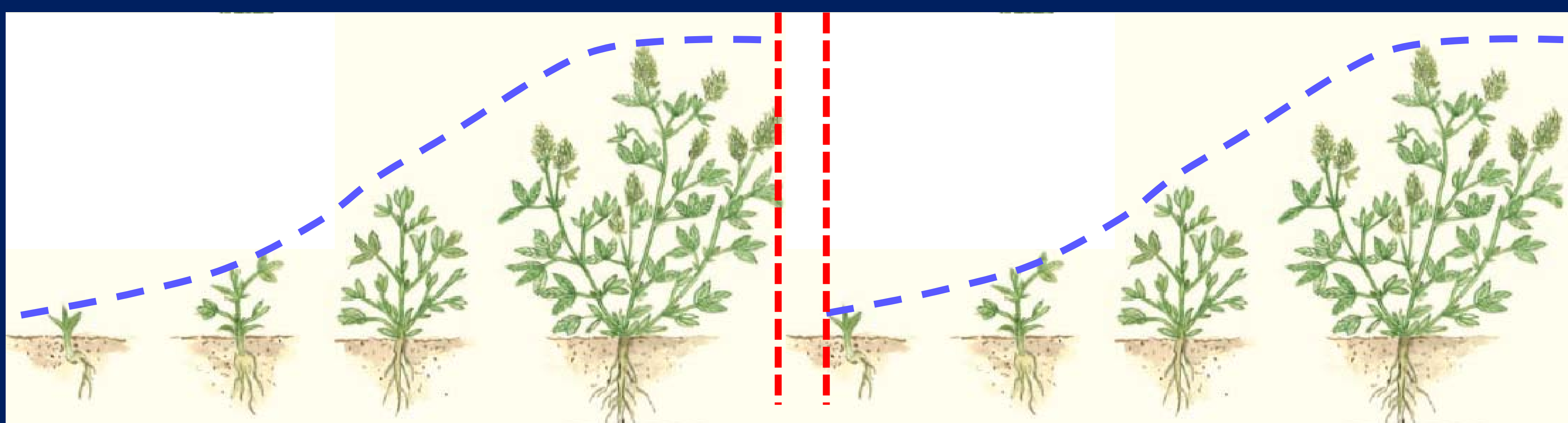
Seasonal Crop Coefficient:

K_c = 0.96-0.98 (averaged over the entire crop season)

Within-cycle Crop Coefficient:

$K_c \approx$ 0.35 after cutting until irrigation (5-6 days)

K_c = 1.10 to 1.15 from 2-3 days after irrigation till the next cutting



ENERGY REQUIREMENTS FOR IRRIGATION

It takes 1.37 whp-hr per each ac-ft of water per foot of lift

(power the pump must provide to lift 1 ac-foot of water by 1 foot)

FUEL SOURCE	PUMP OUTPUT
ELECTRICITY	0.885 whp-hr/kWh
NATURAL GAS (925 BTU)	61.7 whp-hr/MCF
NATURAL GAS (1000 BTU)	66.7 whp-hr/MCF
DIESEL	12.50 whp-hr/gal
PROPANE	6.89 whp-hr/gal

Source of Energy	Energy Units to Lift Water
Electricity	1.55 kWh/ac-ft per foot of lift
Natural Gas (925 BTU)	0.22 MCF/ac-ft per foot of lift
Natural Gas (1000 BTU)	0.20 MCF/ac-ft per foot of lift
Diesel	0.10 Gal/ac-ft per foot of lift
Propane	0.20 Gal/ac-ft per foot of lift

Source: Nebraska Pumping Plant Performance Criteria (NPPPC)

CALCULATION EXAMPLE

Alfalfa ET = 36 inches = 3.0 ft. of water over the crop season

Area = 130 acres

Irrigation methods: Wheel Line Sprinkler (60 psi) Vs. Center Pivot (30 psi)

Water Lift = 60 ft (from well to ground)

$TDH_{WHEEL-LINE}$: 60 ft + 60 psi x 2.31 ft/psi = 200 ft

Total ac-ft $_{WHEEL-LINE}$ = 3.0/0.80 = 3.8 ac-ft

TDH_{PIVOT}: 60 ft + 30 psi x 2.31 ft/psi = 130 ft

Total ac-ft $_{PIVOT}$ = 3.0/0.80 = 3.8 ac-ft

Diesel : 0.10 gal/ac-ft per foot of lift

Cost of Diesel = $ 3.5 per gallon

System	$Eff._A$
Gravity	**0.70**
Drip & SDI	**0.90**
Micro-sprinkler	**0.85**
Sprinkler	**0.80**

Wheel-line: 130 ac x 3.8 ac-ft x 200 ft x 0.10 gal/ac-ft = 9,880 gal = $34,580

Pivot: 130 ac x 3.8 ac-ft x 130 ft x 0.10 gal/ac-ft = 6,422 gal = $22,477

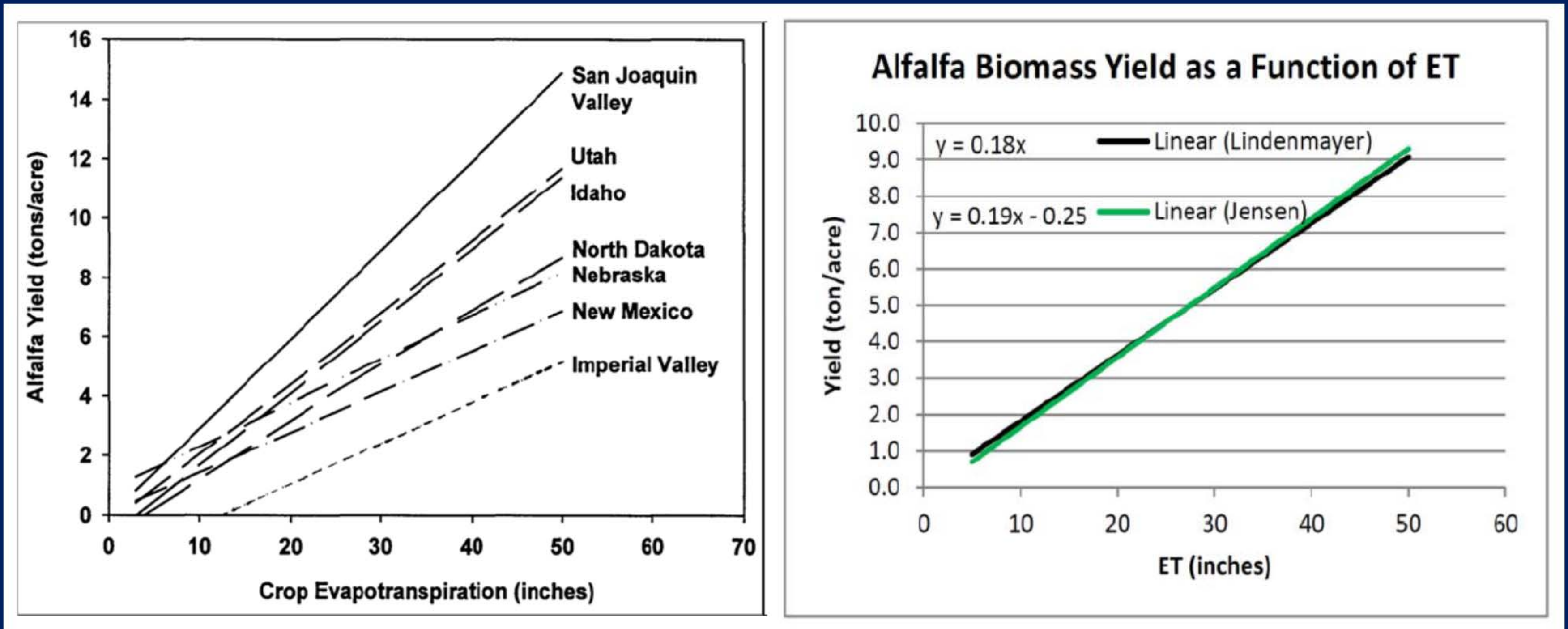
Difference in fuel amount = 9,880 – 6,422 = 3,460 gal

Total saving with surface irrigation = 3,460 gal x $3.5/gal = $12,110

Since all the above-ground biomass is harvested, Alfalfa yield is tightly related to crop ET

(1:1 relationship)

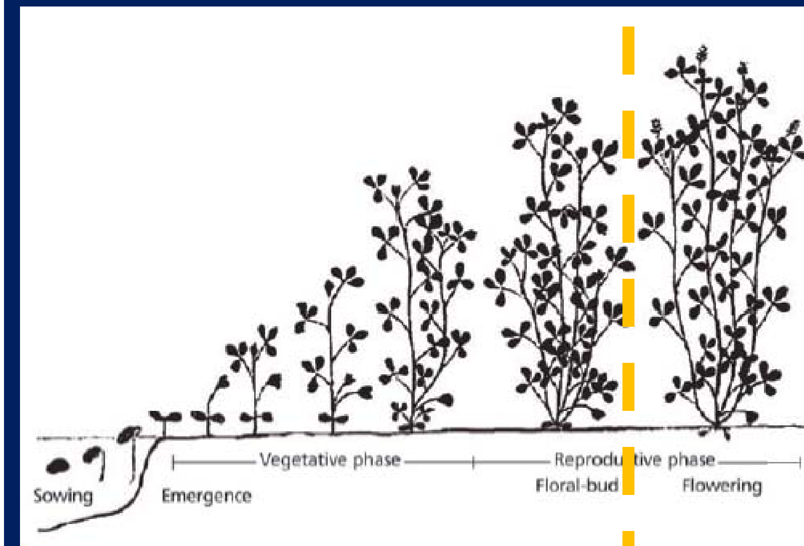
Water stress (deficit & excess) strongly impact yield

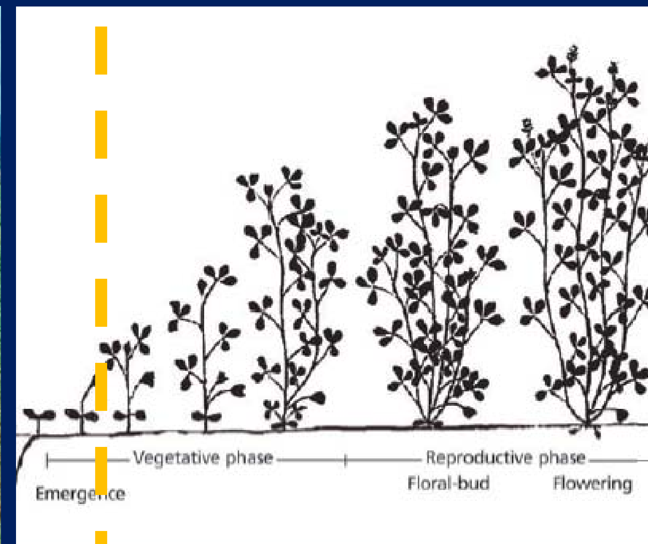


What really matters for high yield is that there is sufficient soil moisture available to meet and sustain the crop ET

IRRIGATION MANAGEMENT IN ALFALFA IS CHALLENGING!

← NO IRRIGATION →





6-20 DAYS

✓ET-based scheduling is complicated by the periodic cutting & re-growth cycles

✓Irrigations are cut back a few days prior to cutting, and during hay curing

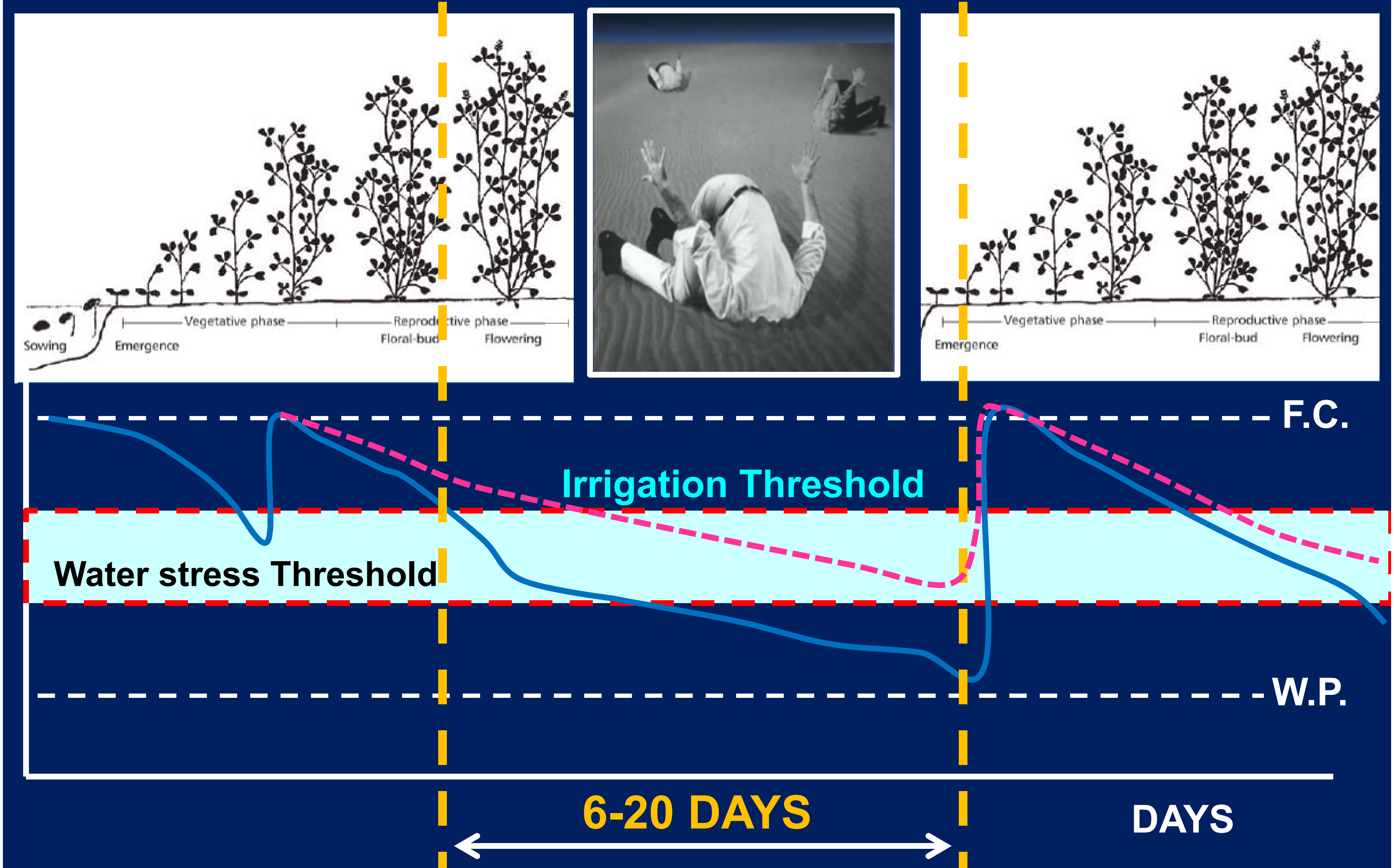
✓**At least 6- to 20-day dry-down periods (no irrigation)**

✓**Irrigation decisions are driven and constrained by the cutting schedule**

WHAT HAPPENS DOWN THERE IN THE SOIL?

Water stress (deficit or excess)?
How much, and for how long?

Is there any deep soil
water storage (buffer)?



FIELD CONSIDERATIONS

In the field practice, a normal cutting cycle of 28-30 days leaves a window available for irrigation only of about 16 days.

With surface and sprinkler systems, within 16 days available growers can only irrigate once or twice.

- ✓ With 1 irrigation we may under-irrigate and therefore impact yield
- ✓ With 2 irrigations, we may apply too much water. Irrigation must be applied before the plants experience stress and in small amounts.

Growers often cannot irrigate <u>ONLY</u> based on ET or the allowable soil moisture depletion.

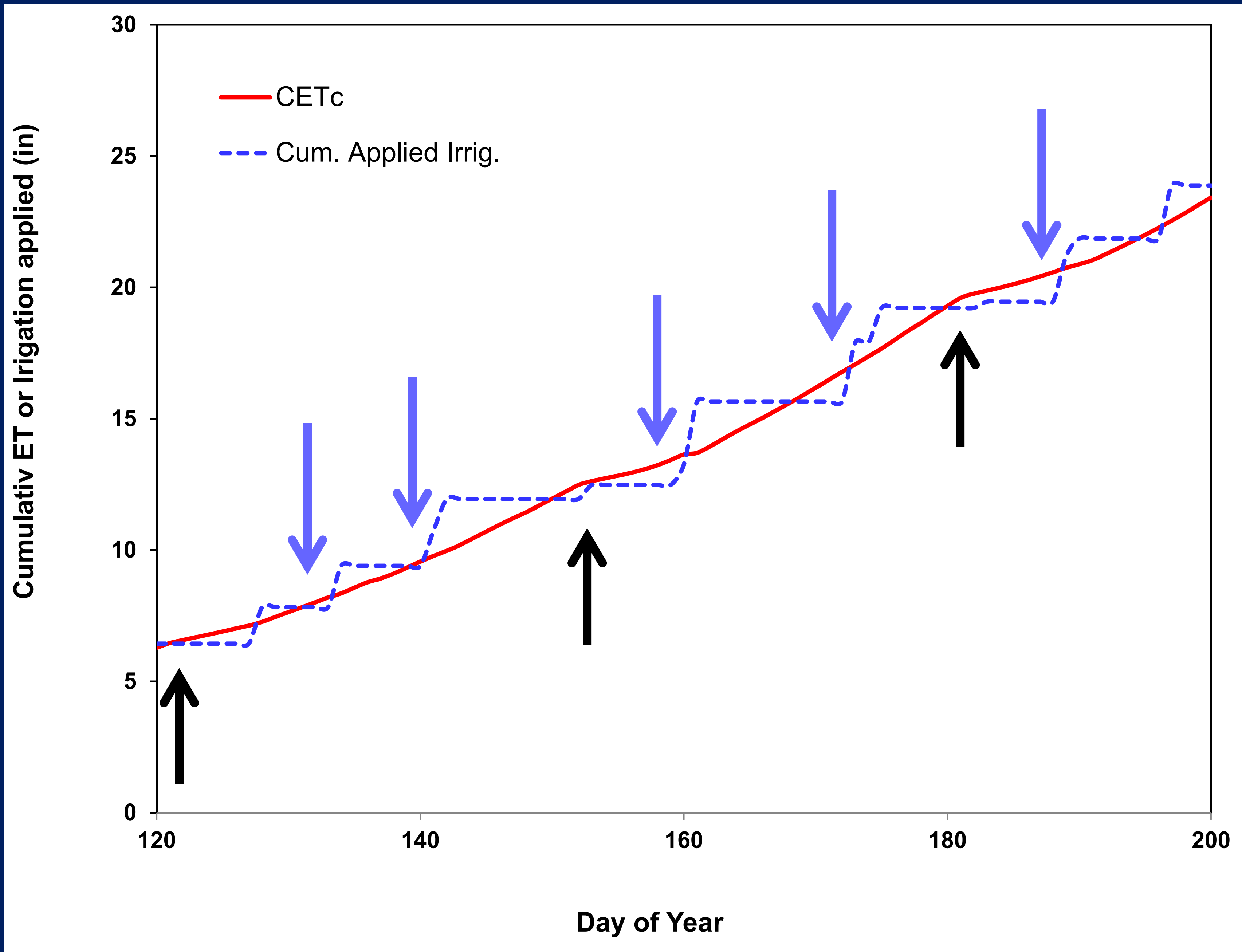
They must use judgement and irrigation timing and amount must be determined from field experience.

Inadequate irrigation is the No. 1 factor limiting Alfalfa yields

Alfalfa gets stressed around cutting times and when the new growth is coming:

MOST SENSITIVE STAGE !!

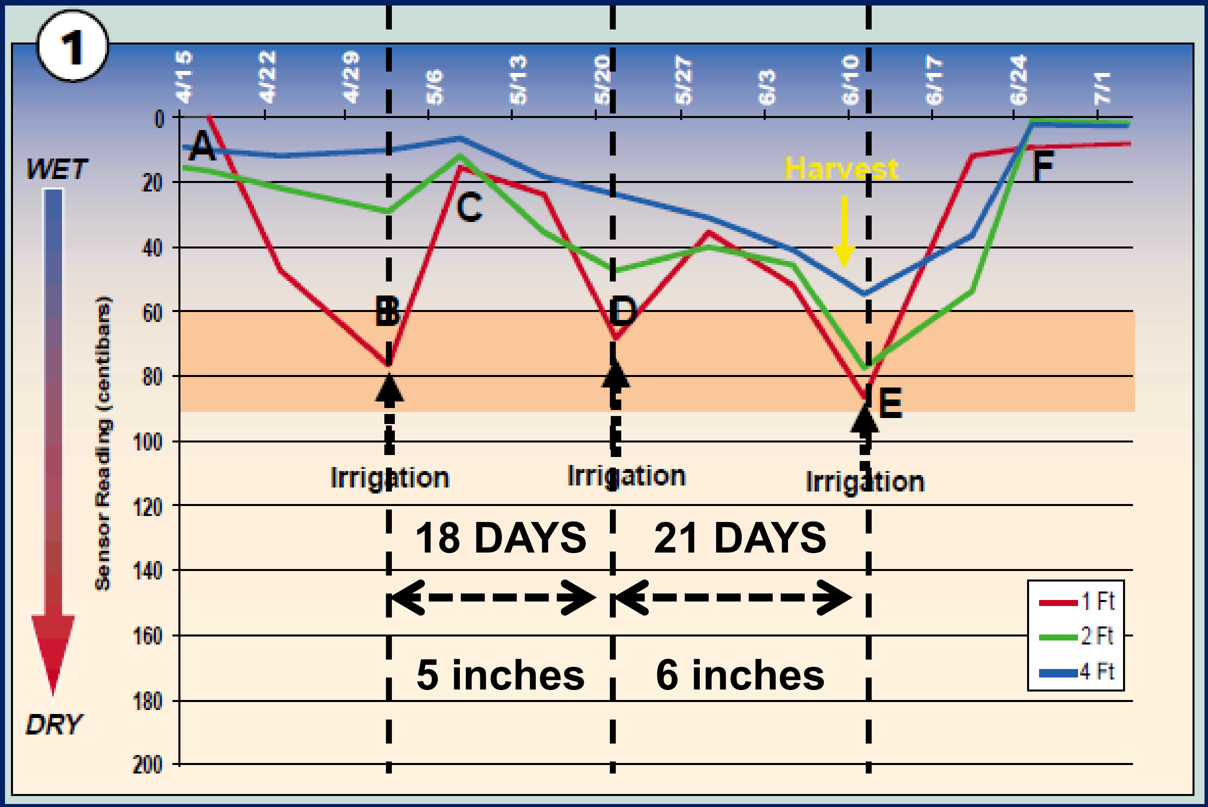
ALFALFA IS VERY FORGIVING BUT ALSO VERY SENSITIVE !



CETc
Cum. Applied Irrig.
Cumulativ ET or Irigation applied (in)
Day of Year
0
5
10
15
20
25
30
120
140
160
180
200

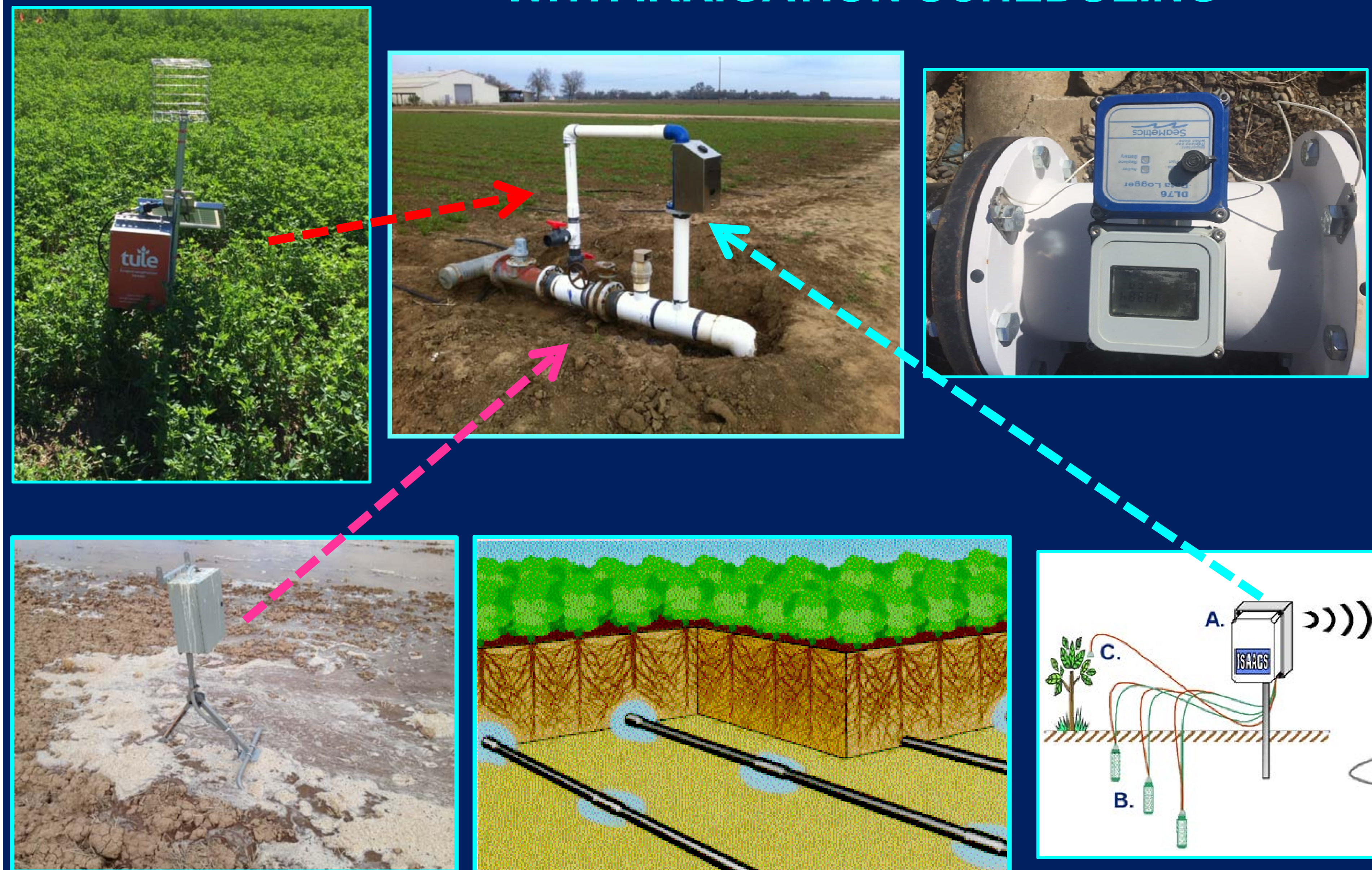
BEST IRRIGATION SCHEDULING APPROACH?

Combination of soil moisture monitoring & ETc

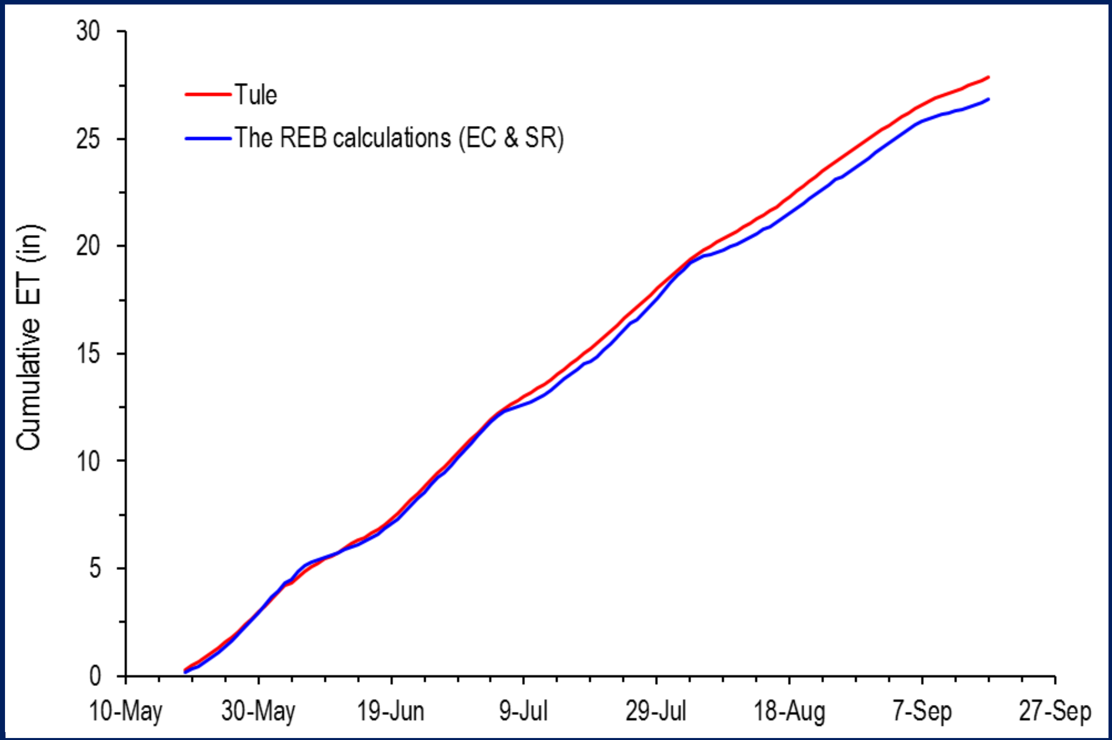


1. **Irrigation start timing from Soil Moisture Sensors**
2. **Irrigation amount (inches) from ETc since last irrigation**
3. **Ground-truthing from Soil Moisture Sensors & Flowmeters**

THINGS THAT CAN HELP IN THE FIELD WITH IRRIGATION SCHEDULING




tule


Tule
The REB calculations (EC & SR)
Cumulative ET (in)
0
5
10
15
20
25
30
10-May
30-May
19-Jun
9-Jul
29-Jul
18-Aug
7-Sep
27-Sep

SOIL MOISTURE MONITORING HELPS ANSWERING QUESTIONS:

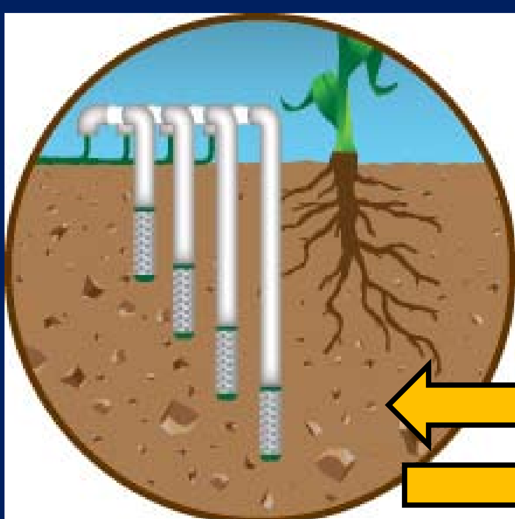
✓When to start irrigating (and when to stop it)?

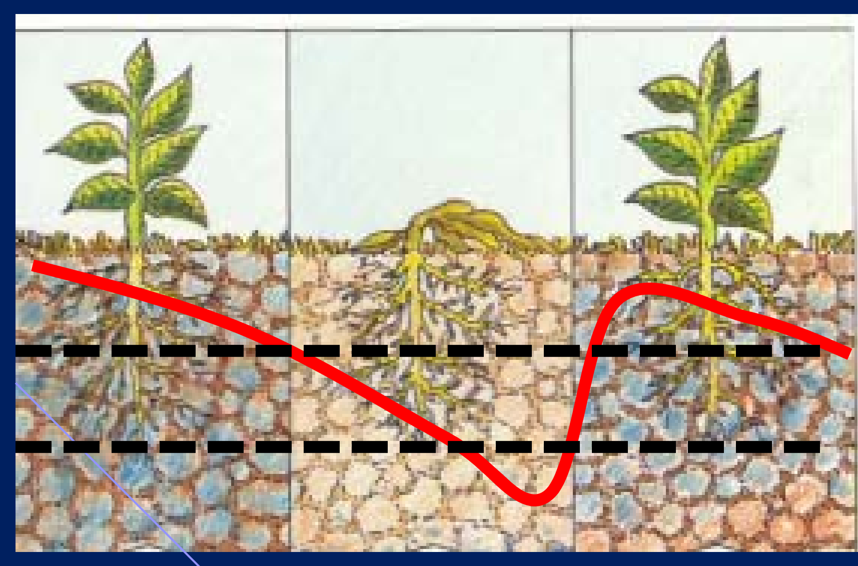
✓How long shall I irrigate?

✓Has enough water infiltrated the soil during an irrigation?

✓Am I applying enough, insufficient, or excessive water?

✓Is there sufficient deep soil water reserve for crop water uptake during periods with no irrigation, or at re-growth?





HOW IS SOIL MOISTURE MEASURED?

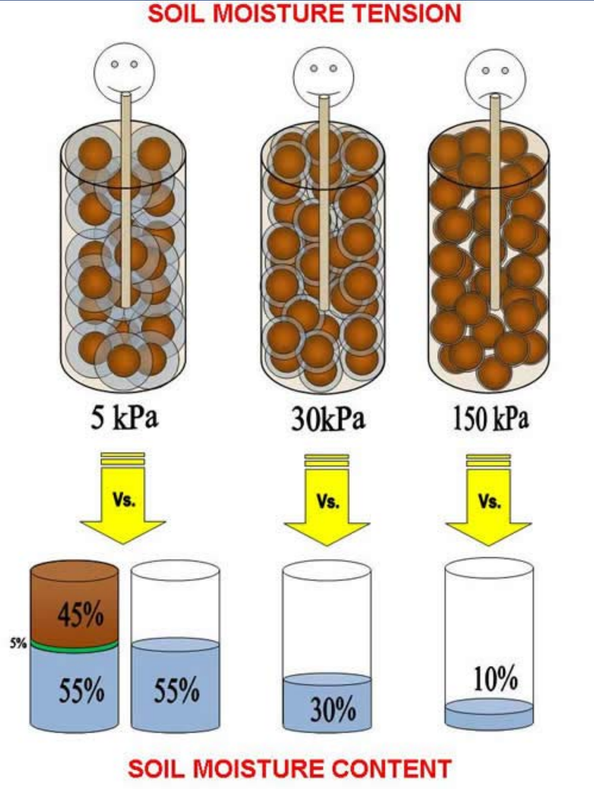
SOIL MOISTURE CONTENT (%, in/ft)

How much water is available per unit of soil?

% weight = (weight of water/weight of dry soil) x 100

% volume = (volume of water/volume of soil) x 100

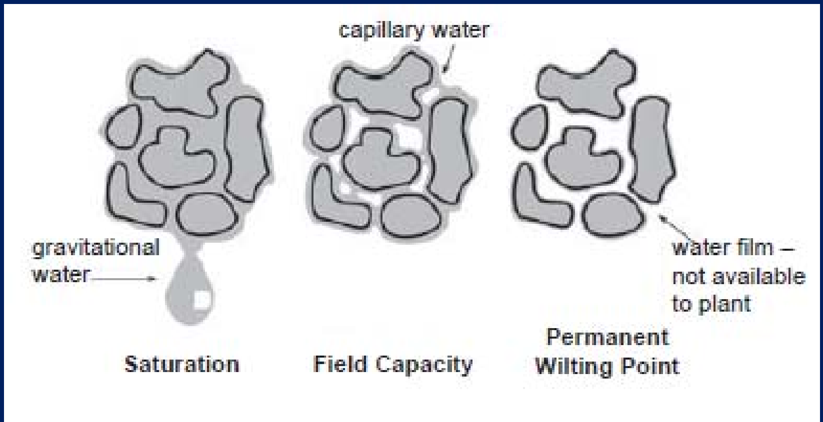
Depth = (inches of water/foot of soil) => MOST COMMON AND PRACTICAL



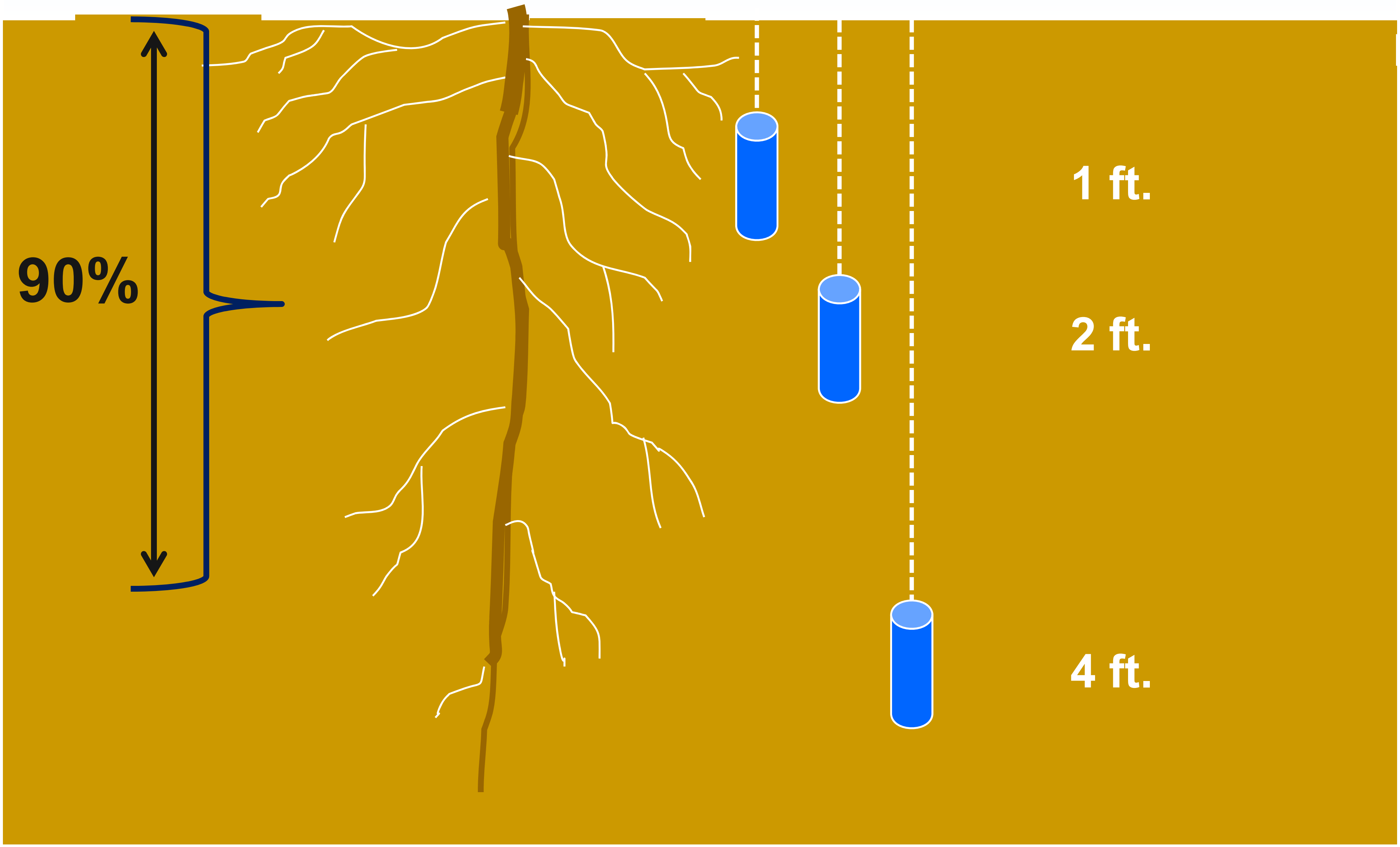
SOIL MOISTURE TENSION (centibars, kPa)

How strongly water is held by soil particles

The higher the tension, the drier the soil and the more difficult is for plant to extract water



Recommended installation of Watermarks



Recommended values of soil moisture tension at which irrigation should occur (50% of TAW)

Soil Type	Soil Moisture Tension (centibars)
Sand or loamy sand	40-50
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

Recommended values of soil moisture content at which irrigation should occur (50% of TAW depleted)

SOIL TYPE	AVAILABLE WATER (IN./FT)	ALLOWABLE DEPLETION (IN./FT)	AVAILABLE WATER IN 4FT ROOT ZONE (IN.)	ALLOWABLE DEPLETION IN 4FT ROOT ZONE (IN.)
COARSE SAND	0.5	0.25	2.0	1.0
LOAMY SAND	1.0	0.50	4.0	2.0
SAND LOAM	1.5	0.75	6.0	3.0
FINE SANDY LOAM	2.0	1.00	8.0	4.0
CLAY LOAM	2.2	1.10	8.8	4.4
CLAY	2.3	1.15	9.2	4.6
ORGANIC CLAY LOAMS	4.0	2.00	16.0	8.0

TABLE 2. Typical quantities of available water and allowable depletion.

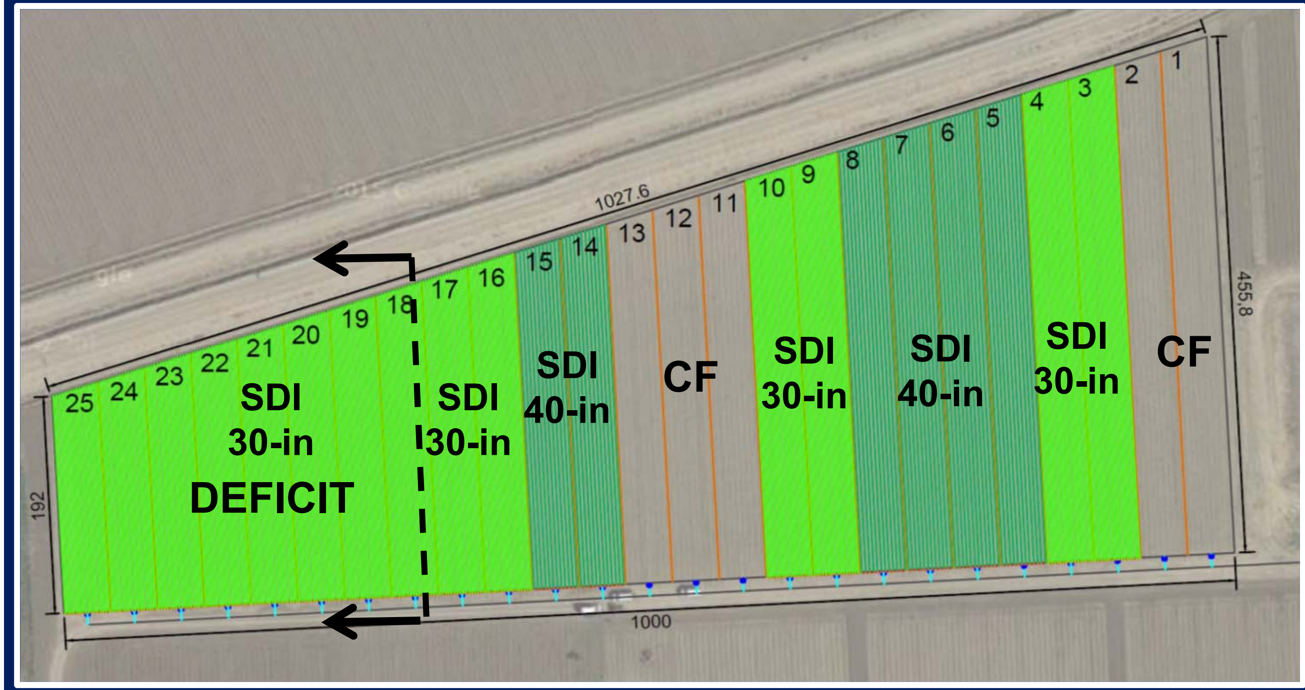
WETTING FRONT DETECTORS

Are soil moisture switches detecting when the wetting front arrives at a certain point along the field

The switch closes the circuit and sends a signal to a gate actuator or valve to close/reduce the flow

ACTUATED GATE

ALFALFA RESEARCH TRIAL on SDI @ RUSSELL RANCH - DAVIS



Area = ~ 8 acres

Established Jan 2016

5 Treatments

3 Replications

Groundwater supply

OBJECTIVES

Document comparative differences between Check Flood (CF) and SDI in:

- ✓ Actual Crop Evapotranspiration (ETa)
- ✓ Hay Yield (HY)
- ✓ Water Productivity (WP)
- ✓ Energy usage (EU) and Energy Productivity (EP)

MAIN DRIVERS FOR SHIFTING TO SDI IRRIGATION IN ALFALFA?

#) Prospect of increased yield

#) Higher land and water productivity

#) More control on irrigation & nutrients

✓Timing & amounts

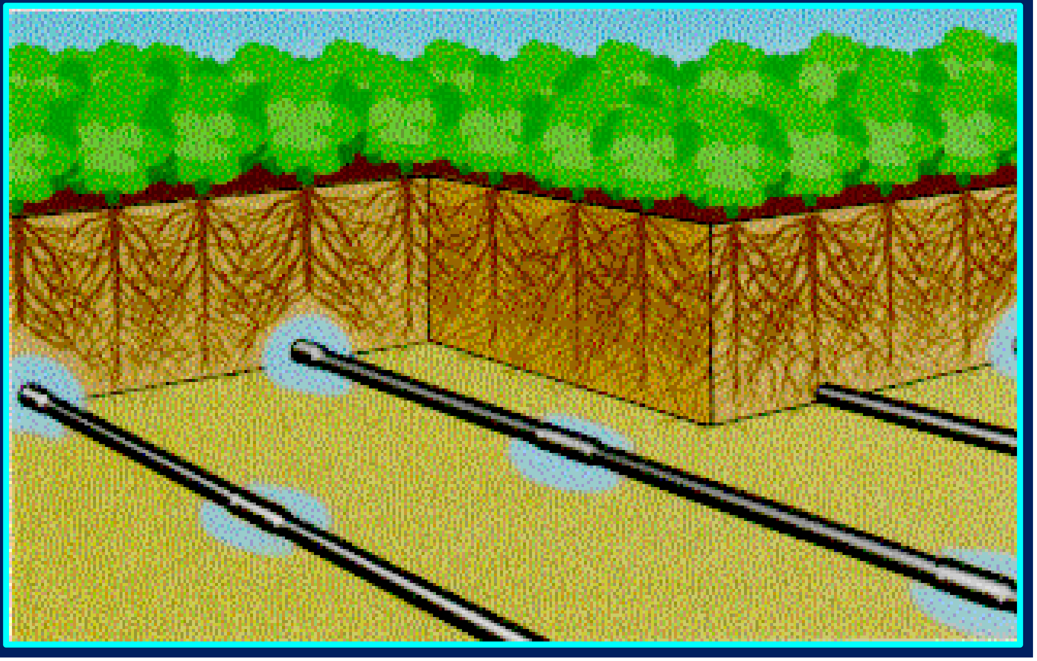
✓Avoidance of deficits and stress

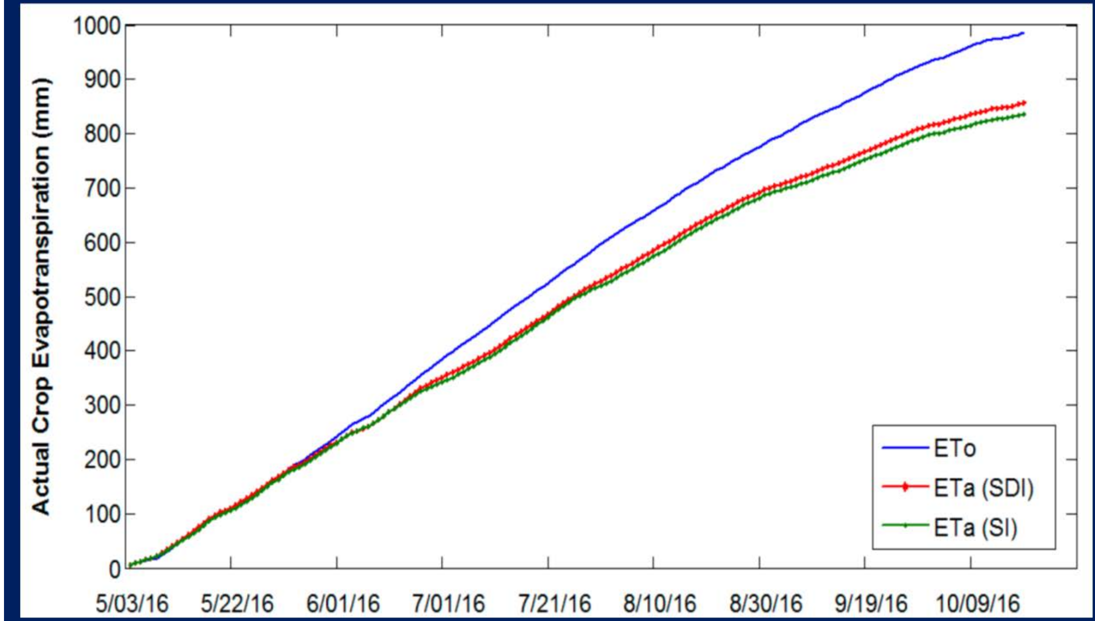
✓Excess & leach-outs

Better soil-water-air conditions

⬇

SPOON-FEEDING THE CROP RATHER THAN WETTING & DRYING =>> UNCERTAINTIES

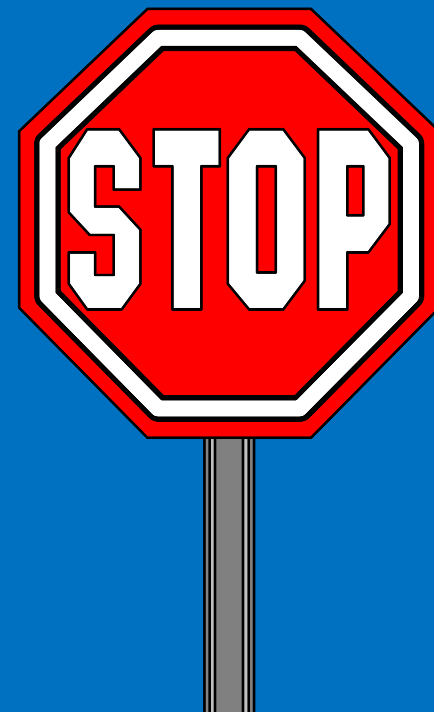




MAIN FINDINGS

1ST YEAR	SI (CF)	SDI	Difference SDI vs. SI (%)
ETa (ac-in/ac)	32.8	33.6	+2.5
YIELD (Ton/ac)	8.0	8.40	+5.0
ENERGY (kWh)	58.3	120.8	+107.2
GHG (Ton-EqCO_2/ac)	0.022	0.045	+104.5
WP (Ton/in)	0.24	0.25	+4.1
EN P (Ton/Kwh)	0.14	0.07	-50.0
GHG-P (Ton/Ton-EqCO_2)	364	186	-48.9

Abbreviations—SI: surface irrigation; SDI: sub-surface drip irrigation; ETa: actual crop evapotranspiration; HY: hay yield; WP: water productivity; EN: energy usage; EN P: energy productivity; GHG: greenhouse gas emissions; GHG P: greenhouse gas emission productivity. Note: Significant differences (Tukey's Range Tests, $p \leq 0.05$) among the treatments are denoted by different bracketed letters (a, b); ns = non-significant.



THANK YOU !!

QUESTIONS OR COMMENTS?

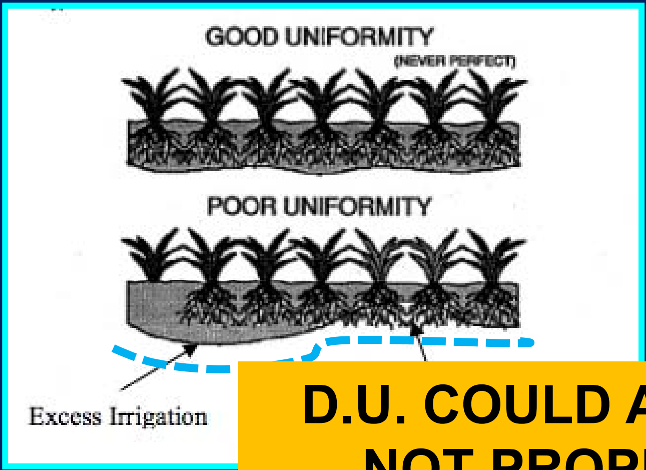
DO WE NEED ANY PRELIMINARY EVALUATION?

How uniform is our soil within the field?

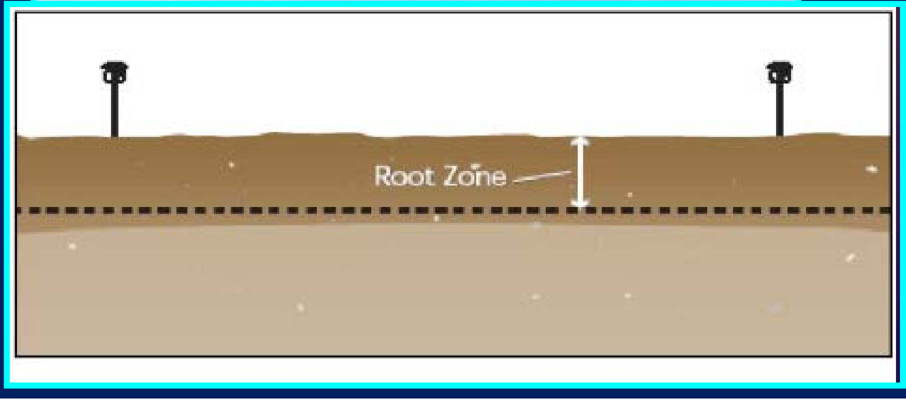
ZONING + Accurate evaluation of soil differences ($30-50/Ac)

LIMITATIONS OF CHECK-FLOOD IRRIGATION

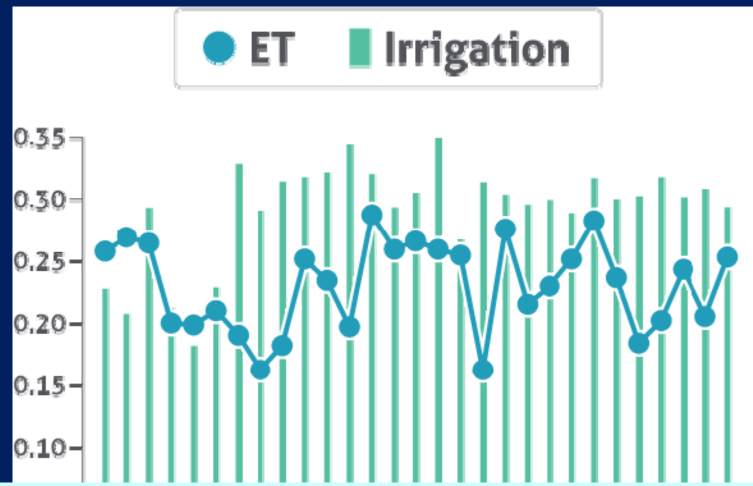
1) **Inability to apply small water amounts to match crop ET during re-growth periods**
2) **Often low Distribution Uniformity (D.U.)**



D.U. COULD ALSO BE POOR IN SDI IF SYSTEM IS NOT PROPERLY DESIGNED AND OPERATED



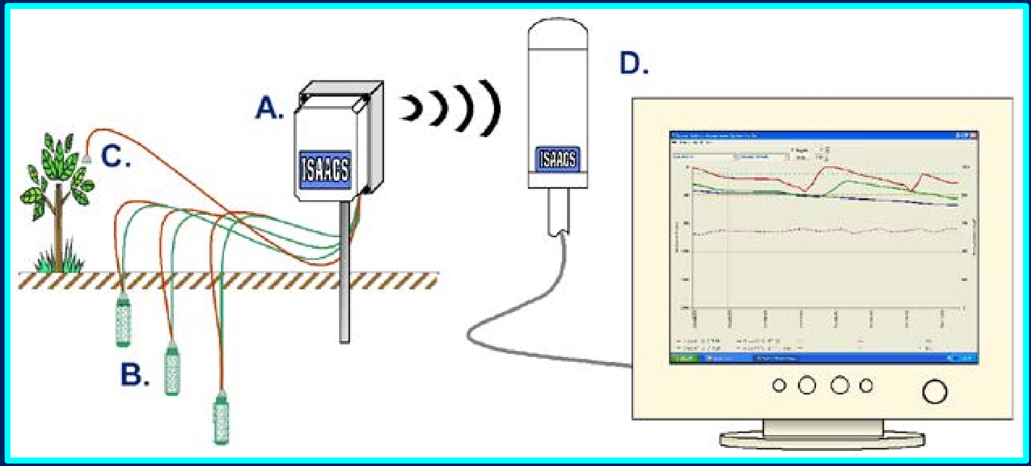
MEASUREMENTS CONDUCTED IN 2016

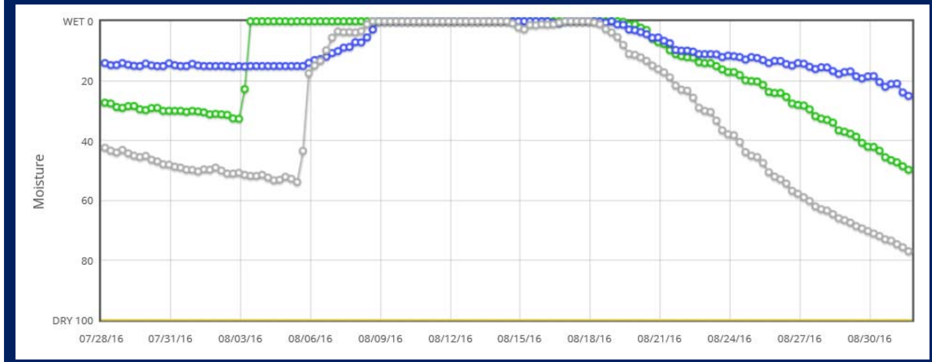


Actual crop evapotranspiration (ETa): with commercial surface renewal units (residual of energy balance method)

Applied water: with calibrated flow-meters

Soil moisture tension was monitored with Watermarks, data-loggers and telemetry along the entire crop season 2016





SCHEDULING EXAMPLE

Crop: Alfalfa
Location: McArthur, CA
Soil: Clay Loam
Root depth: 5 ft
Period: July (1-31)

Tot. Available soil moisture: 1.7 in/ft x 5 ft = 8.5 in
Total Allowable Depletion = 50% of 8.5 in = 4.3 in
Crop ET (McArthur): 0.26 in/day (July)
Irrigation timing: at soil moisture depletion of 4.3 in
Irrigation interval: 4.3 in/0.26 in/day = 16 days

Soil Texture	Water Holding Capacity (in/ft)	Total available soil moisture storage for 5-ft depth (in)	50% of Available Soil Moisture (in)
Sand	0.7	3.5	1.8
Loamy sand	1.1	5.5	2.8
Sandy loam	1.4	7.0	3.5
Loam	1.8	9.0	4.5
Silt loam	1.8	9.0	4.5
Sandy clay loam	1.3	6.5	3.3
Sandy clay	1.6	8.0	4.0
Clay loam	1.7	8.5	4.3
Silty clay loam	1.9	9.5	4.8
Silty clay	2.5	12.5	6.3
Clay	2.2	11.0	5.5

WHAT IT TAKES TO BE EFFICIENT?

Good System Design

- ✓Accurate & Skilled
- ✓Flexible Operation

Proper **Installation**

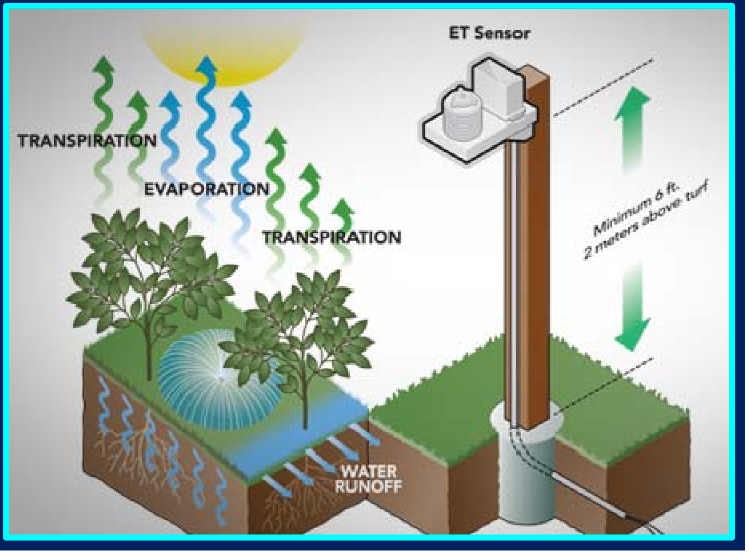
Regular **Maintenance**

System **Evaluation**

Defined Irrigation Strategy

- Full Irrigation
- Deficit Irrigation

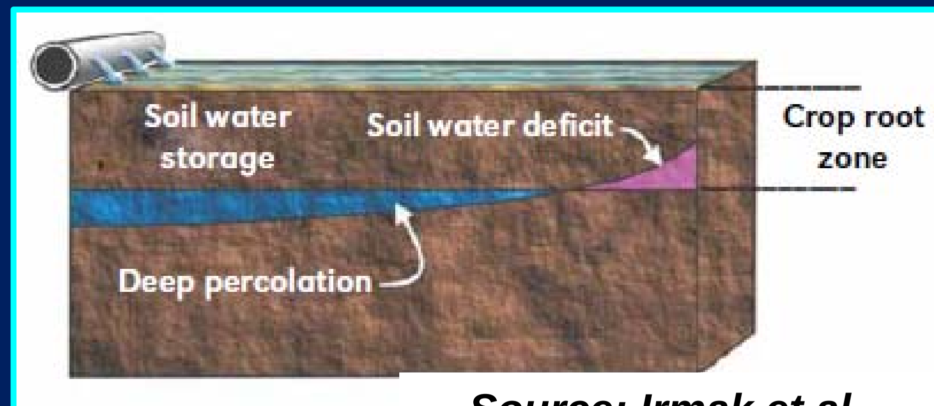
Accurate Irrigation Scheduling



DIFFERENCES BETWEEN IRRIGATION METHODS

SURFACE IRRIGATION METHODS

Water infiltrating the soil mainly depends on soil intake rate, field length and slope, and available flow rate **(water travels along the field)**



Source: Irmak et al.,

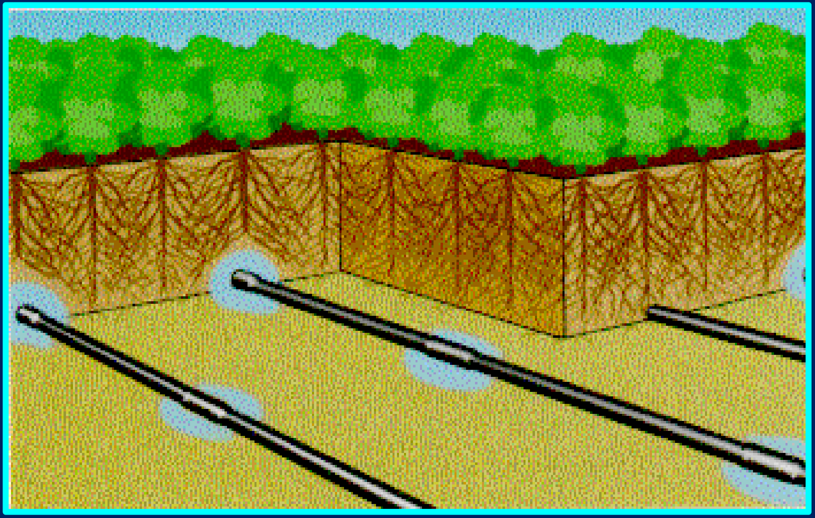
Distrib. Uniformity in Space: some areas of the field receive less water than others

Distrib. Uniformity in Time: some areas of the field may receive water at much longer intervals than others (may be more subject to water deficit)

SPRINKLER & MICRO-IRRIGATION

Water infiltrating the soil mainly depends on system's characteristics (water travels along the pipe system and is applied in the vicinity of plants)

Distrib. Uniformity in Space: some areas may receive less water than others



Efficiencies of Standard and Energy-efficient Electric Motors

Horsepower	Standard	Energy Efficient
10	86.5	91.7
20	86.5	93.0
50	90.2	94.5
75	90.2	95.0
100	91.7	95.8
125	91.7	96.2

Irrigation Scheduling Principles

When should we irrigate? ⟷ How much water should we apply?

When should we irrigate?	How much water should we apply?
Before yield is impacted by insufficient soil moisture	Refill the amount of water (inches) depleted between two irrigations
How much soil moisture can be depleted before yield is impacted?	It requires estimation of Crop Water Use (ET) between irrigations
< 40-50 % of Available S.M	**ETc or ETo x Kc**
Accurate ways to track S.M.	**Accurate ways to track crop ET**