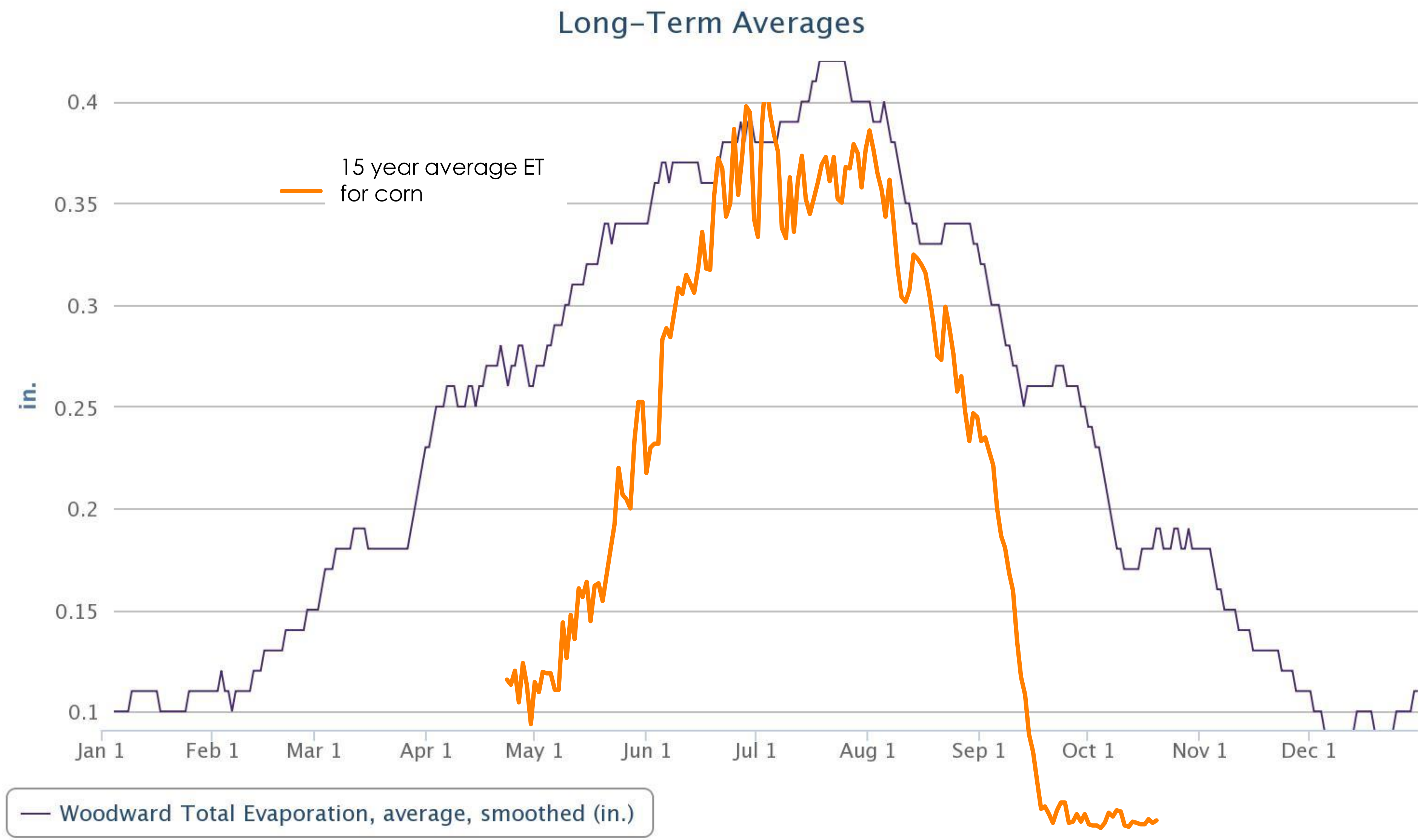
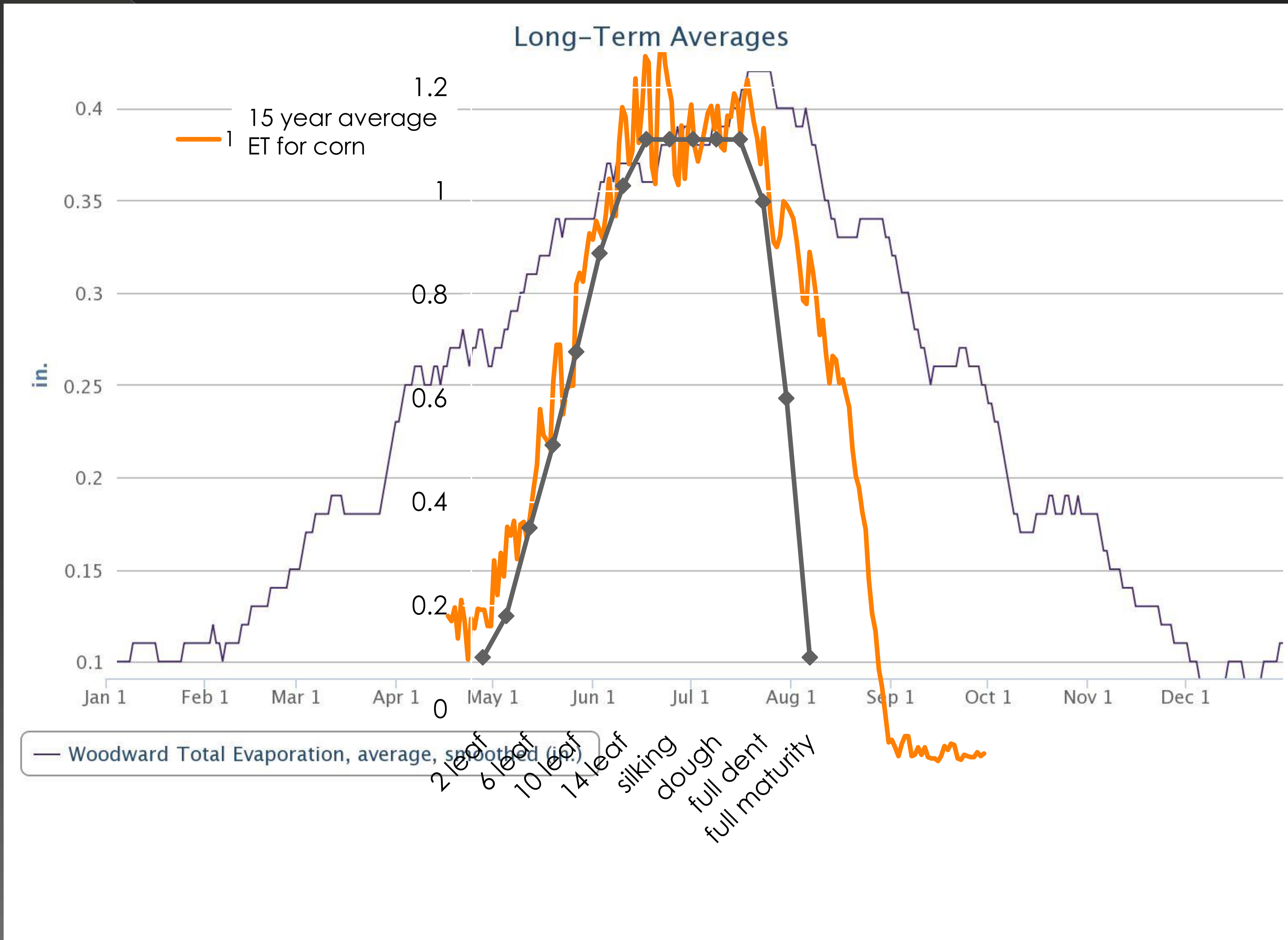

Long-Term Averages
15 year average ET
for corn
in.
0.4
0.35
0.3
0.25
0.2
0.15
0.1
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Woodward Total Evaporation, average, smoothed (in.)

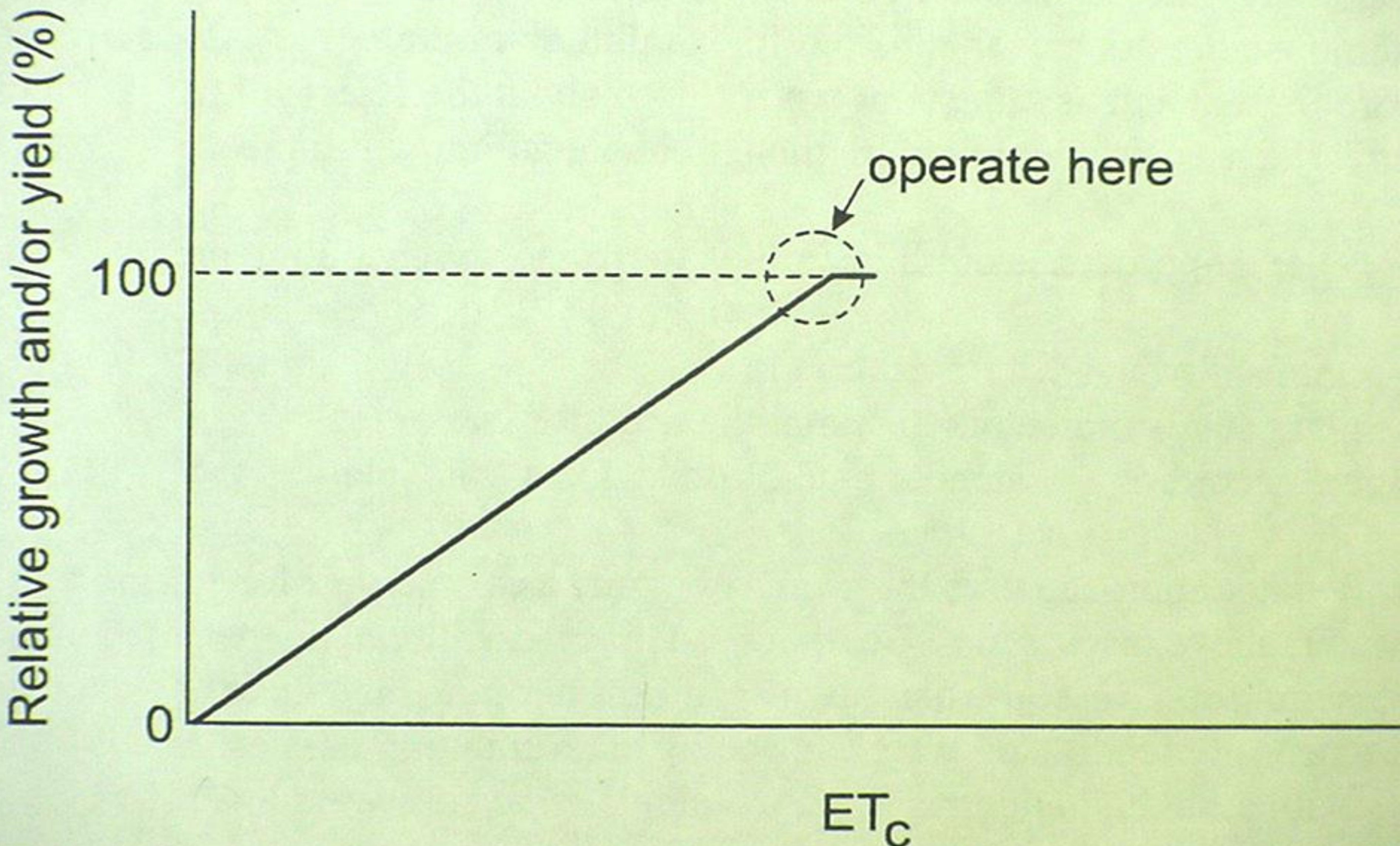


Long-Term Averages
15 year average ET for corn
1
in.
0.4
0.35
0.3
0.25
0.2
0.15
0.1
1.2
1
0.8
0.6
0.4
0.2
0
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Woodward Total Evaporation, average, smoothed (in.)
2 leaf
6 leaf
10 leaf
14 leaf
silking
dough
full dent
full maturity

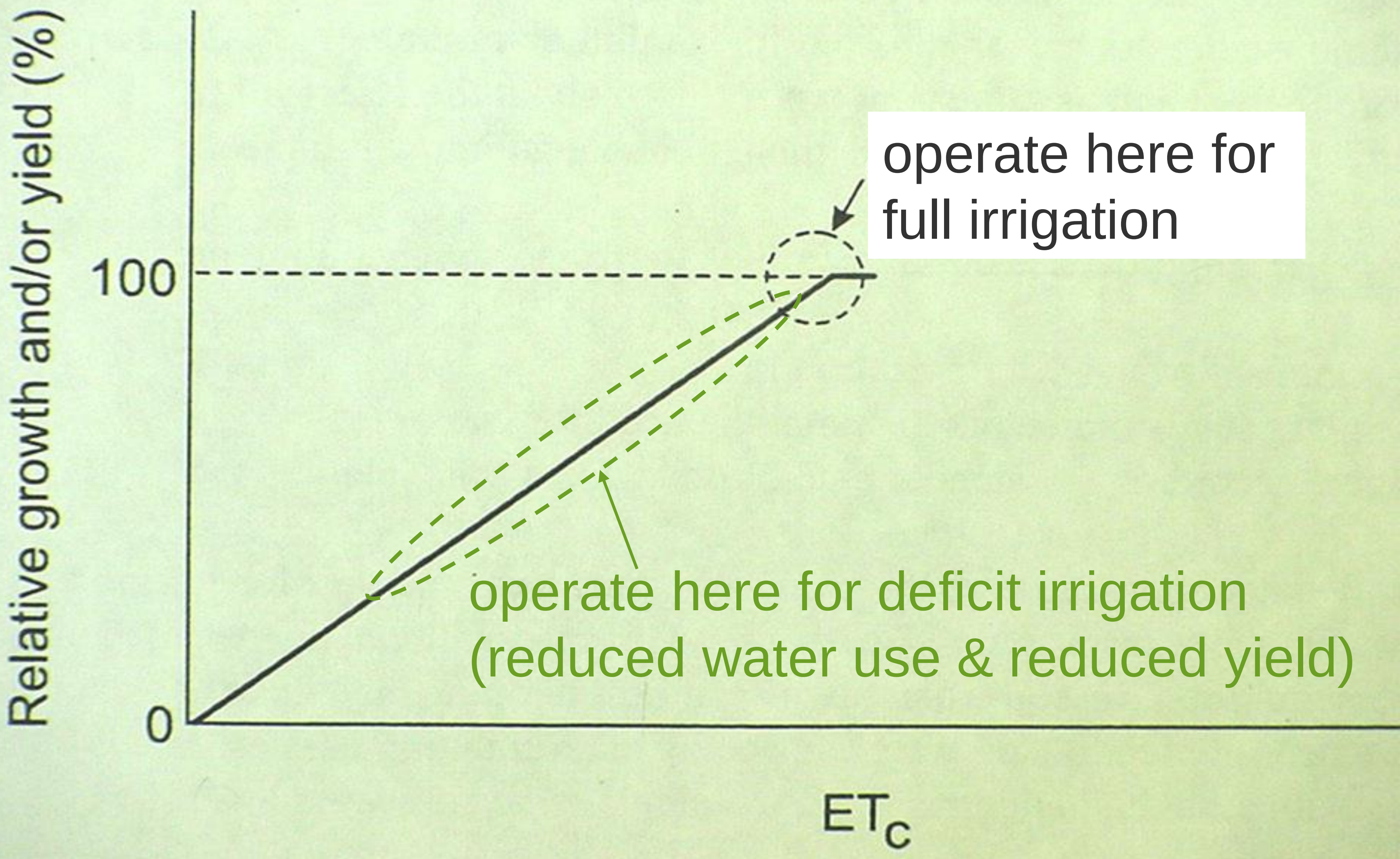
General Approaches

- Maintain soil moisture within desired limits
  - direct measurement
  - moisture accounting
- Use plant status indicators to trigger irrigation
  - wilting, leaf rolling, leaf color
  - canopy-air temperature difference
- Irrigate according to calendar or fixed schedule
  - Irrigation district delivery schedule
  - Watching the neighbors

Yield/Appearance vs. ET_c

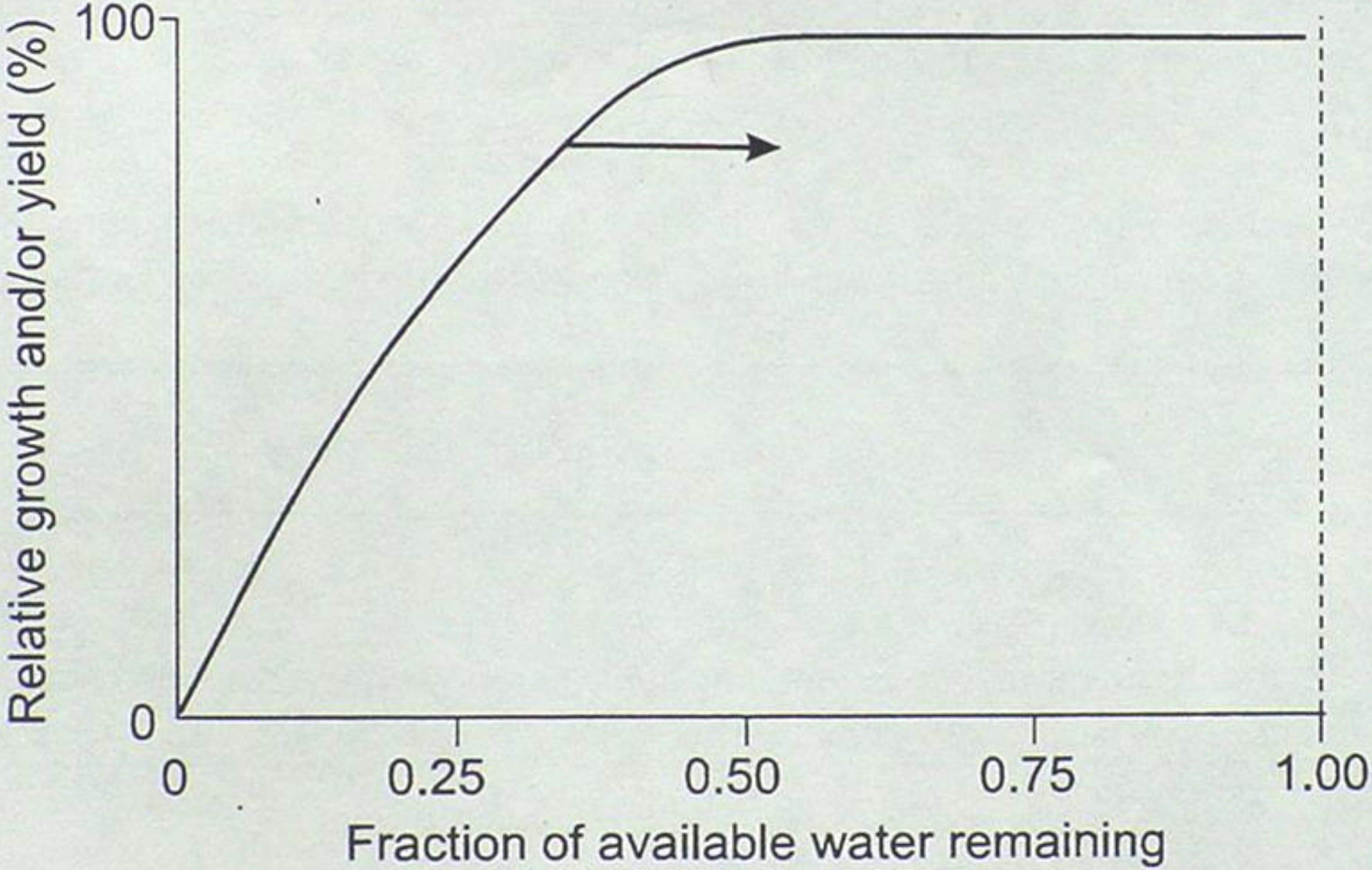


Deficit Irrigation



Growth/Yield vs. fr

(Figure 6.2)



Water Availability Thresholds

- fr_{min} = minimum fraction of available water remaining before plant stress occurs
- fd_{max} = maximum allowable fraction of available water depletion before plant stress occurs
- $fd_{max} = 1 - fr_{min}$
- fd_{max} depends on species, genotype, weather
- Rule-of-Thumb: $fd_{max} = 0.50$ (use this rule with caution)

fd_{max} by Crop and Maximum Crop ET Rate

Table 6.1. Estimated maximum allowable fraction depletion to maintain maximum yields of crops grouped according to sensitivity (modified from Doorenbos and Kassam, 1979).

Group	Crops
1	onion, pepper, potato
2	banana, cabbage, pea, tomato
3	alfalfa, bean, citrus, groundnut, pineapple, sunflower, watermelon, wheat
4	cotton, sorghum, olive, grape, safflower, corn, soybean, sugarbeet, tobacco

	f_{dmax} to Maintain Maximum Evapotranspiration Rates								
	Maximum ET_c (in/d)								
Crop Group	0.08	0.12	0.16	0.20	0.24	0.28	0.31	0.35	0.39
1	0.50	0.43	0.35	0.30	0.25	0.23	0.20	0.20	0.18
2	0.68	0.58	0.45	0.40	0.35	0.33	0.28	0.25	0.23
3	0.80	0.70	0.60	0.50	0.45	0.43	0.38	0.35	0.30
4	0.88	0.80	0.70	0.60	0.55	0.50	0.45	0.43	0.40

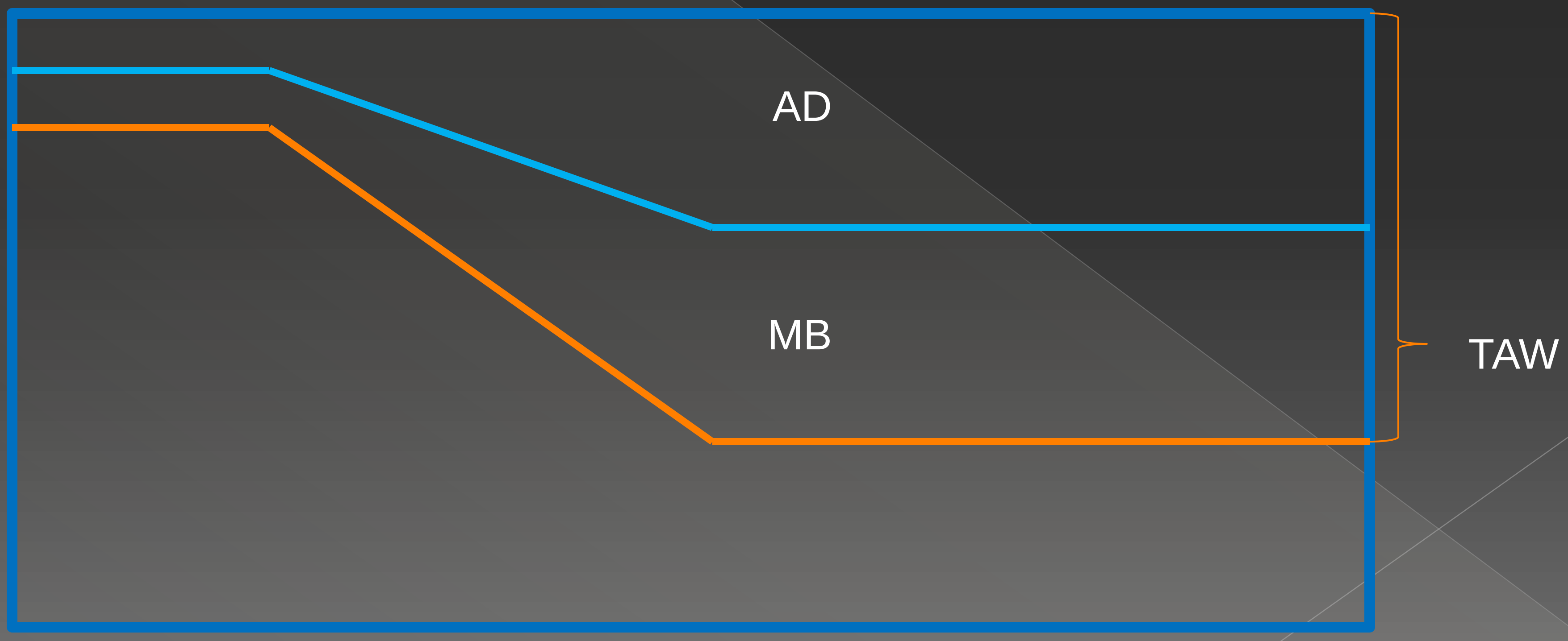
Possible Irrigation Scheduling Management Objectives

- Maximum yield/biomass production
- Maximum economic return
- Keeping plants alive

-Moisture Accounting- Soil Water Reservoir

- $TAW = (R_d)\ (AWC)$
  - TAW = total available water, (in. or mm)
- $AD = fd_{max}\ (TAW)$
  - AD = management allowed deficit, (in. or mm)
- $MB = fr_{min}\ (TAW)$
  - MB = minimum balance (min. allowable available soil water), (in. or mm)
- $TAW = AD + MB$

- Change in TAW as rooting depth increases



Plant Root Zones

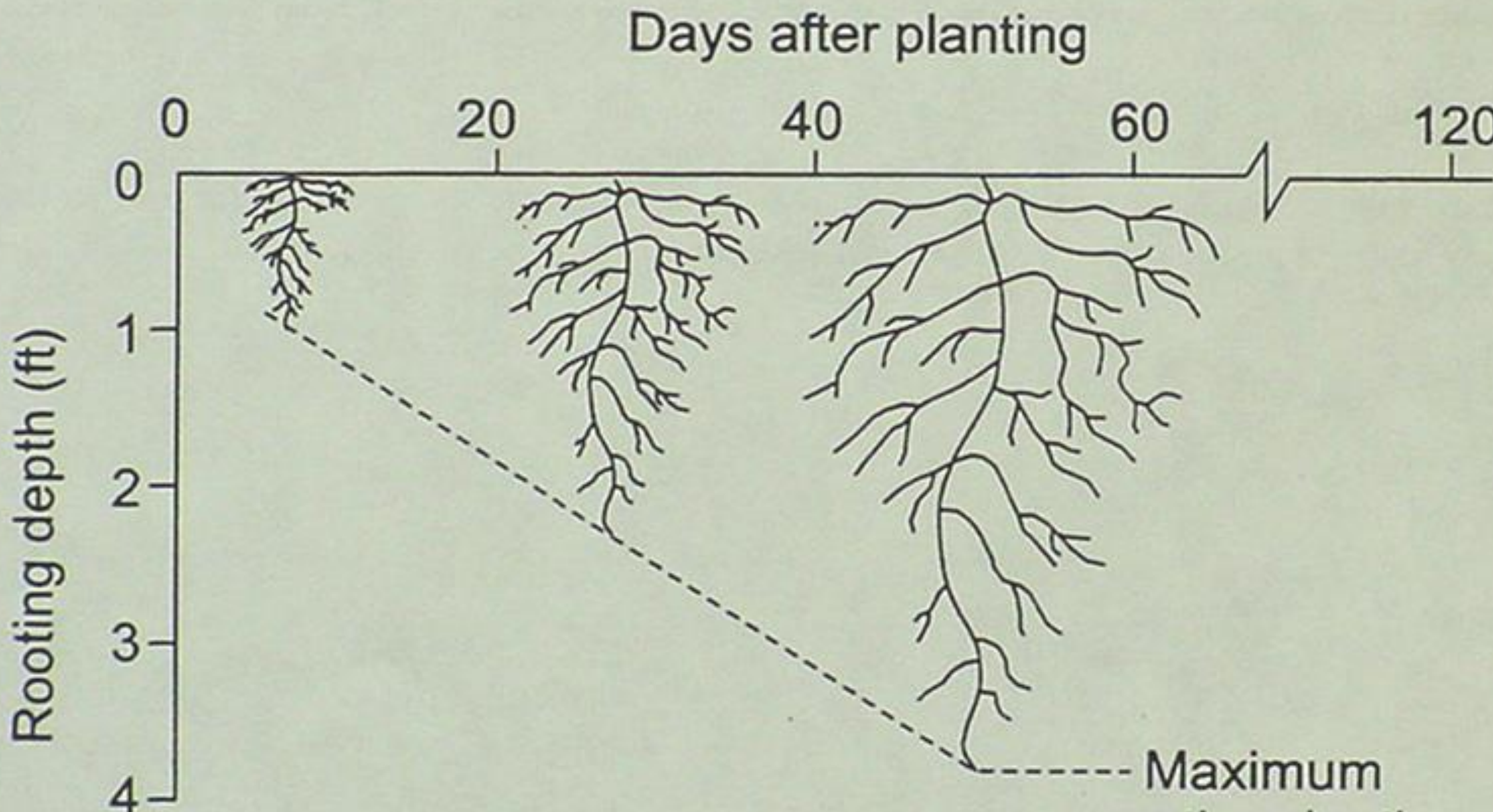
- Depth used for scheduling vs. maximum depth where roots are found
- Influenced by soil characteristics
  - Soil texture
  - Hardpan
  - Bedrock
- Perennial vs. annual plants

Table 6.2. Range of maximum effective rooting depths for fully grown plants.

Crop	Maximum Effective Depth, ft	Crop	Maximum Effective Depth, ft
Alfalfa	3.0 - 10	Onions	2.6 - 6.6
Banana	1.3 - 2.6	Other small grains	3.3 - 5.0
Barley	3.3 - 4.3	Palm trees	2.3 - 3.6
Beans	1.3 - 2.6	Peas	2.0 - 3.3
Cabbage	2.0 - 3.3	Peppers	1.7 - 3.3
Carrots	1.6 - 3.3	Pineapple	1.0 - 2.0
Celery	1.0 - 1.7	Potatoes	1.3 - 2.6
Citrus	3.3 - 5.9	Safflower	3.3 - 6.6
Clover	2.0 - 3.0	Sisal	1.7 - 3.3
Cotton	3.3 - 6.6	Sorghum	3.3 - 6.6
Cucumber	2.3 - 4.0	Soybeans	2.6 - 5.0
Dates	5.0 - 8.3	Spinach	1.0 - 1.7
December orchards	3.3 - 9.9	Strawberries	0.7 - 1.0
Flax	3.3 - 5.0	Sugarbeet	2.6 - 6.6
Grapes	3.3 - 6.6	Sugarcane	4.0 - 6.6
Grass	1.7 - 5.0	Sunflower	3.3 - 8.3
Groundnuts	1.7 - 3.3	Sweetpotatoes	3.3 - 5.0
Lettuce	1.0 - 1.7	Tobacco	1.7 - 3.3
Maize	3.3 - 6.6	Tomatoes	2.3 - 5.0
Melons	3.3 - 5.0	Vegetables	1.0 - 2.0
Olives	2.6 - 6.6	Wheat	3.3 - 6.6

Modified from Doorenbos and Pruitt (1977).

Root Development of Annual Plants



Assumes linear increase in rooting depth from germination to maximum depth

Figure 6.3. Development of a corn plant's root zone.

Example 6.2

Determine the root zone depth for corn at early tassel assuming that depth at germination is 6 inches, maximum rooting depth is 4 feet, full depth occurs 90 days after germination, and early tassel occurs 50 days after germination.

Given: D_{ag} = 50 days,
D_{tm} = 90 days,
R_{dmin} = 0.5 feet, and
R_{dmax} = 4.0 feet.

Find: R_d at early tassel.

Use Equations 6.6 and 6.7

$$R_f = \frac{50\ days}{90\ days} = 0.56$$

$$R_d = 0.5 \text{ ft} + (4.0 \text{ ft} - 0.5 \text{ ft})\ 0.56 = 2.5 \text{ feet}$$

4-3-2-1 Rule-of-Thumb

- Divide the crop root depth into quarters
- Upper ¼ provides 40% of water uptake
- 2nd ¼ provides 30% of water uptake
- 3rd ¼ provides 20% of water uptake
- Lowest ¼ provides only 10% of water uptake
- Applies only when most of root zone irrigated to field capacity
- Dictated by distribution of root mass

Maximum vs. Effective Rooting Depth

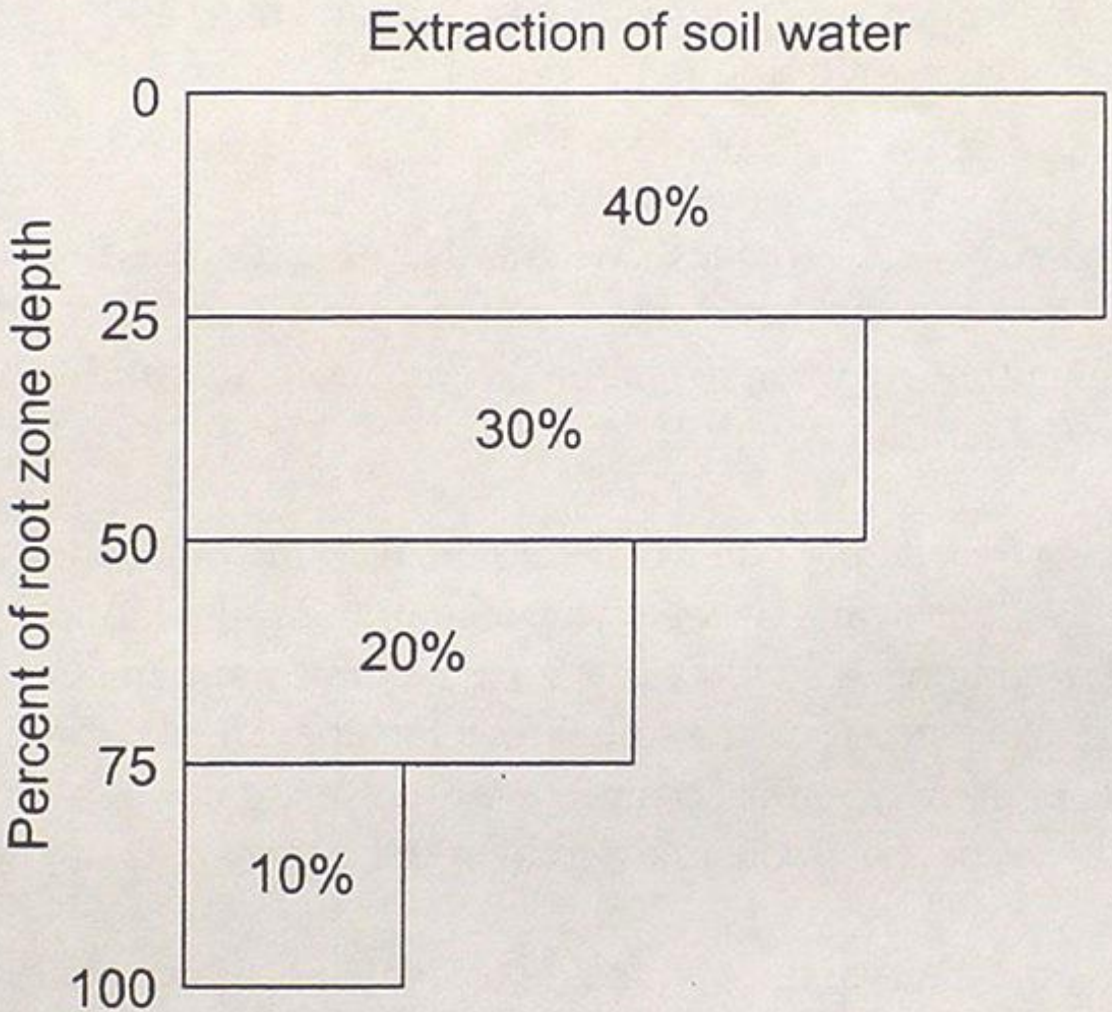


Figure 6.4. Average moisture extraction from the plant root zone, the 4-3-2-1 rule.

Irrigation Timing

- Maximum irrigation interval, (days)

$$T_{max} = \frac{AD}{ET_c}$$

- Actual irrigation interval, (days)

$$T = \frac{d_e}{ET_c}$$

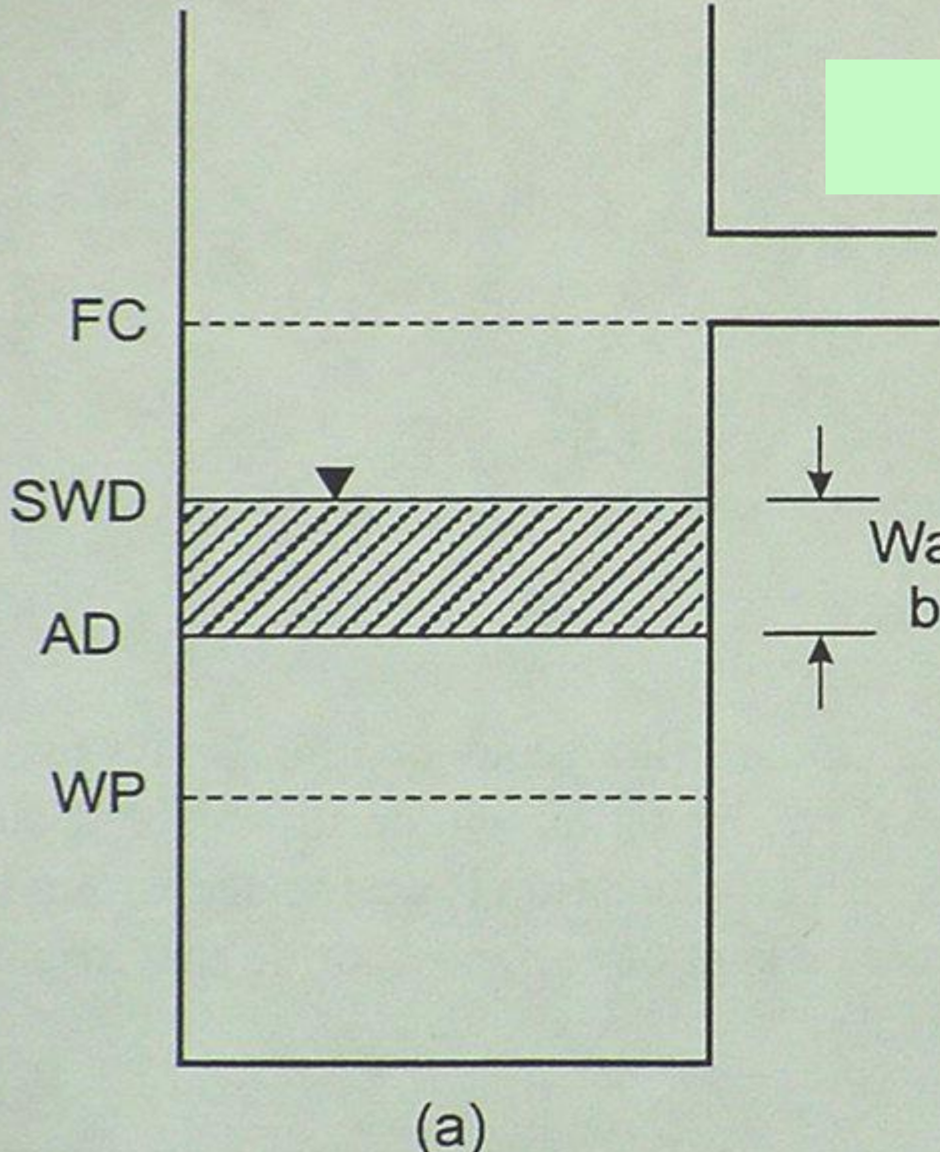
d_e = effective depth of irrigation, (in. or mm)

Latest Date

$$LD = \frac{AD - SWD}{ET_c(forecast)}$$

- LD = maximum number of days before irrigation should occur
- ET_c(forecast) can be based on long-term averages or last few days

Latest Date



$$LD = \frac{AD - SWD}{ET_C}$$

Figure 6.5. Illustration of LD concept.

Example 6.3

Field beans (crop group 3) are being grown in a fine sandy loam soil (AWC = 0.13 in/in). The feel and appearance method for determining soil water revealed that the average $f_r = 0.80$ in the root zone. Determine the latest date for irrigation. Assume that the root zone depth is 24 inches, and ET_c of the unstressed crop is 0.3 in/d.

Given: AWC = 0.13 in/in,
$R_d = 2$ feet = 24 in,
Current $f_d = 0.20$, and
ET_c (forecast) = 0.30 in/d.

Find: LD
$f_{dmax} = 0.38$

Solution: AD = (24 in)(0.13 in/in)(0.38) = 1.2 in
SWD = (24 in)(0.13 in/in)(0.20) = 0.6 in

$$LD = \frac{1.2\ in - 0.6\ in}{0.3\ in/d} = 2 \text{ days}$$

Alternate solution:

Since $f_{dmax} = 0.38$, $f_{rmin} = 0.62$
MB = (24 in)(0.13 in/in) (0.62) = 1.9 in
WB = (24 in)(0.13 in/in) (0.80) = 2.5 in

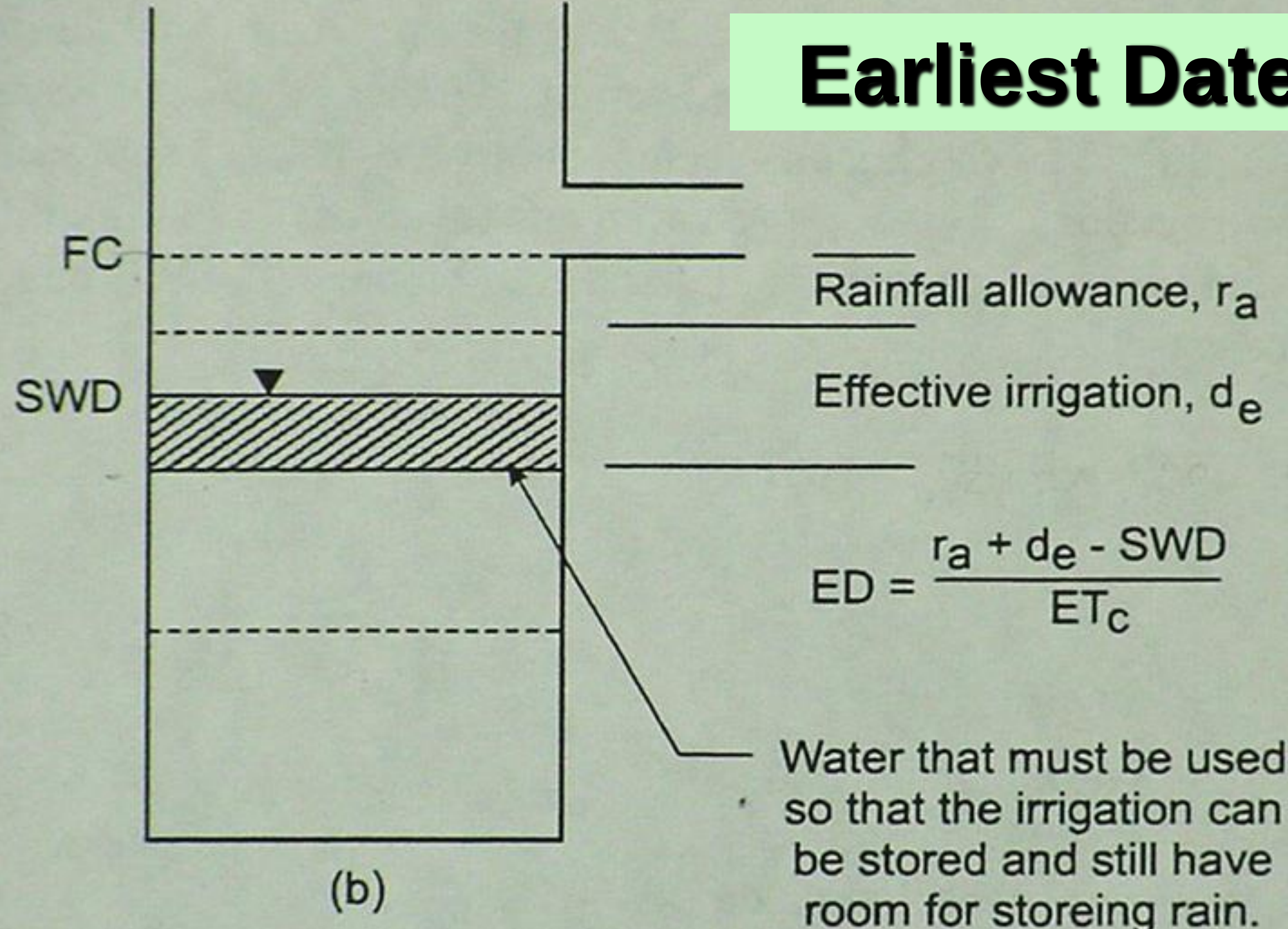
$$LD = \frac{2.5\ in - 1.9\ in}{0.3\ in/d} = 2 \text{ days}$$

Earliest Date

$$ED = \frac{r_a + d_{ep} - SWD}{ET_c(\,forecast\,)}$$

- ED = minimum number of days before irrigation should occur
- d_{ep} = planned effective depth of water
- r_a = rainfall allowance (allow room in the profile beyond d_{ep})

Earliest Date



$$ED = \frac{r_a + d_e - SWD}{ET_c}$$

Figure 6.7. Illustration of ED concept.

Example 6.4

Suppose in Example 6.3 that $d_{ep} = 0.5$ in, $r_a = 0.4$ in, and from the previous example, SWD = 0.6 in. Find the earliest date that you should irrigate.

Given: $d_{ep} = 0.5$ in
$r_a = 0.4$ in
SWD = 0.6 in

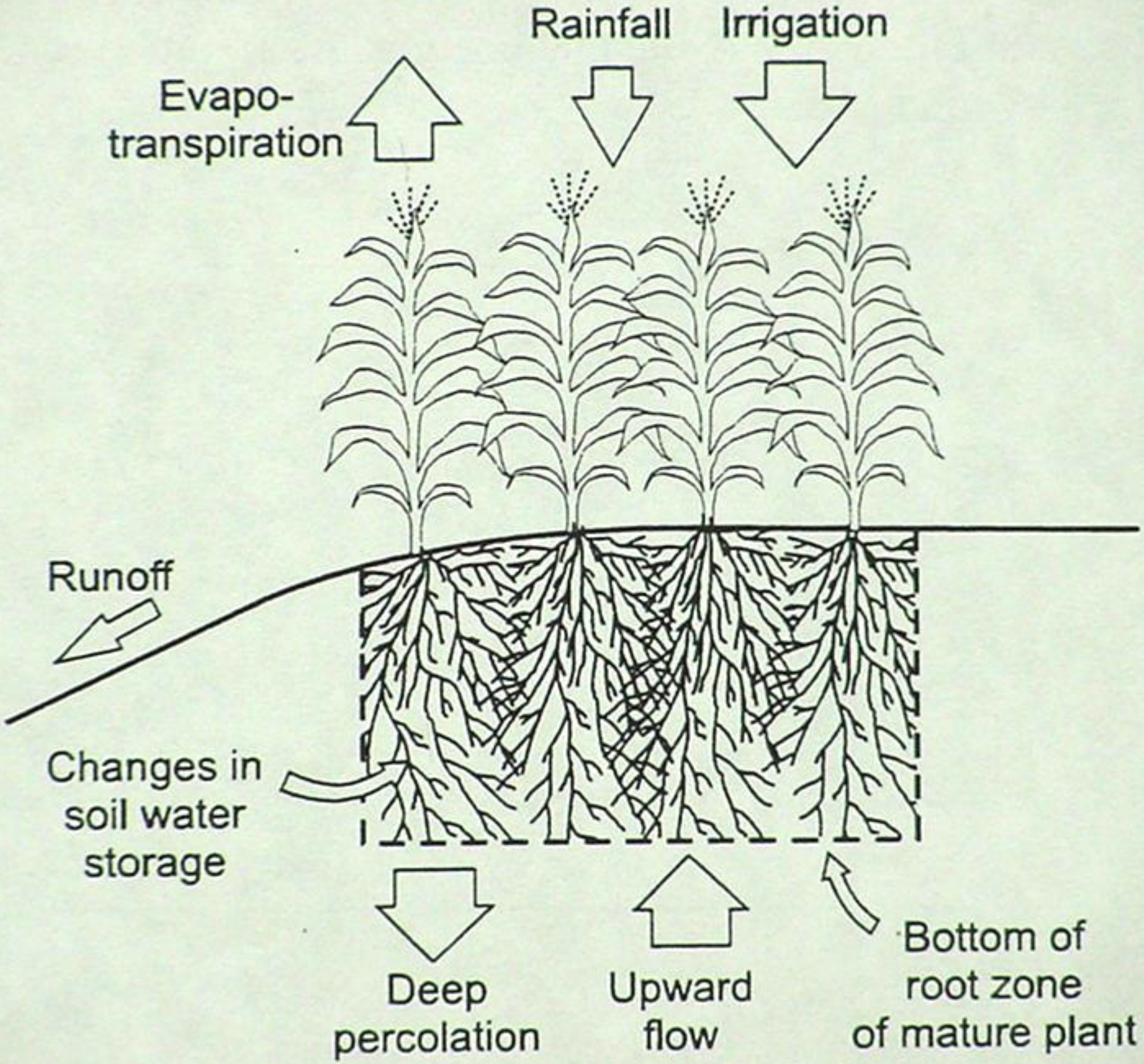
Find: ED

Solution:

$$ED = \frac{(0.4 + 0.5)\ in - 0.6\ in}{0.3\ in/d} = 1\ day$$

Since the ED date was 2 days, irrigation should occur either 1 or 2 days from now.

Components of Crop Root Zone Water Balance



Soil Water Budget Calculations

$$SWD_i = SWD_{i-1} + ET_{c\ i-1} - d_{e\ i-1} - P_{e\ i-1} - U_{f\ i-1}$$

Subscripts: i = today i-1 = yesterday

(all quantities below in consistent depth units: inches, mm, etc.)

SWD= soil water deficit

ET_c = crop evapotranspiration

d_e = effective irrigation

P_e = effective precipitation

U_f = upward flow of water from a shallow water table

Example 6.5

Corn is grown on a silt loam soil. The pertinent site conditions are:

Given: $f_{dmax} = 0.45$,
$R_d = 2.5$ feet = 30 in,
AWC = 0.2 in/in,
AD = (30 in)(0.2 in/in) (0.45) = 2.70 in,
r_a = rainfall allowance = 0.5 in,
$d_{ep} = 1.1$ inches, and
Depth to water table = 10 feet.

The SWDs at the start of June 25 were 2.2 and 0.80 inches for Locations 1 and 2 in the irrigated area, respectively. The ET_c and P_e for June 25-28 are known.

Find: Determine the LD and ED for each location for June 25-28.

Solution: Use Equations 6.10, 6.14 and 6.16

The results of the calculations are shown in the emphasized italics print in Table 6.6.

Table 6.6. Checkbook accounting irrigation scheduling data sheet.

					Location 1				Location 2			
Date	Actual ET_c	Forecast ET_c	P_c	U_f	SWD	d_c	ED	LD	SWD	d_c	ED	LD
	(in/d)		(in)		(in)		(days)		(in)		(days)	
June 25					2.20		–	***3***	0.80		***4***	***11***
	0.20	0.18	0.0	0.0		0				0		
26					***2.40*** *		–	***2***	***1.00***		***3***	***9***
	0.21	0.18	0.0	0.0		0				0		
27					***2.61***		–	***1***	***1.21***		***2***	***8***
	0.13	0.18	0.3	0.0		1.1				0		
28					***1.34***		***1***	***8***	***1.04***		***3***	***9***
	0.17	0.18	0.0	0.0		0				0		

* all numbers in bold italics are computed using equations in this chapter

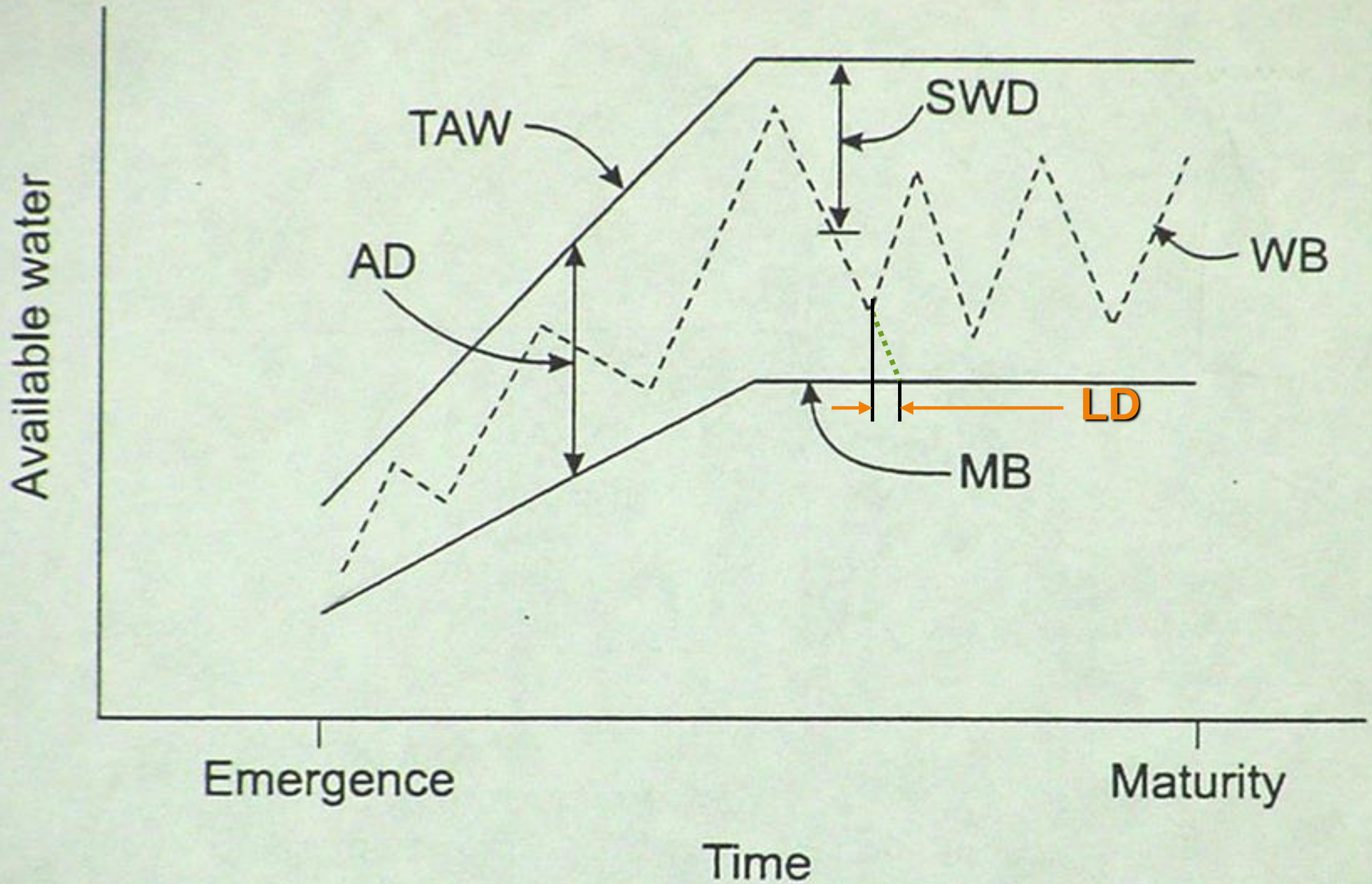


Figure 6.8. Illustration of key irrigation scheduling terms and their changes with time for annual crops.

Other Irrigation Scheduling Methods

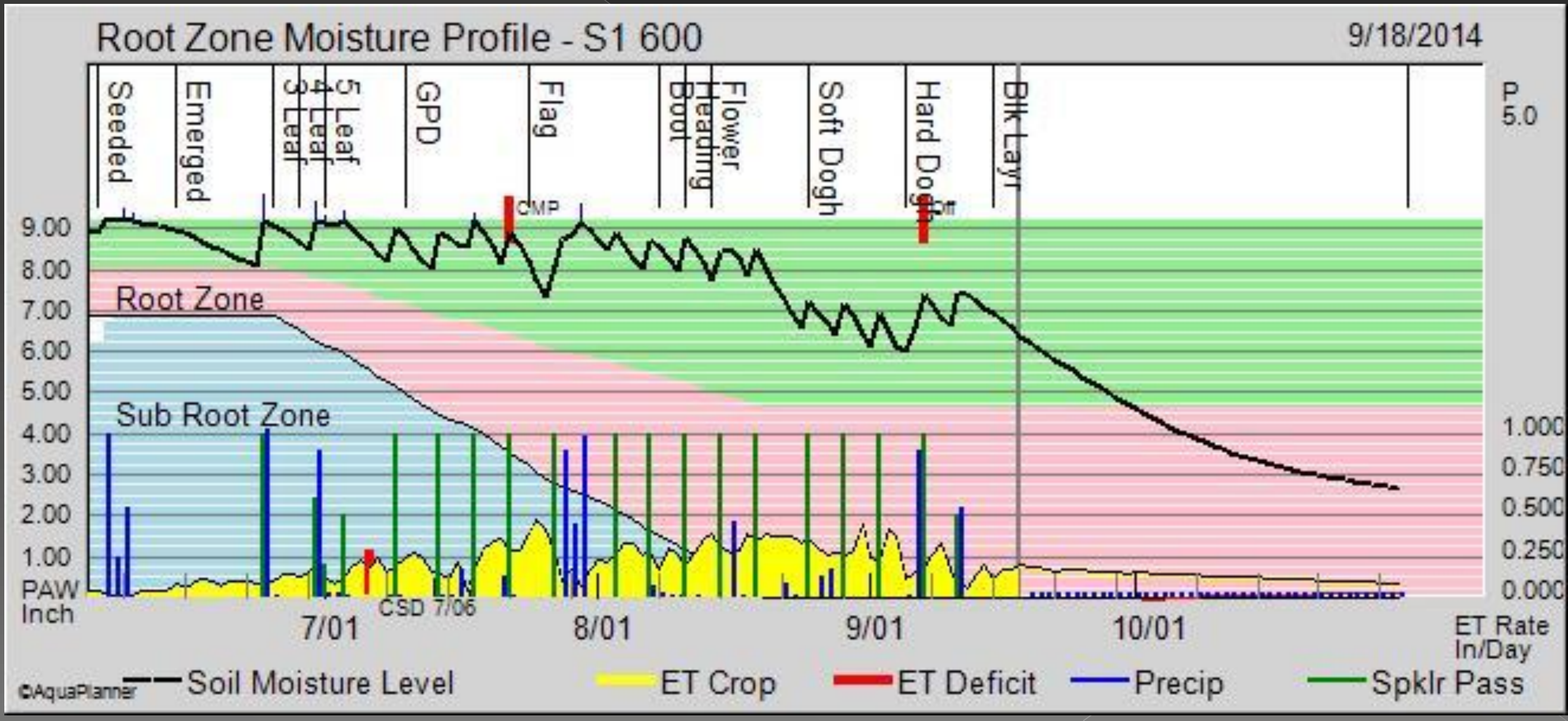
- Soil Water Measurement
  - Determine SWD by measuring:
    - fr or fd (feel and appearance of soil)
    - θ_m (gravimetric sampling)
    - θ_v (neutron scattering)
    - ψ_p (potential: w/ tensiometers or resistance blocks (must convert ψ_p to water content)
  - Need measurements at several locations
  - Need measurements throughout root zone depth
  - Difficult to predict Latest Date
  - Doesn't indicate how much water to apply

Other Irrigation Scheduling Methods

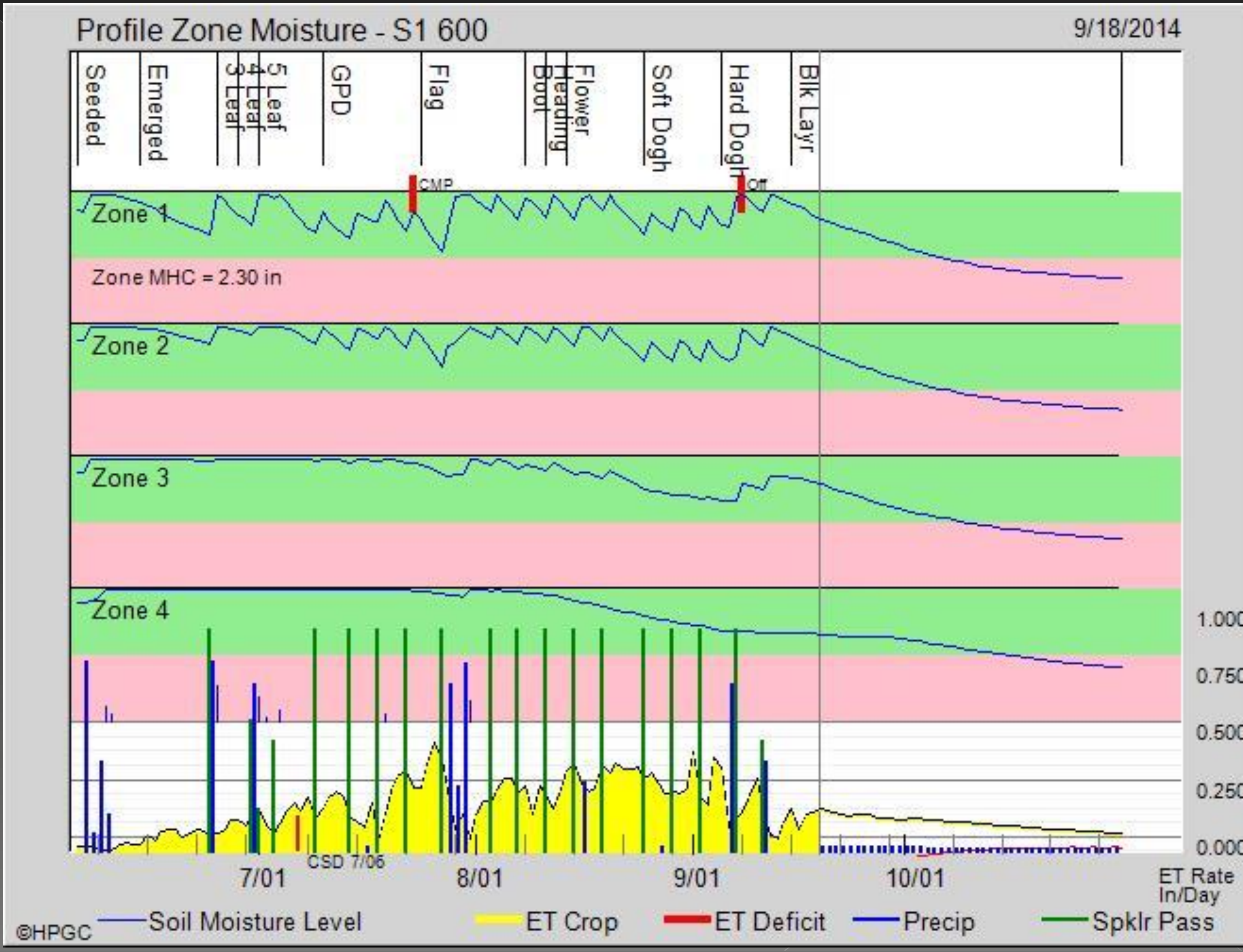
- Plant Status Indicators
  - Leaf water potential (energy status of leaf water)
    - Use pressure chamber or thermocouple psychrometer
    - Measured at mid-day; many samples needed
  - Foliage/Air temperature difference
    - Well-watered plants cooler than air
    - Use infrared thermometer
  - Leaf appearance
    - Color, wilting, etc.
    - Indicators show up too late
  - Irrigate at critical growth stages (e.g.: flowering)

600 gpm

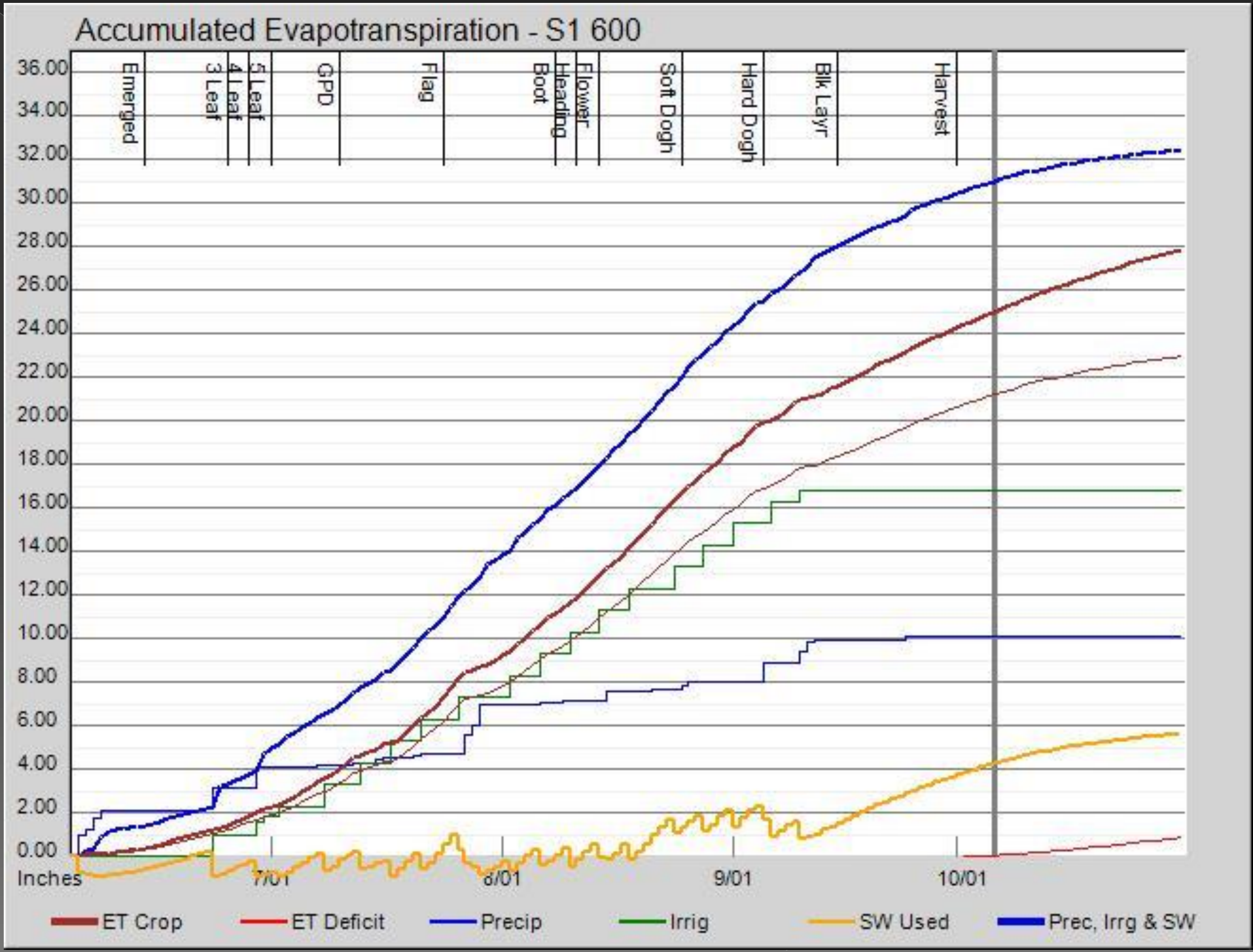
- 10 inchs of rain, 16.8 inches irrigation



600 gpm by depth

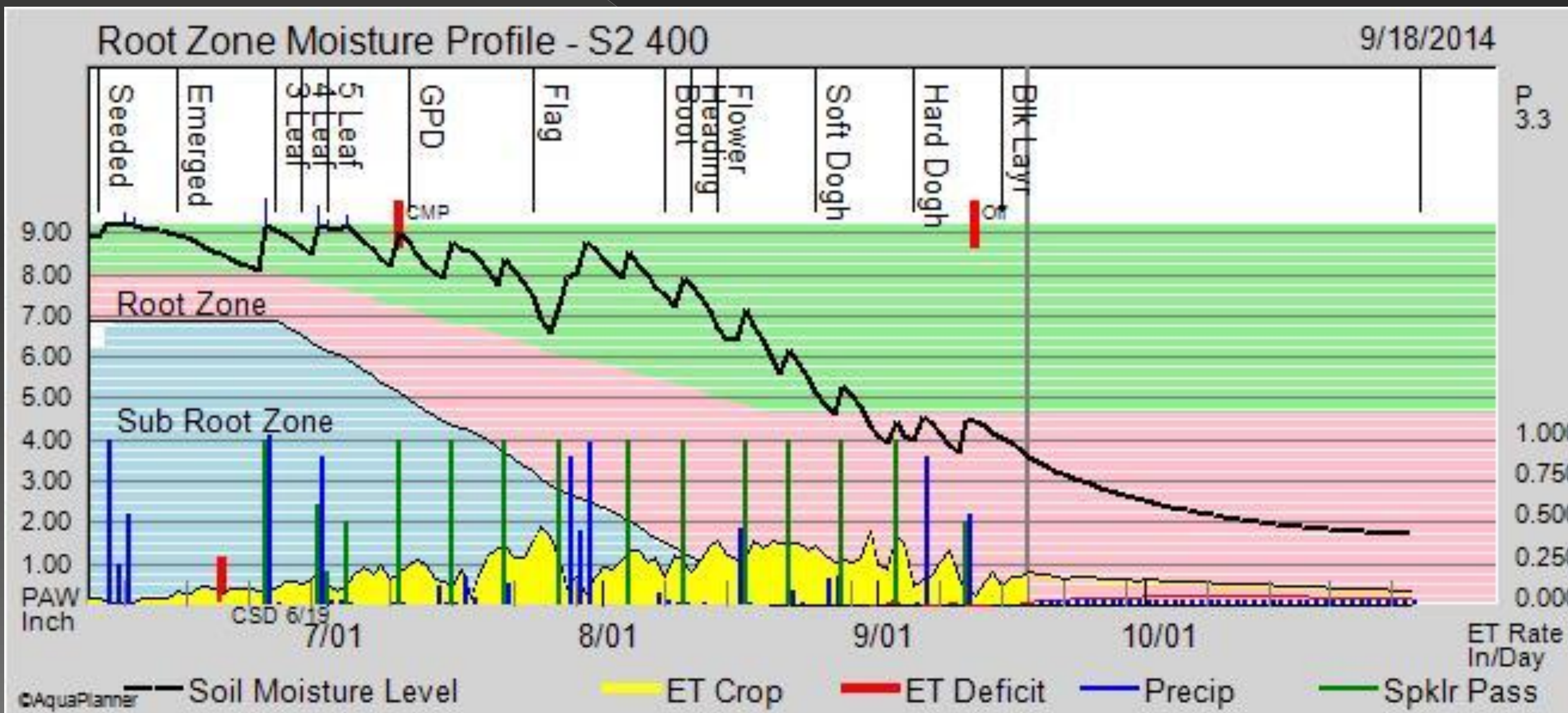


600 gpm cumulative water balance

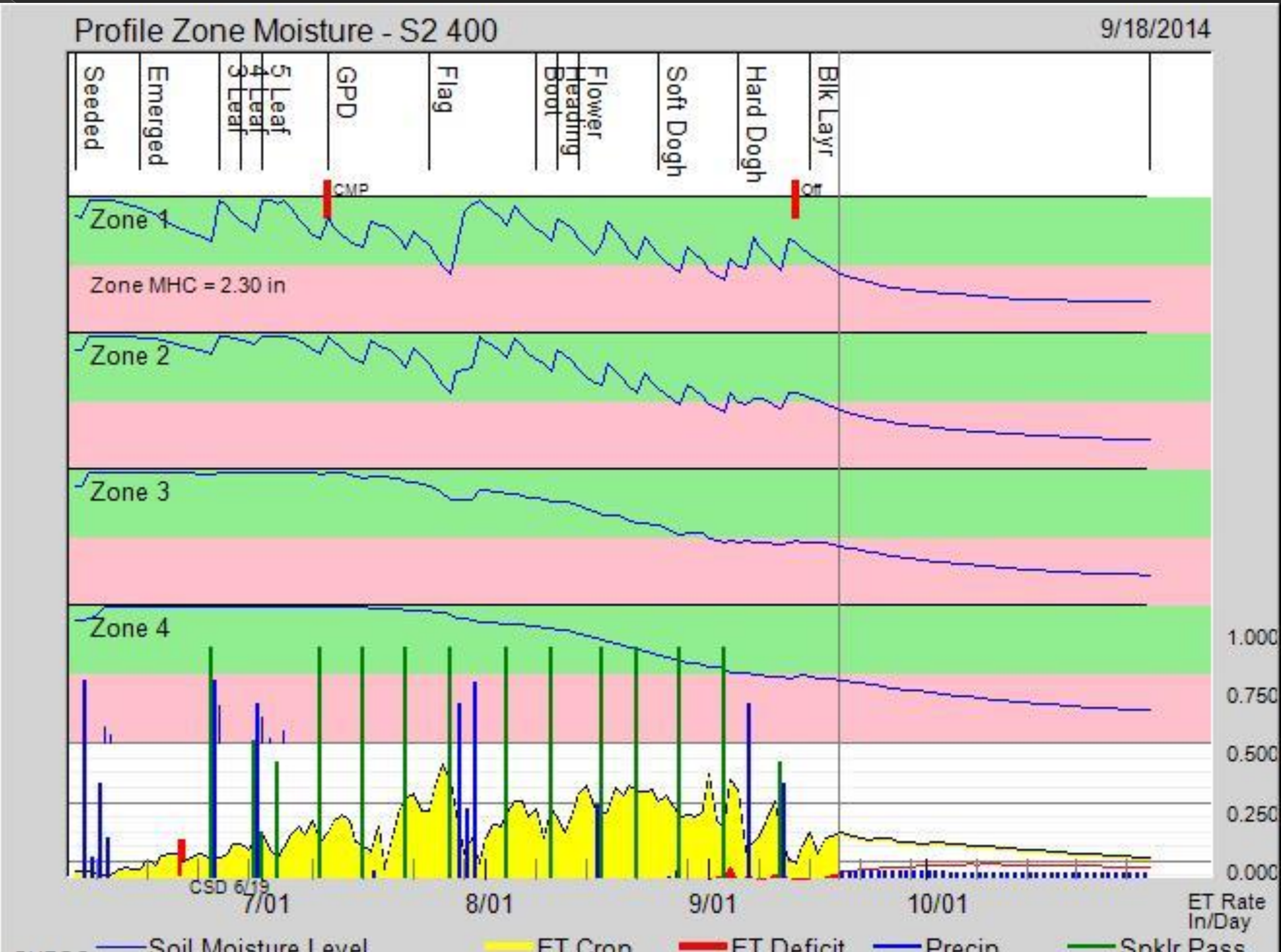


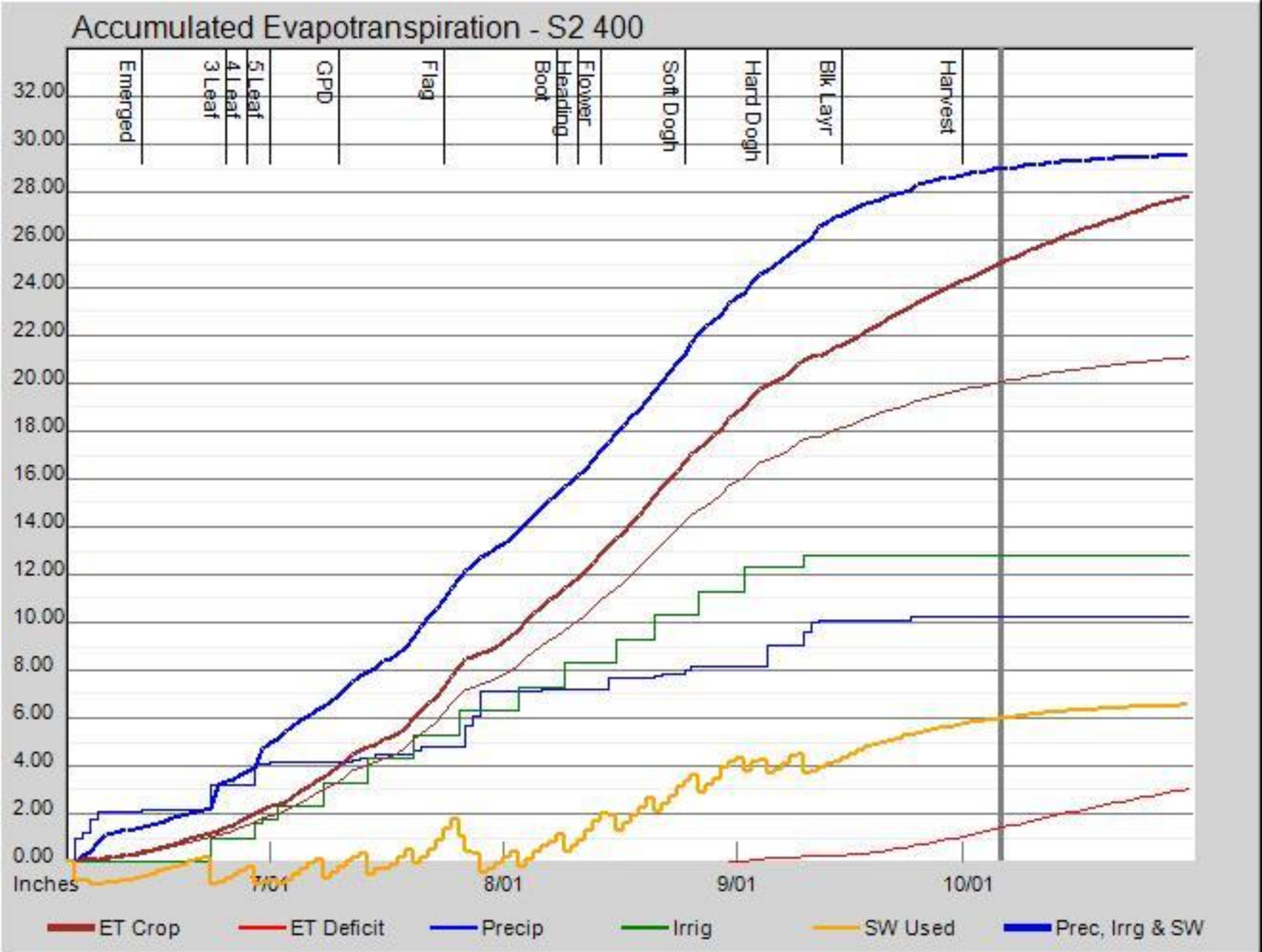
400 gpm

- 10 inches of rain, 12.8 inches of irrigation



400 gpm by depth

- 



Accumulated Evapotranspiration - S2 400
Emerged
3 Leaf
4 Leaf
5 Leaf
GPD
Flag
Boot
Heading
Flower
Soft Dogh
Hard Dogh
Blk Layr
Harvest
32.00
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Inches
7/01
8/01
9/01
10/01
ET Crop
ET Deficit
Precip
Irrig
SW Used
Prec, Irrg & SW