Crop Coefficients

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Irrigation Water Management: Science, Art, or Guess?

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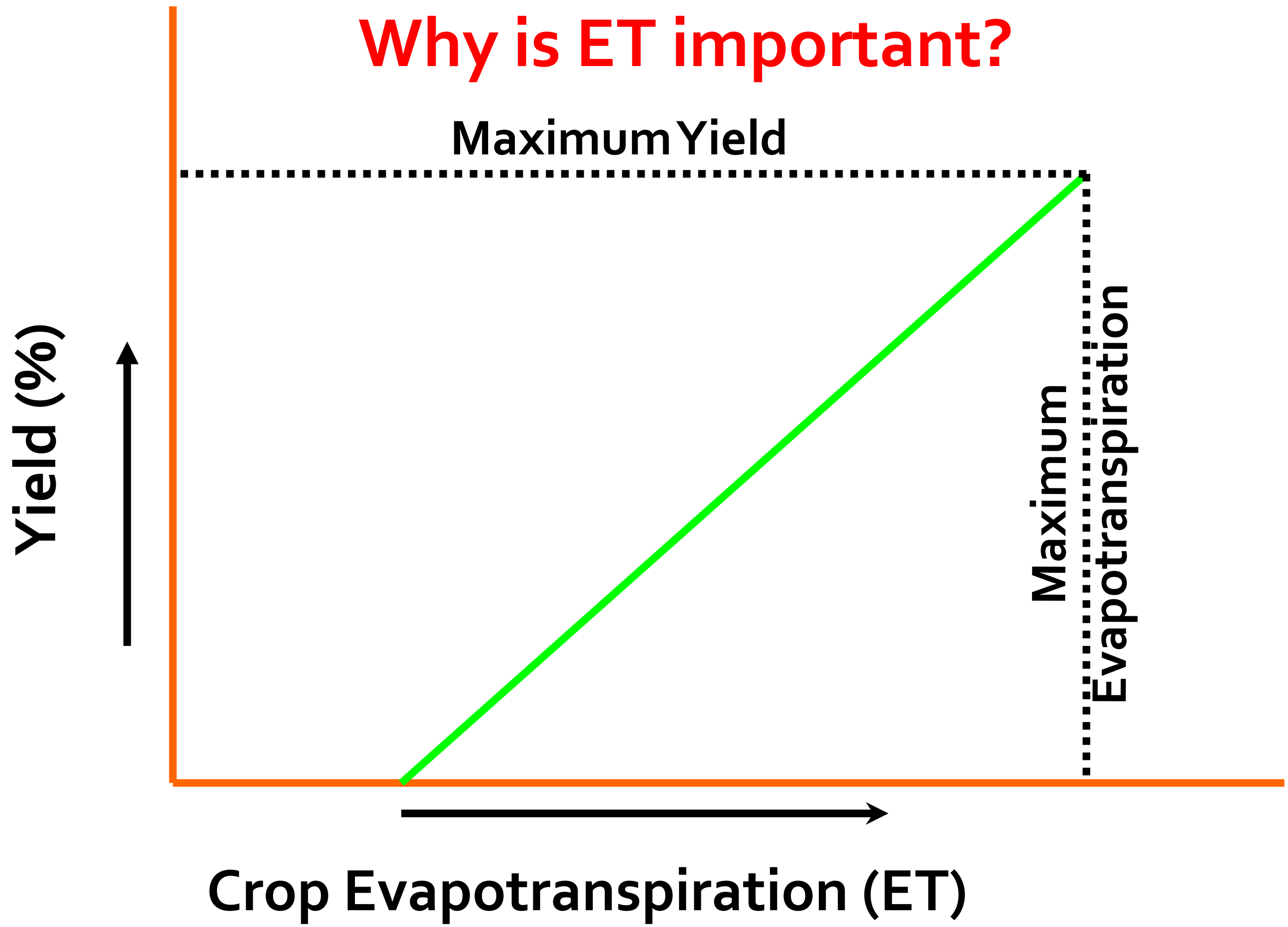
Evapotranspiration (ET)

- Evapotranspiration = crop water use
  - Transpiration (T) - water evaporation from leaves
  - Evaporation (E) - water evaporation from soil
- Small plant canopy – E greater than T
- Large plant canopy - T greater than E
- Most of the evaporation occurs during stand establishment
- More than 95% of the soil water uptake by plants becomes transpiration
- Very difficult to separate T and E
- Very difficult to measure ET

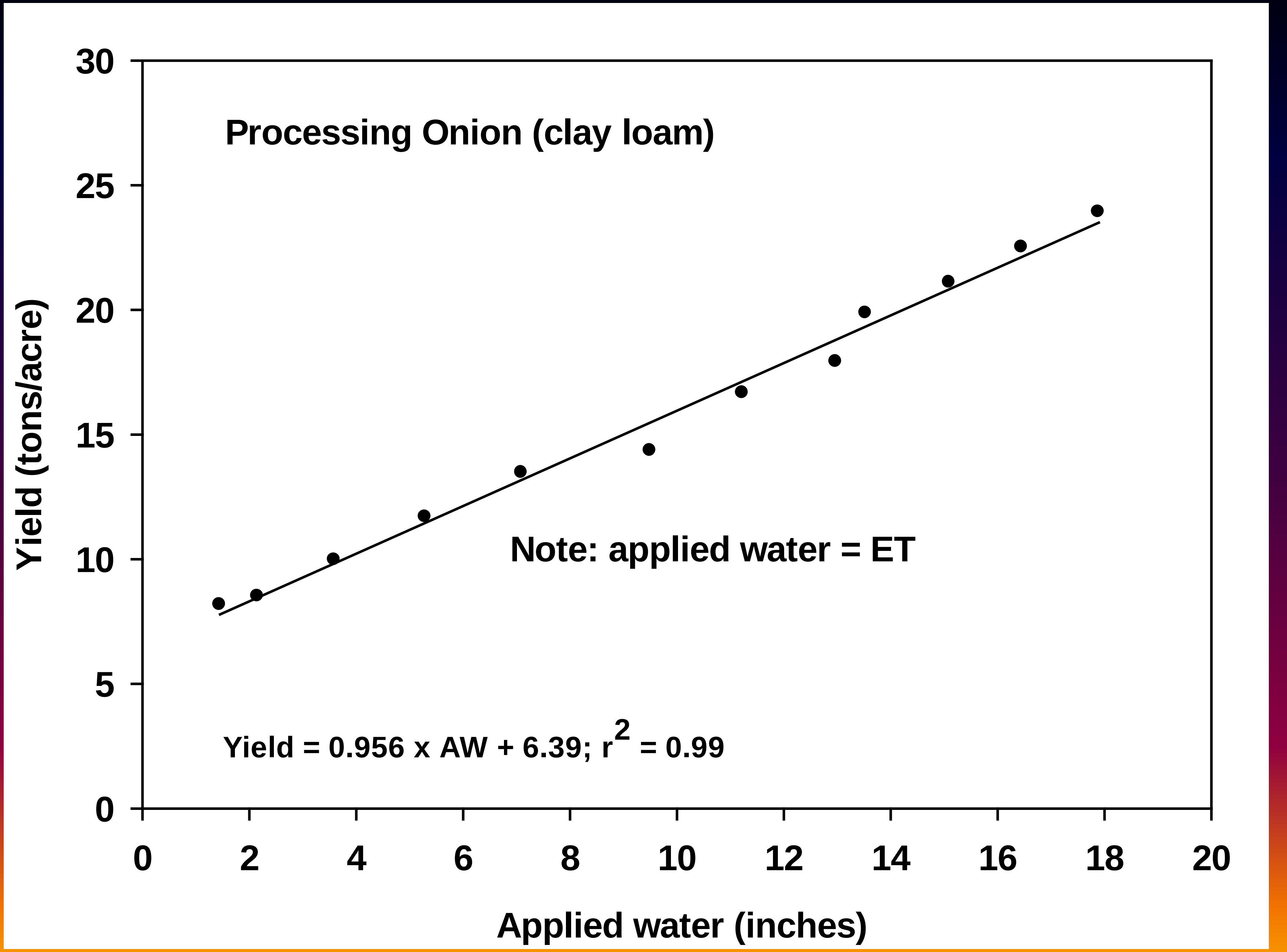
Units of evapotranspiration

- Depth of water = volume of water ÷ area
  - 1 inch of water = amount of water ponded one inch deep over 1 acre
  - 1 foot of water = amount of water ponded one foot deep over 1 acre
- Standardizes water
  - Independent of field size
  - Crop water use expressed in inches of water is the same for all fields
- Volume of water (acre-inches) = inches of water x acres irrigated

Why is ET important?



Main cause of ET less than maximum ET is insufficient soil moisture


Processing Onion (clay loam)
Note: applied water = ET
Yield = 0.956 x AW + 6.39; r2 = 0.99
Yield (tons/acre)
Applied water (inches)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14
16
18
20

Measuring evapotranspiration (ET)

- Difficult and expensive to measure
- Even more difficult to separate transpiration and soil evaporation
- Methods
  - Lysimeter
  - Meteorological methods
  - Soil moisture measurements
  - Other

Lysimeter

- Very expensive
- Not practical for commercial field measurements
- Soil/crop characteristics inside lysimeter similar to those in immediate vicinity
- Potential for accurate measurements
- Daily/hourly values

Micrometeorological Methods

Net radiation, air temperature, humidity, wind speed, soil temperature, soil heat flux

Moderate expense

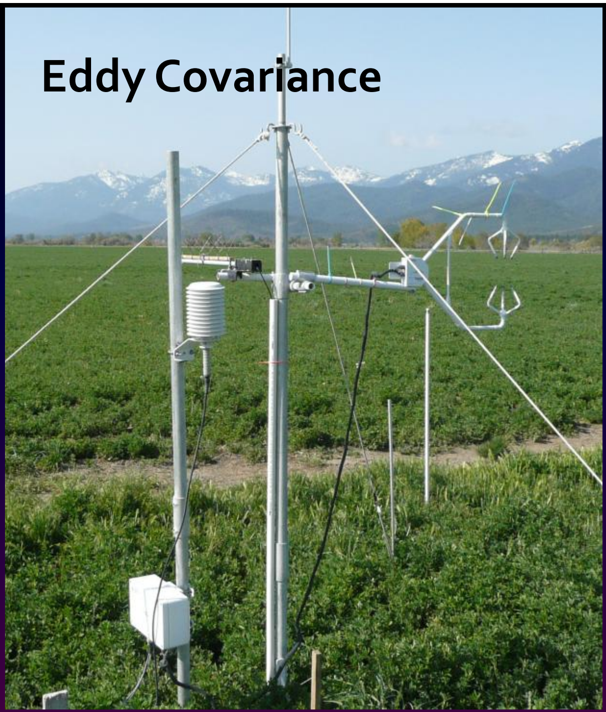
Flexible – can be use in commercial fields

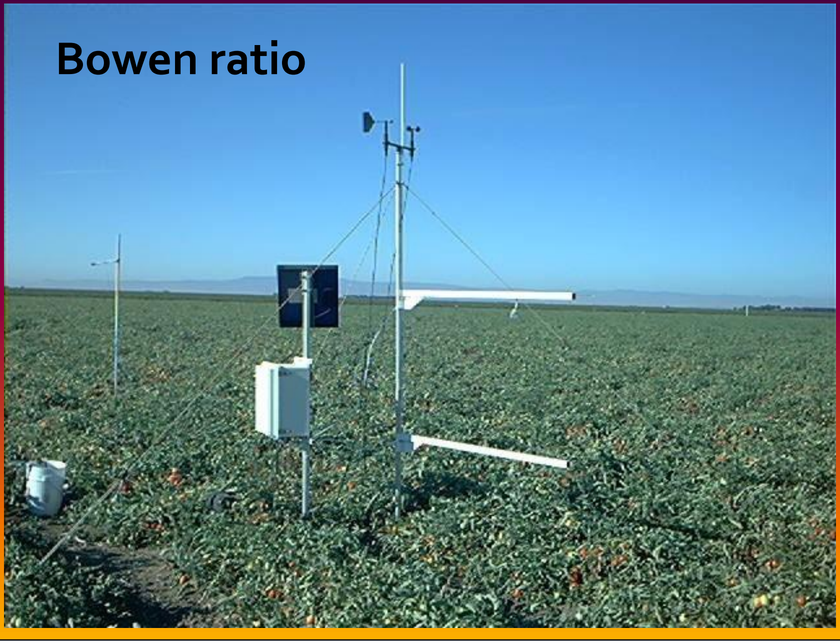
Reasonable accuracy under proper conditions

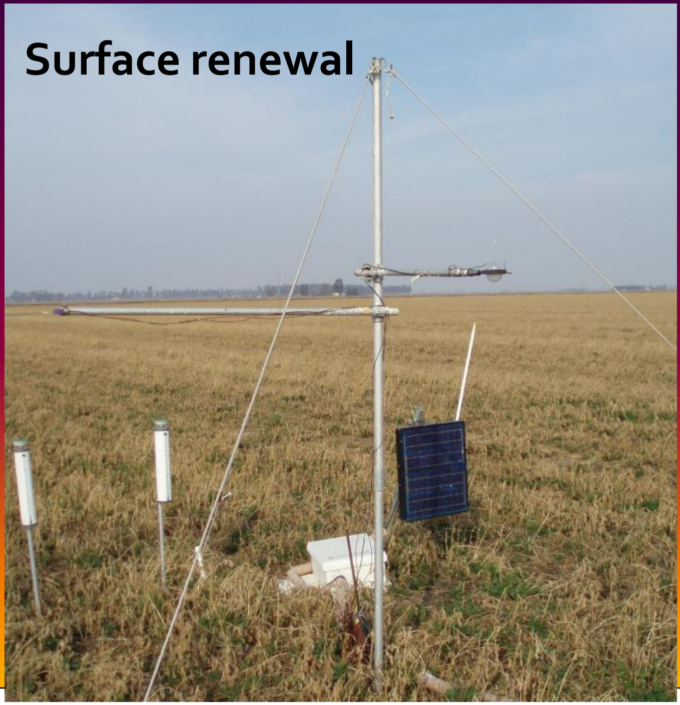
Measurements reflect field-wide conditions

Fetch requirements, sensor damage, data logger problems

Daily/hourly data







Soil moisture measurements

Relatively inexpensive

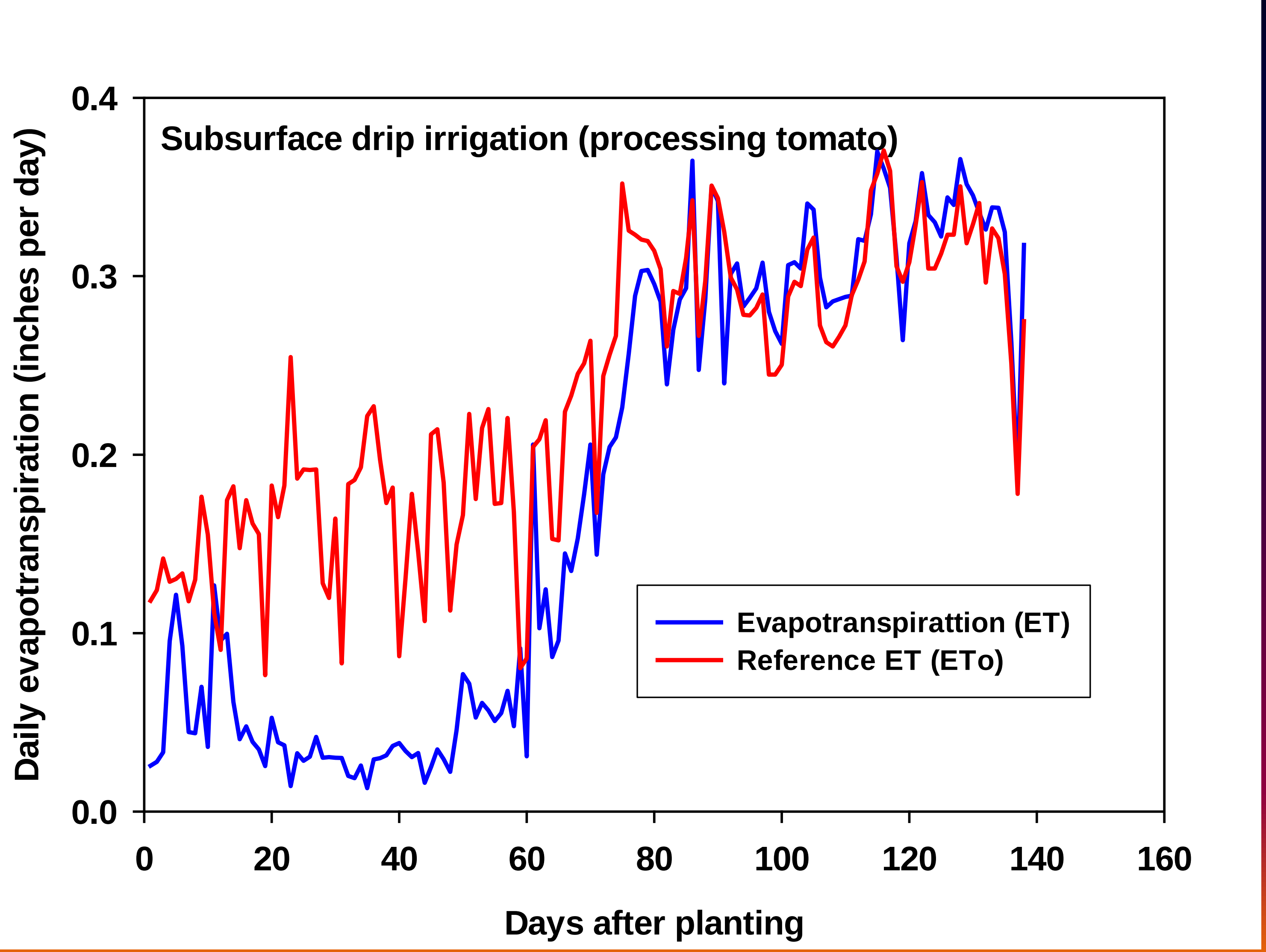
Flexible – can be used in commercial fields

Suitable method – accurate if properly calibrated, volume of soil measured, measurement location relative to root distribution, etc.

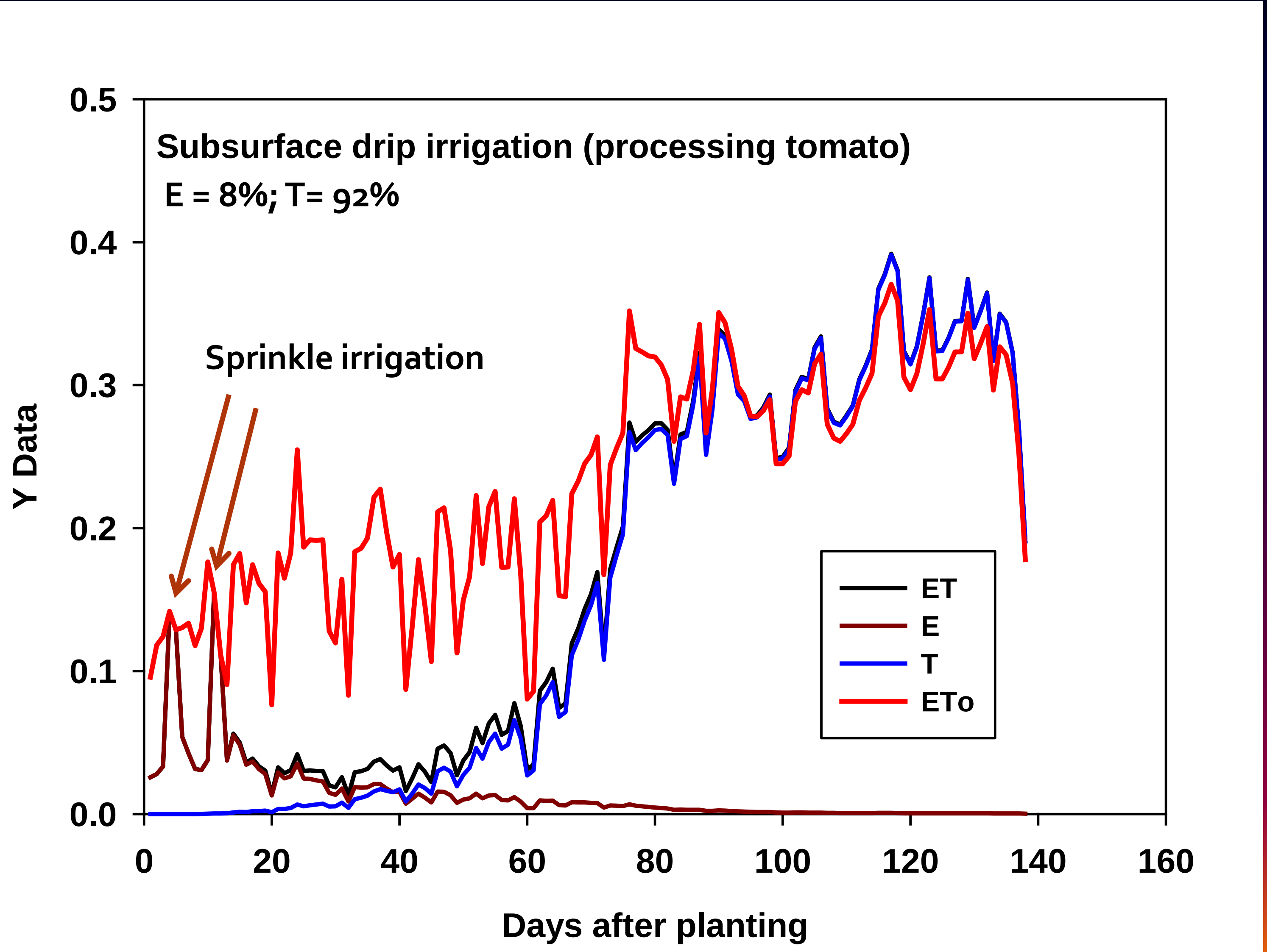
Assumes change in soil moisture over time equals ET (may not be appropriate under shallow ground water conditions)

Missing data due to inaccessibility during and just after irrigation

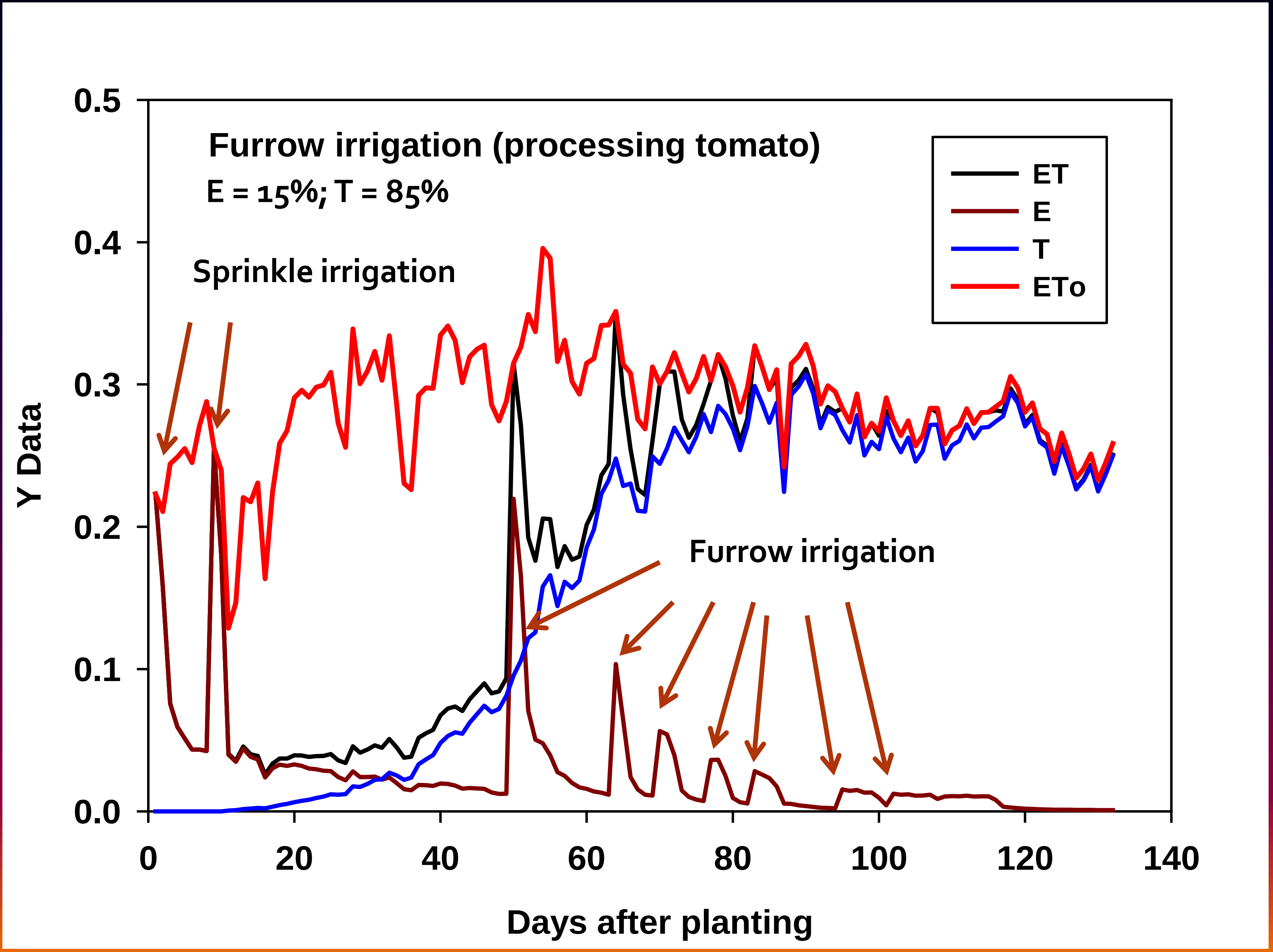
Daily/hourly values not practical



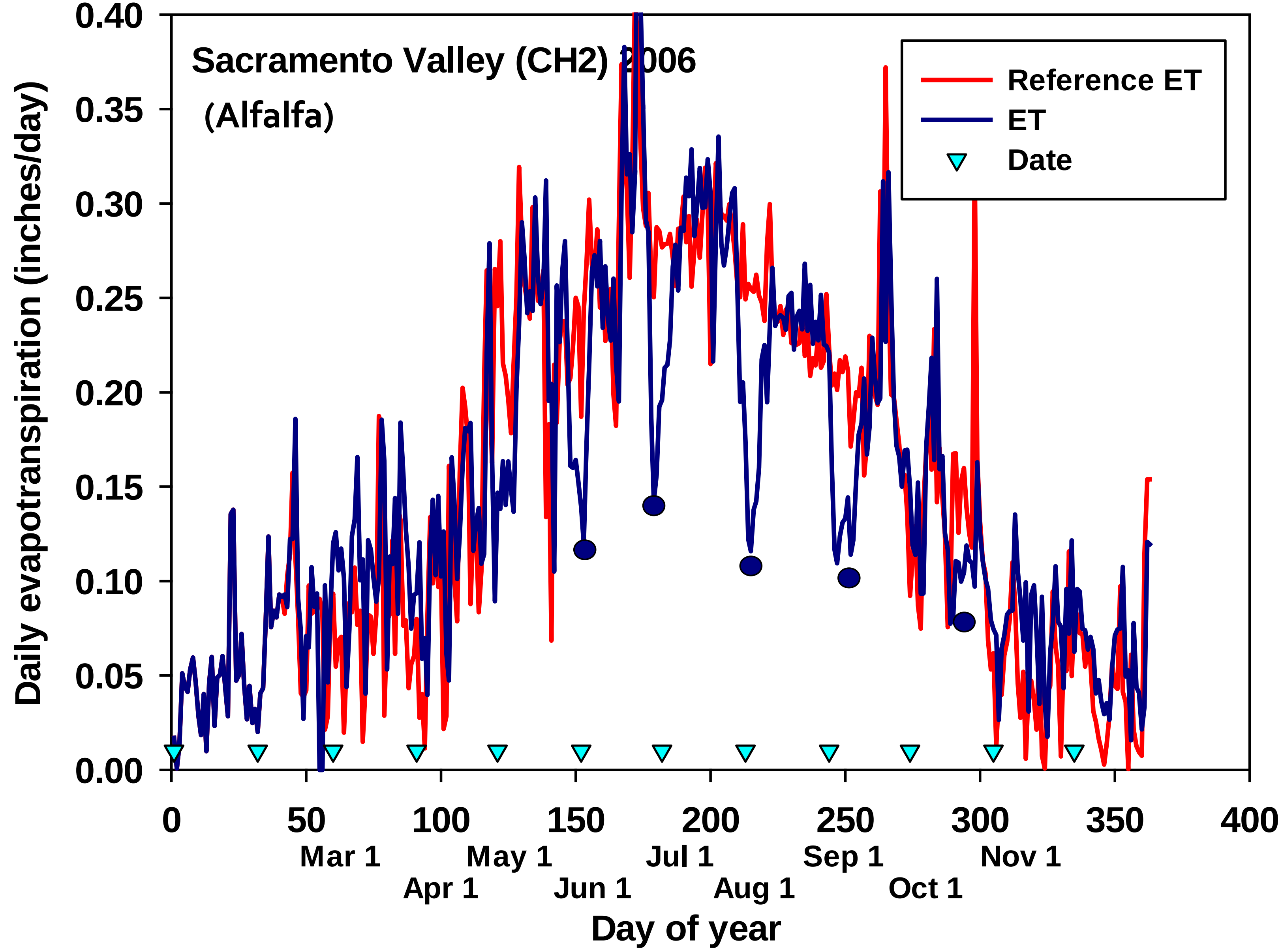
Subsurface drip irrigation (processing tomato)
Daily evapotranspiration (inches per day)
0.0
0.1
0.2
0.3
0.4
0
20
40
60
80
100
120
140
160
Days after planting
Evapotranspirattion (ET)
Reference ET (ETo)



Subsurface drip irrigation (processing tomato)
E = 8%; T= 92%
Sprinkle irrigation
Y Data
Days after planting
ET
E
T
ETo
0.0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
140
160



Furrow irrigation (processing tomato)
E = 15%; T = 85%
Sprinkle irrigation
Furrow irrigation
ET
E
T
ETo
Y Data
Days after planting
0.0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
140



Sacramento Valley (CH2) 2006
(Alfalfa)
Reference ET
ET
Date
Daily evapotranspiration (inches/day)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0
50
100
150
200
250
300
350
400
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Day of year

Estimating ET at the farm level

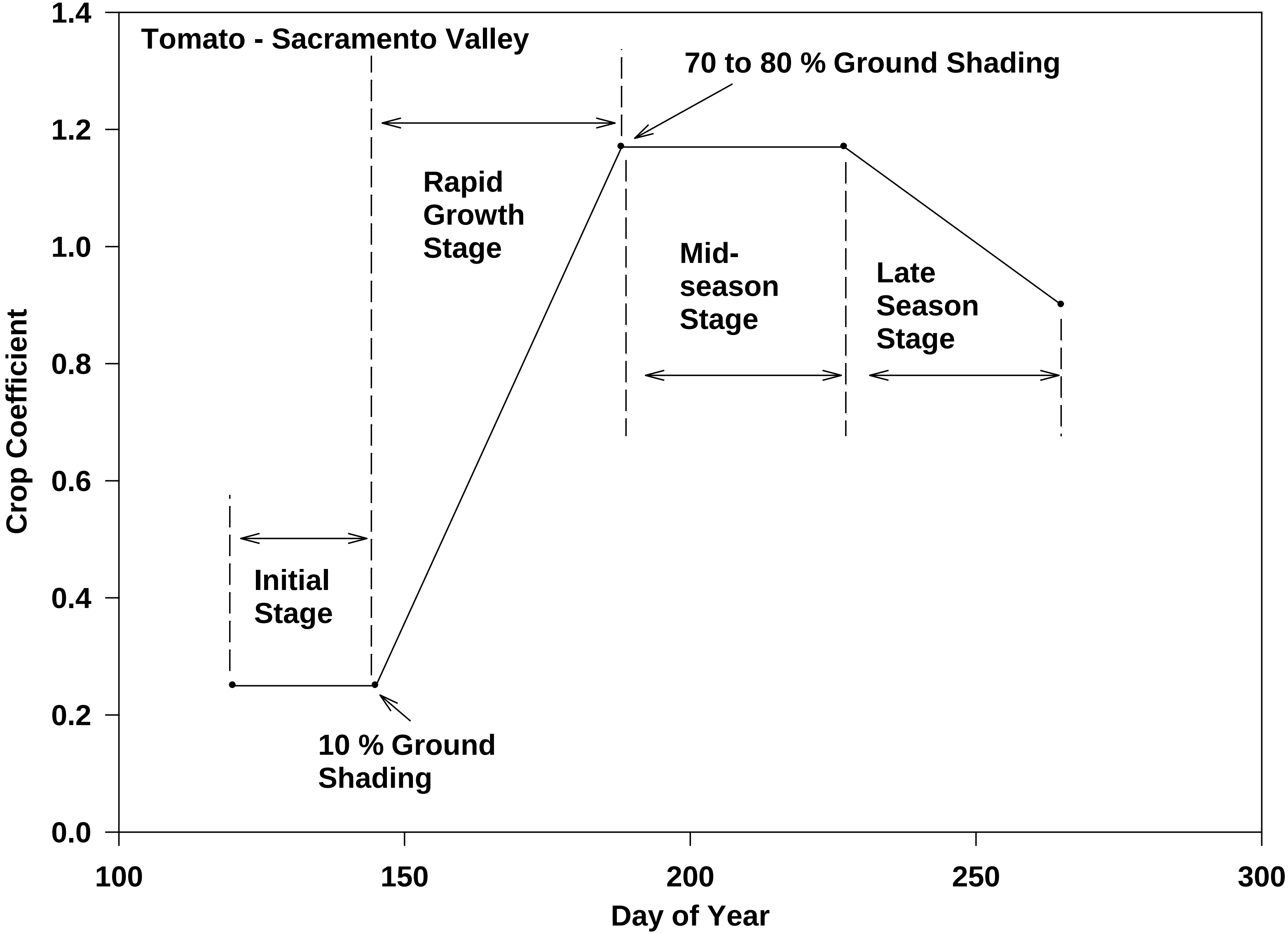
- ET = Kc x ETo
  - Kc = crop coefficient (crop type, stage of growth, plant health)
  - ETo = reference crop ET
    - ET of well-watered grass (California) or alfalfa (Idaho)
    - Determined from climatic data and complex equations developed experimentally
- California Irrigation Management Information System (CIMIS)
  - Network of weather stations used to collect climate data for calculating ETo
  - Installed by UCD /DWR and maintained by DWR

Crop coefficients

- Crop coefficient (Kc) = ET ÷ ETo
  - ET = crop evapotranspiration
  - ETo = reference crop ET (obtained from CIMIS in California)
- Factors affecting Kc
  - Crop type
  - Stage of Growth
  - Soil moisture
  - Health of plants
  - Cultural practices
- Crop coefficients are normally determined under highly controlled conditions of adequate soil moisture, good plant health, and cultural practices

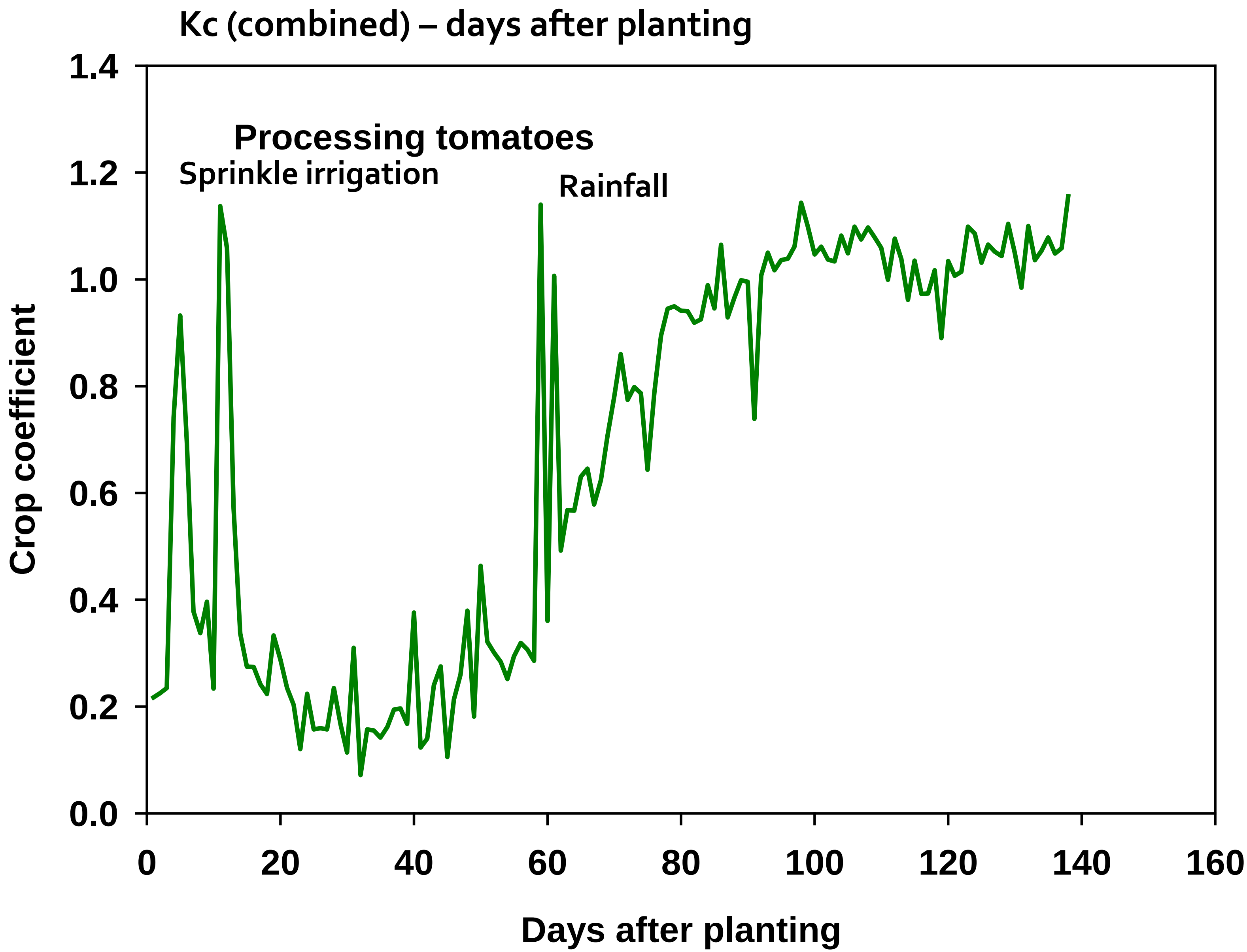
CIMIS weather station – data and complex equations are used to calculate a reference crop ET

Crop Coefficients - Annual Crops

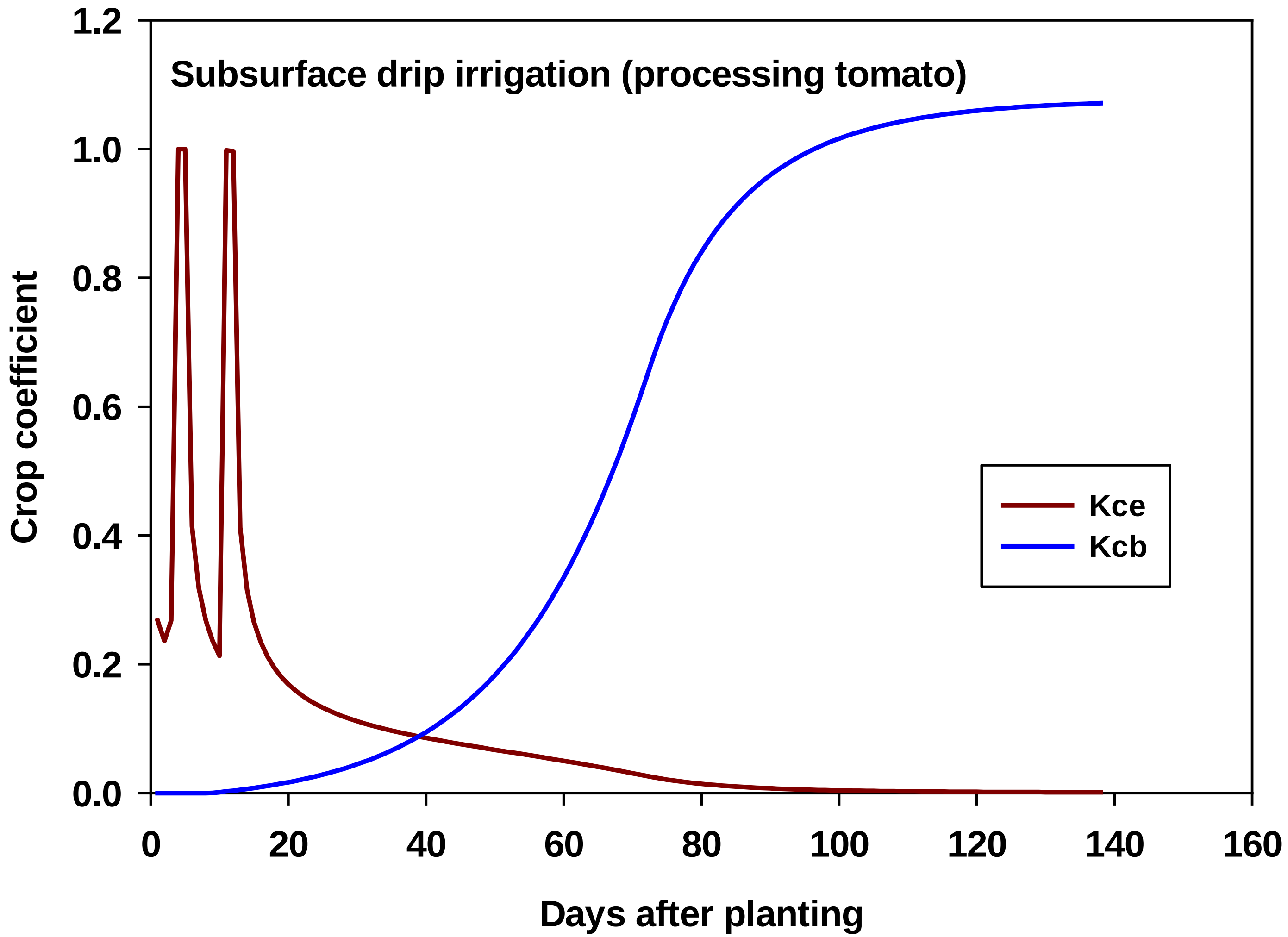


Types of crop coefficients

- Basil crop coefficients (Kcb)
  - Dry soil surface conditions
  - Transpiration only
- Dual crop coefficients
  - Separate coefficients for evaporation (Kce) and transpiration (Kcb) conditions
  - Kc = Kce + Kcb
  - Very little data exist on Kce
  - Most evaporation occurs during stand establishment
  - Not appropriate for farm level water management
- Combined crop coefficients (Kc)
  - Evaporation and transpiration are not separated
  - Most common type of crop coefficient



Kc (combined) – days after planting
Processing tomatoes
Sprinkle irrigation
Rainfall
Crop coefficient
Days after planting
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
20
40
60
80
100
120
140
160



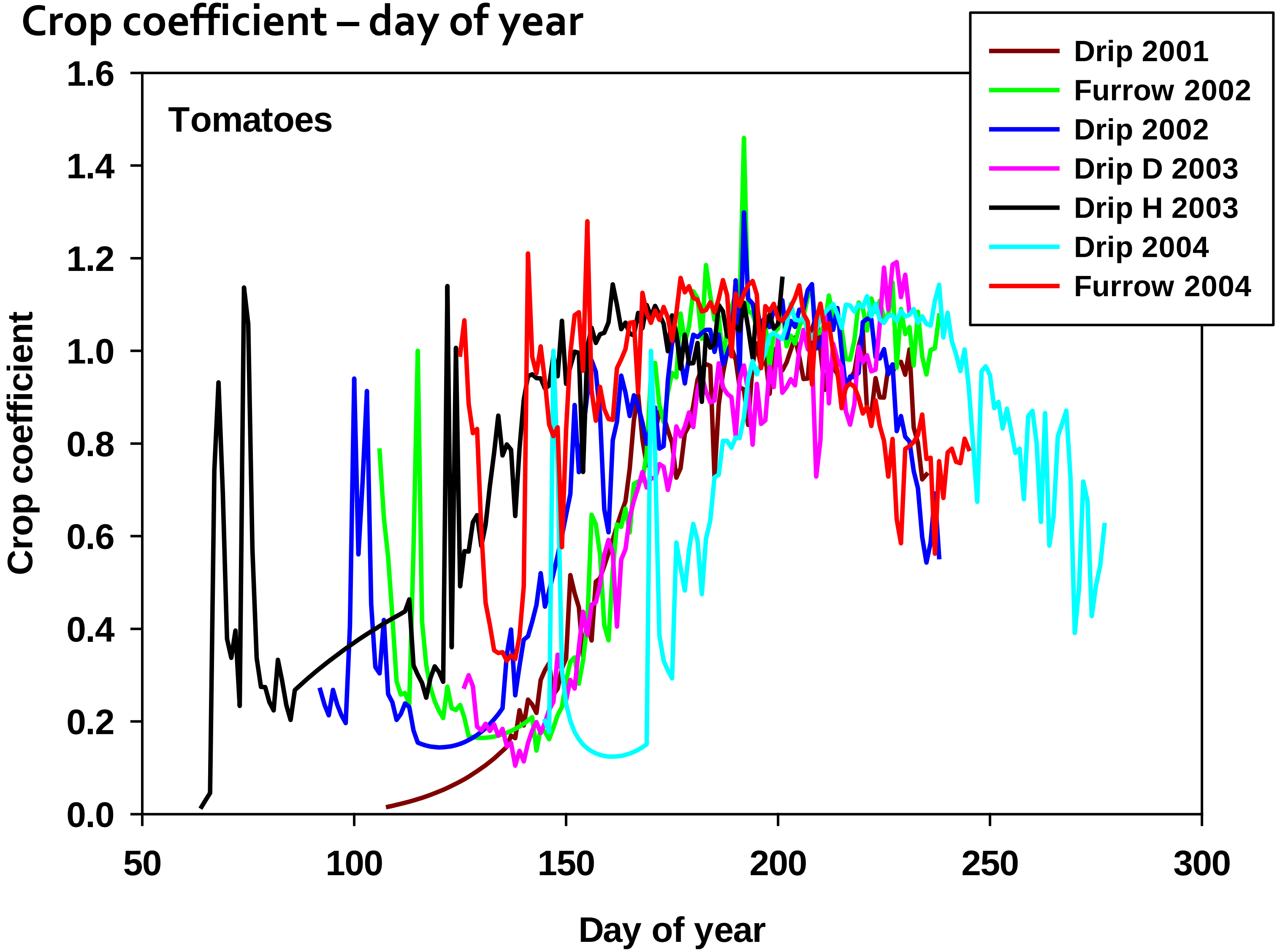
Subsurface drip irrigation (processing tomato)
Crop coefficient
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
Days after planting
Kce
Kcb

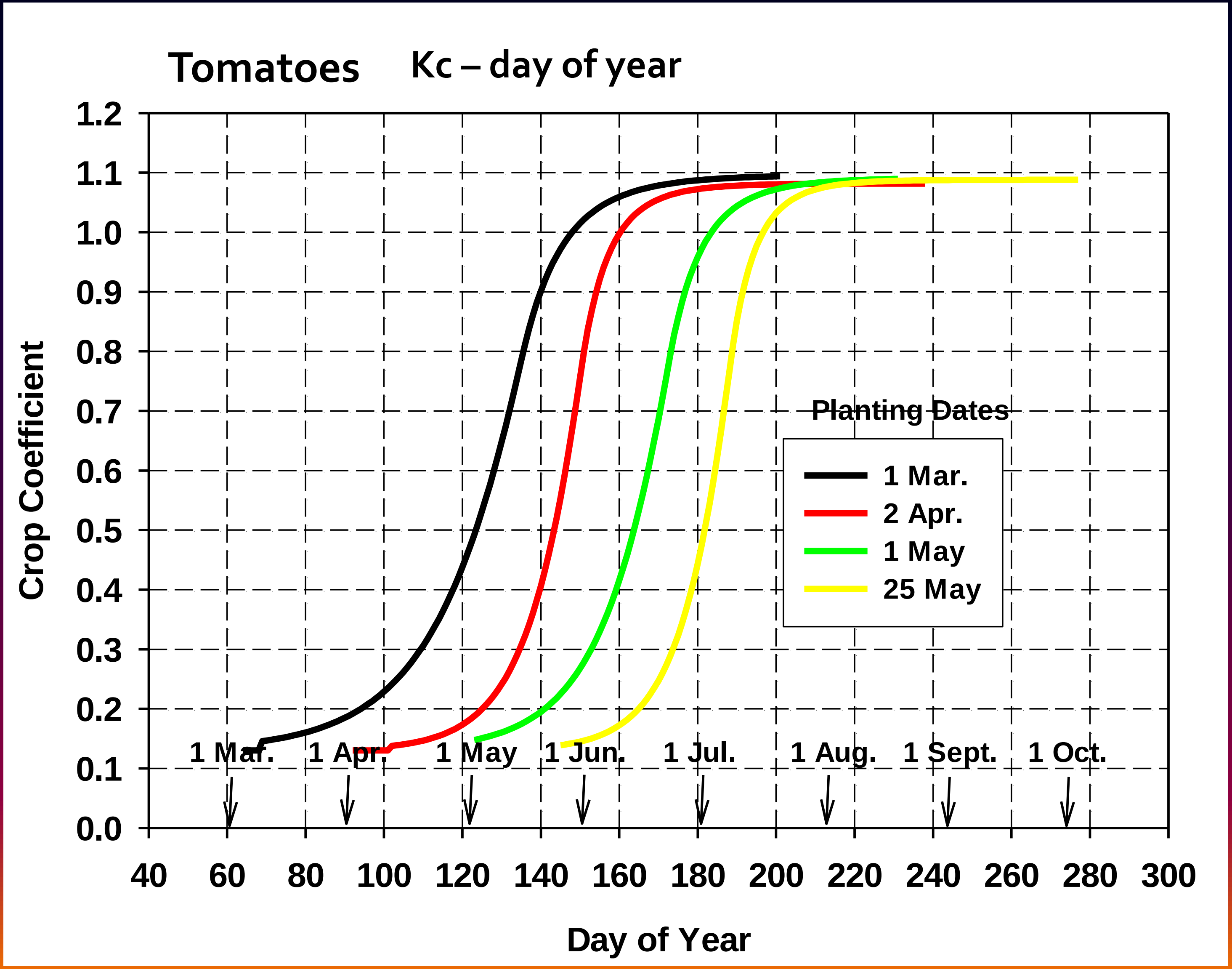
Expressing crop coefficients (Kc)

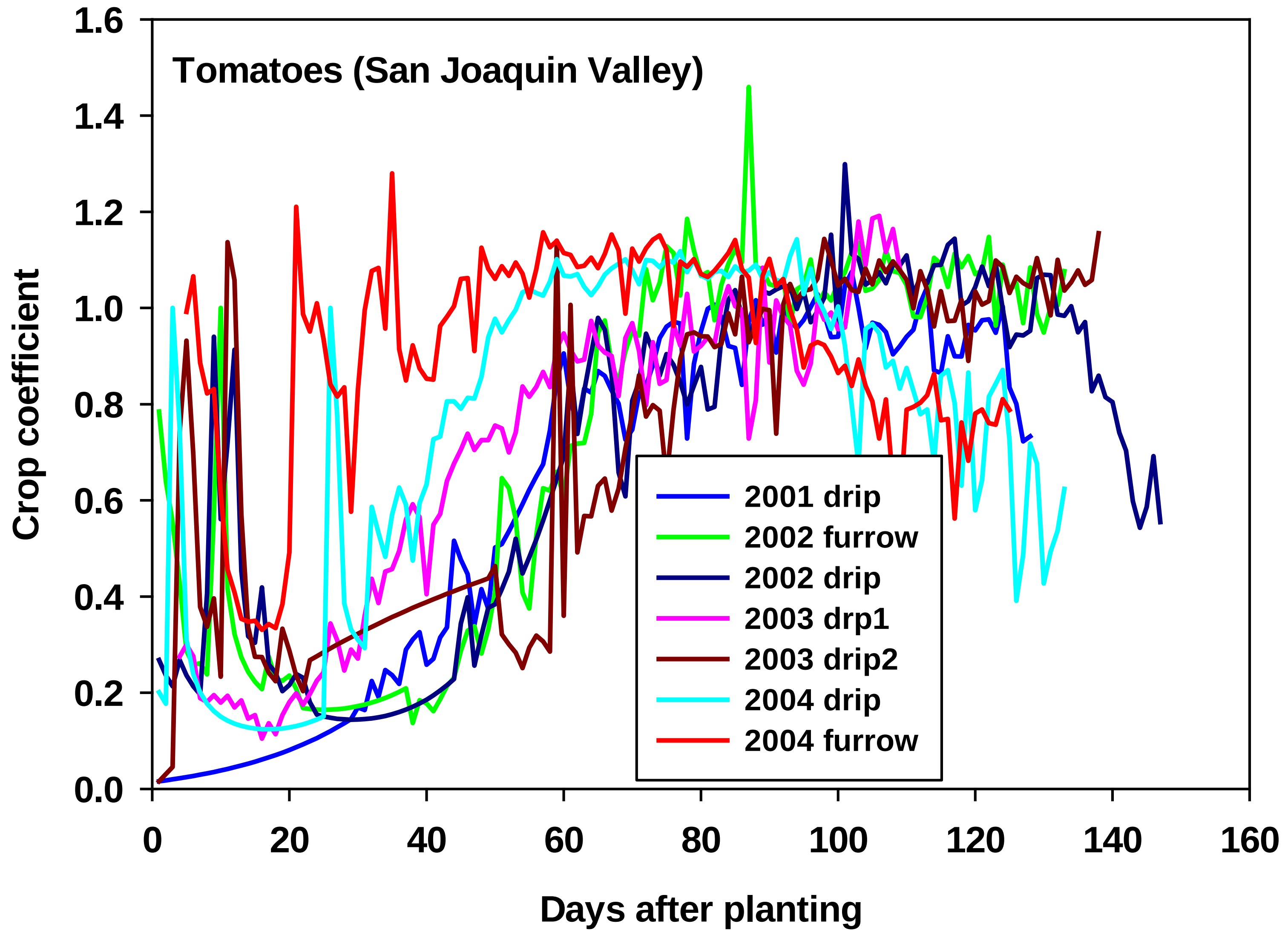
- Kc - calendar (day of year) basis: site, time, and climate specific
- Kc - days after planting: site, time, and climate specific
- Kc - canopy cover: universal?, limited data; requires measuring canopy cover during the crop season
- Kc - growing degree days (heat units): universal?, calculated values of growing degree days not available in California
  - $GDD = [(T_{max} - T_{min}) \div 2] - T_{base}$
  - T_{max} = maximum daily temperature
  - T_{min} = minimum daily temperature
  - T_{base} = minimum temperature at which no plant growth occurs

Kc – day of year or days after planting relationships

Crop coefficient – day of year

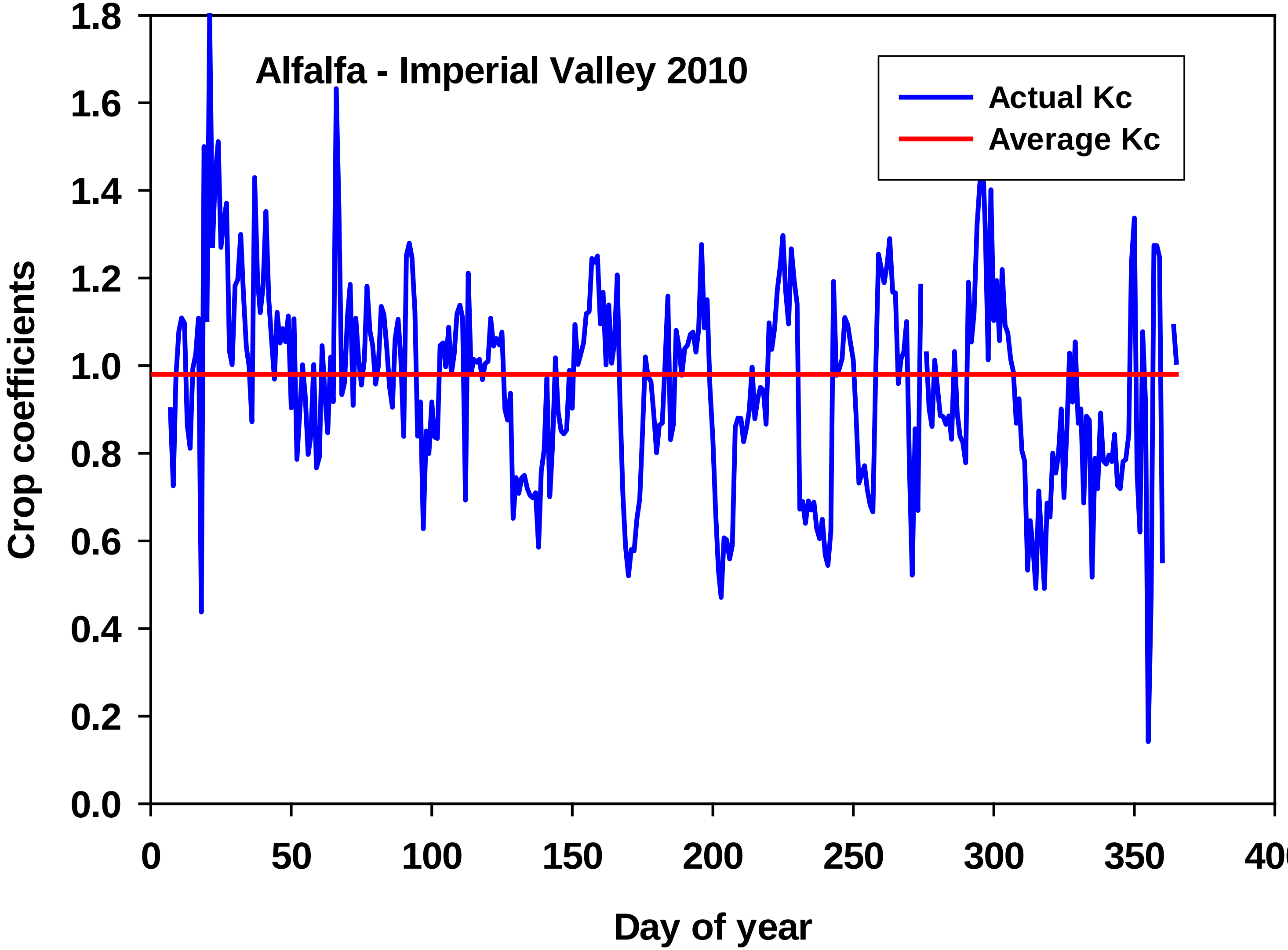



Tomatoes
Kc – day of year
Crop Coefficient
Day of Year
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
40
60
80
100
120
140
160
180
200
220
240
260
280
300
1 Mar.
1 Apr.
1 May
1 Jun.
1 Jul.
1 Aug.
1 Sept.
1 Oct.
Planting Dates
1 Mar.
2 Apr.
1 May
25 May

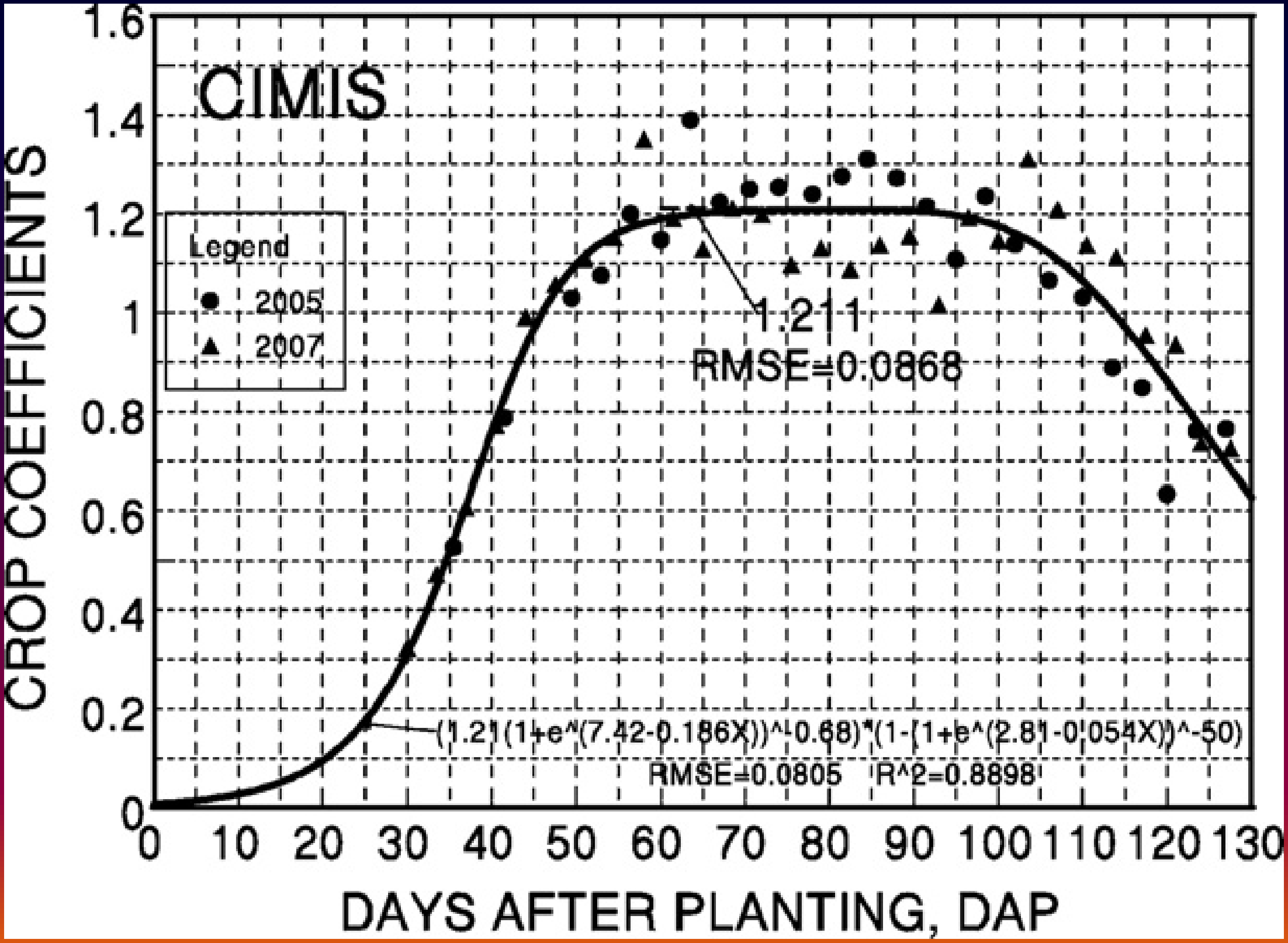


Tomatoes (San Joaquin Valley)
Crop coefficient
Days after planting
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
20
40
60
80
100
120
140
160
2001 drip
2002 furrow
2002 drip
2003 drp1
2003 drip2
2004 drip
2004 furrow

Kc – day of year



Cowpea (W. R. DeTar, 2009)

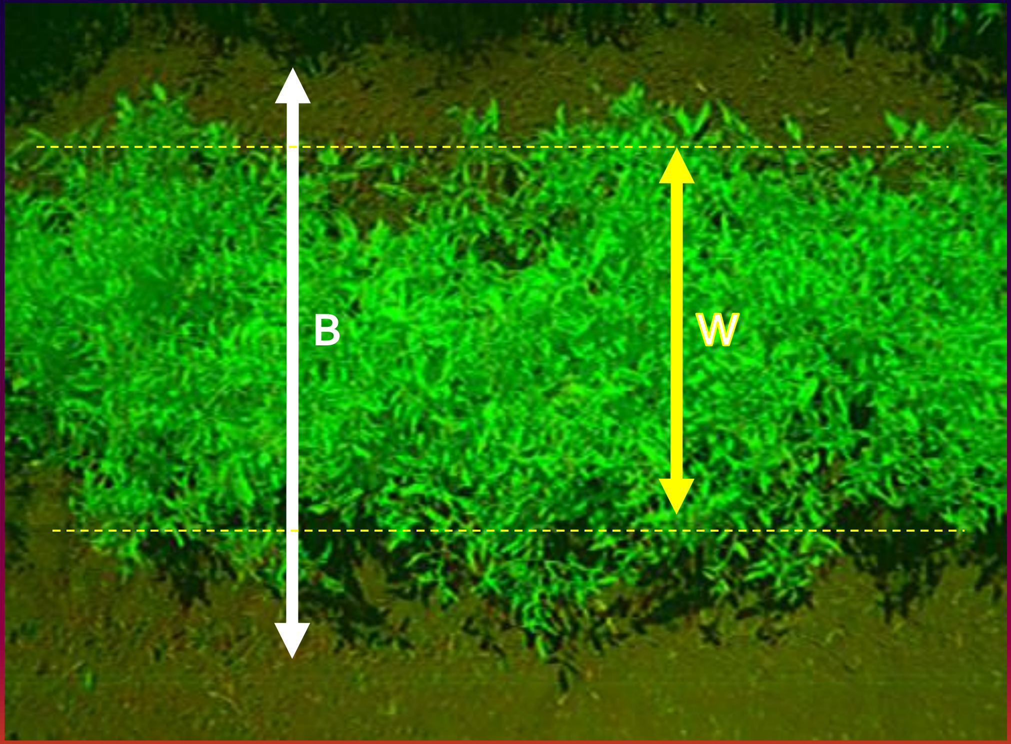


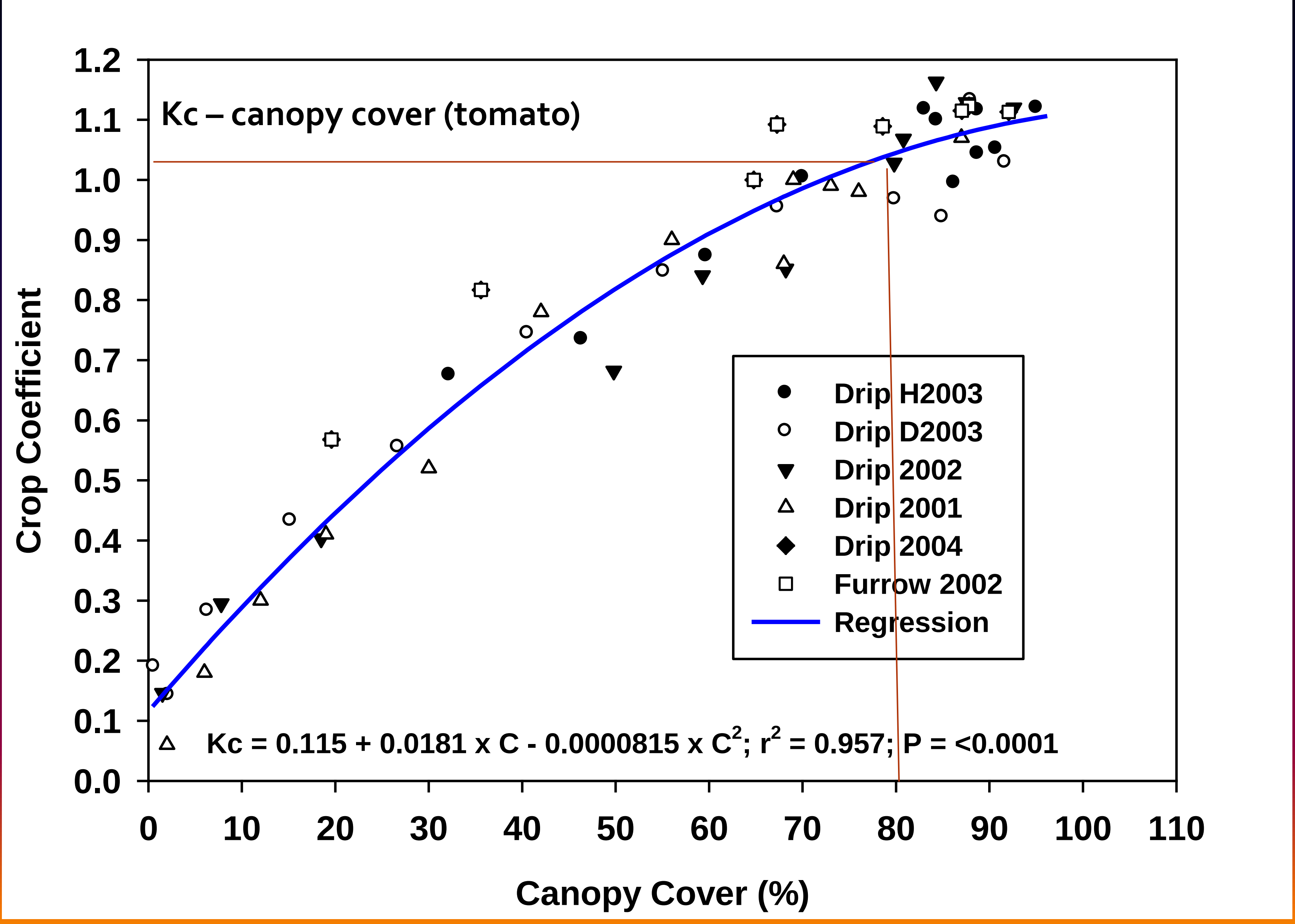
Kc – canopy cover (C) relationships

Canopy cover = percent of soil surface shaded by the plant cover at mid-day

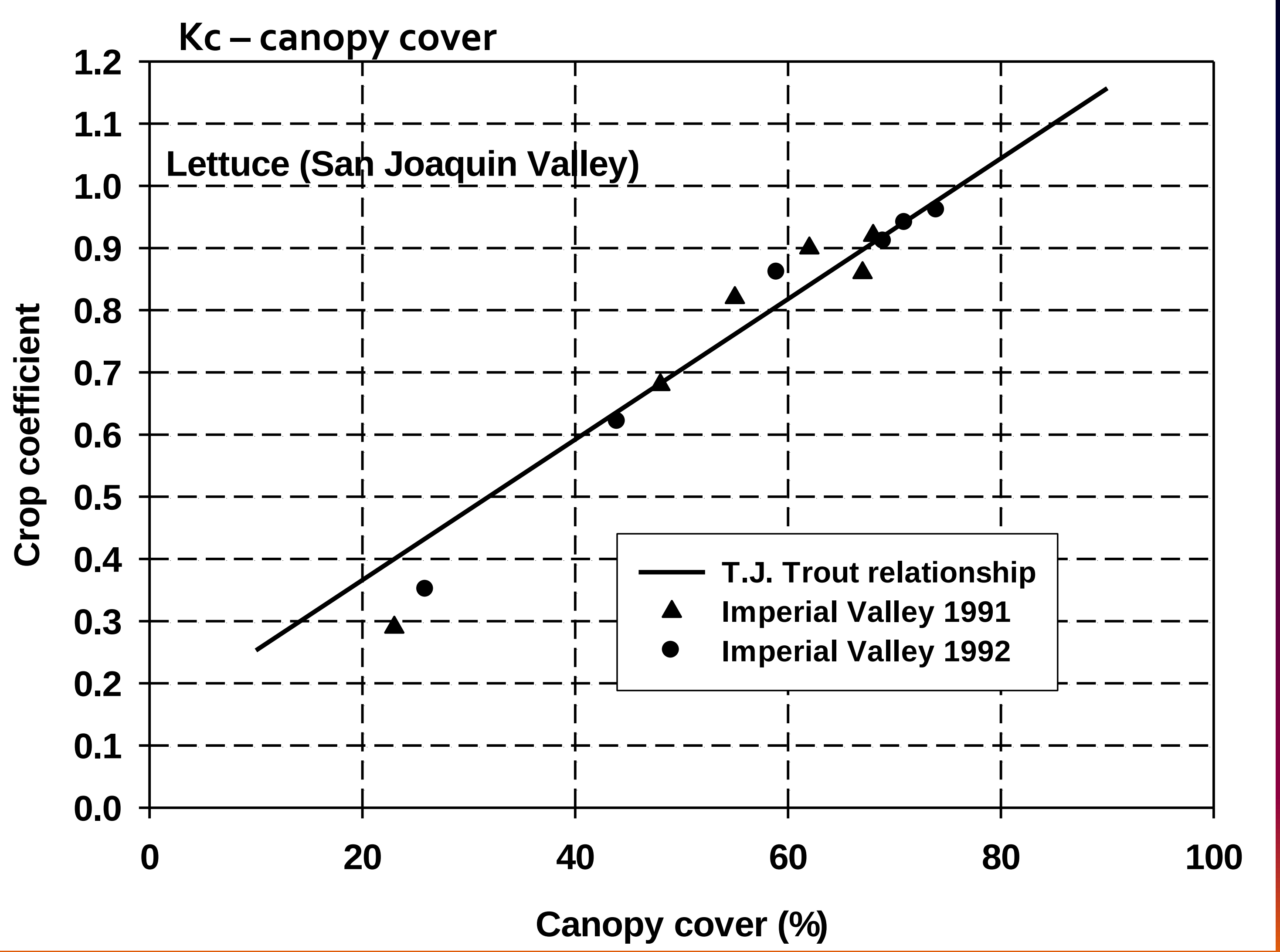
Canopy cover = 100 x canopy width (W)   bed spacing (B)

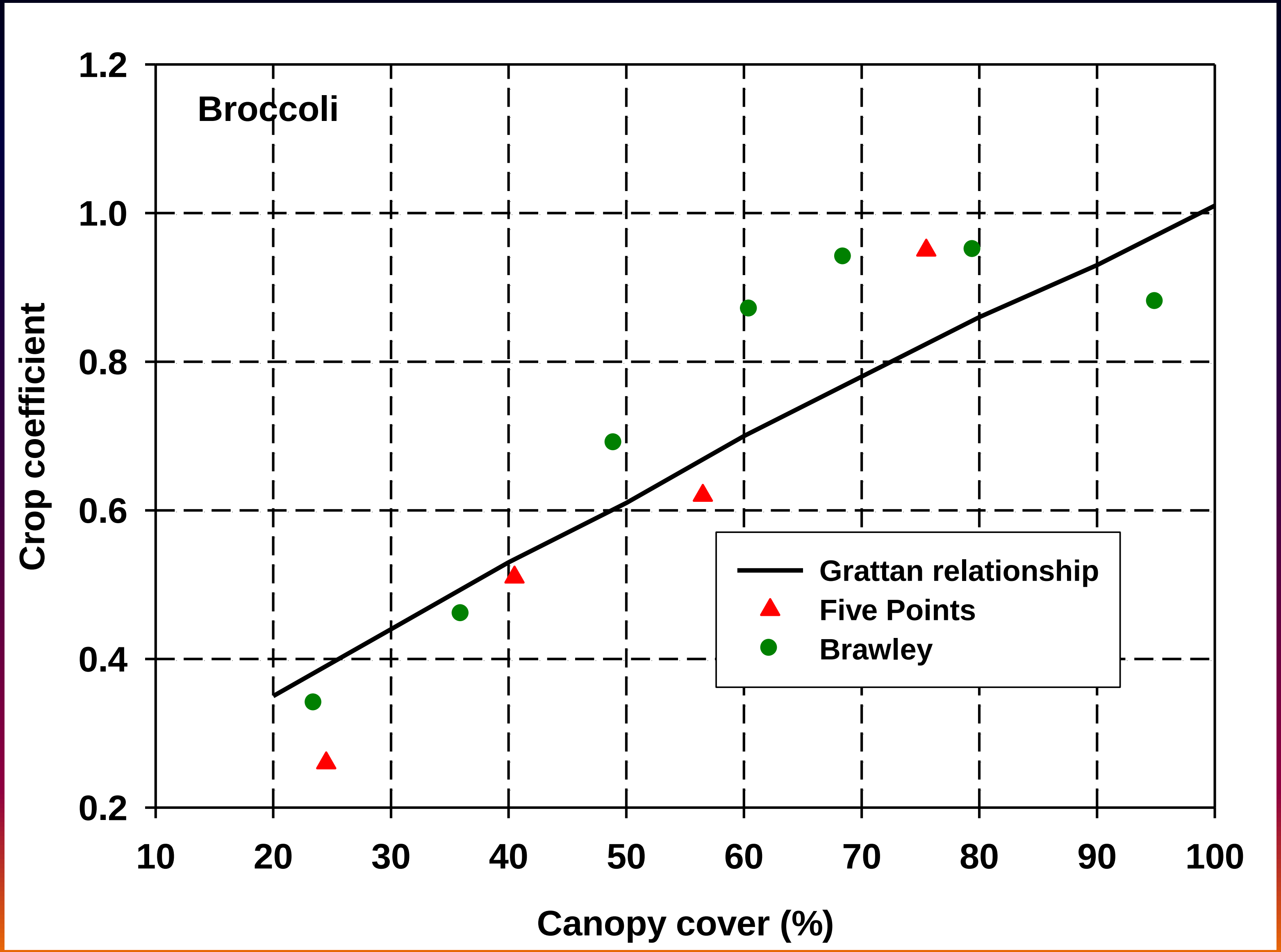
Tomato



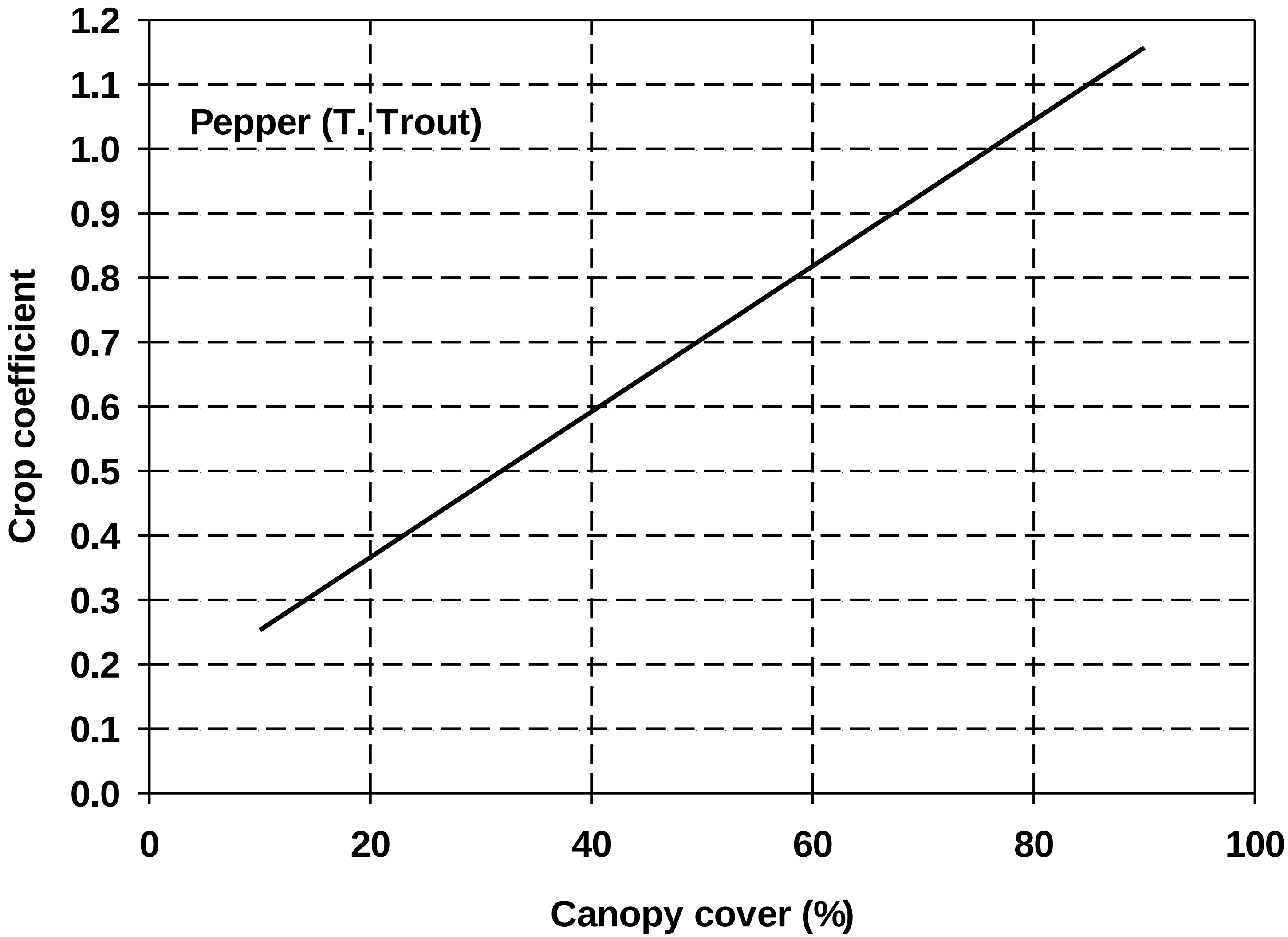


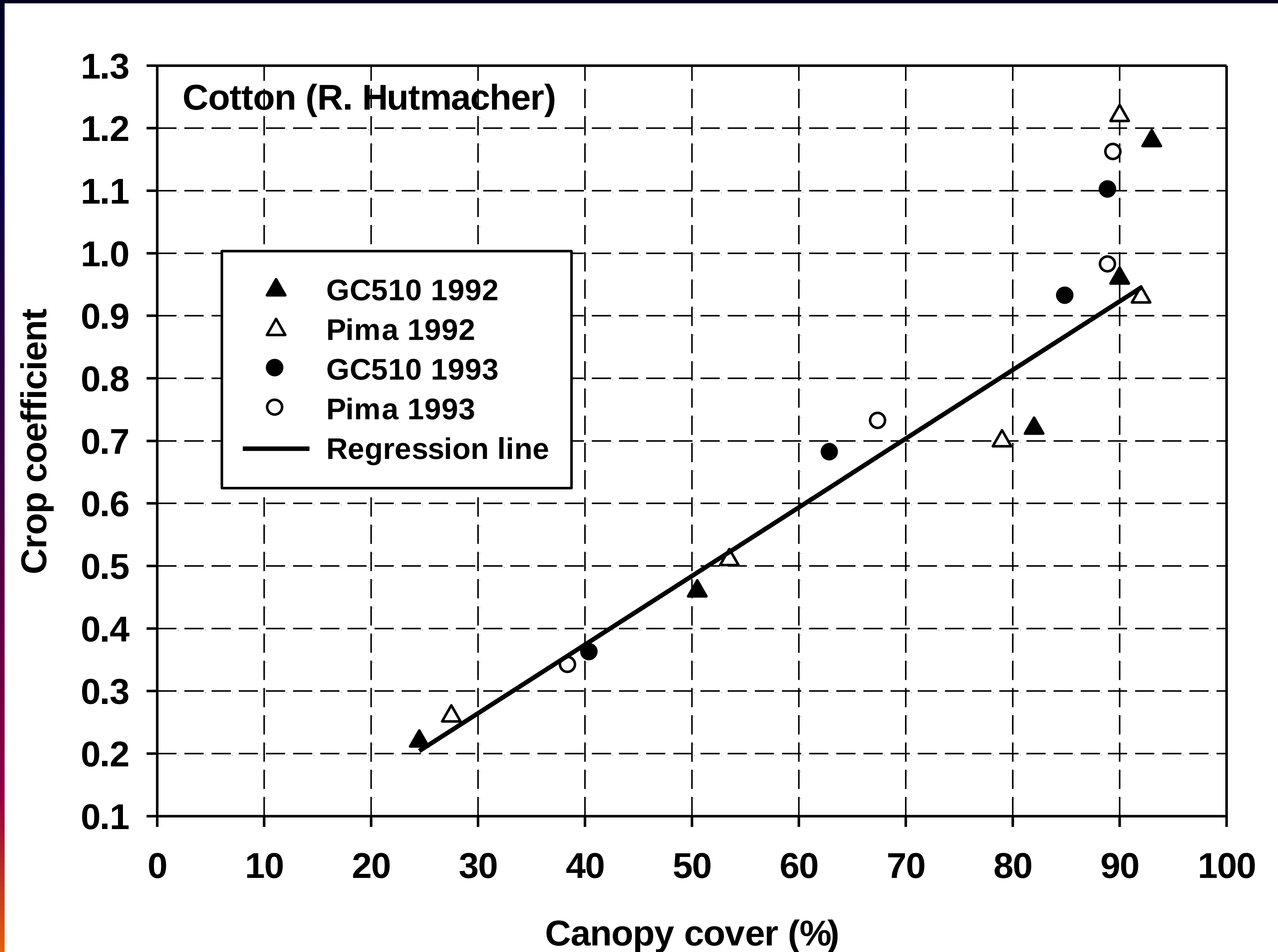
Kc – canopy cover (tomato)
Crop Coefficient
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
110
Canopy Cover (%)
Drip H2003
Drip D2003
Drip 2002
Drip 2001
Drip 2004
Furrow 2002
Regression
Kc = 0.115 + 0.0181 x C - 0.0000815 x C2; r2 = 0.957; P = <0.0001


Kc – canopy cover
Lettuce (San Joaquin Valley)
Crop coefficient
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
Canopy cover (%)
T.J. Trout relationship
Imperial Valley 1991
Imperial Valley 1992

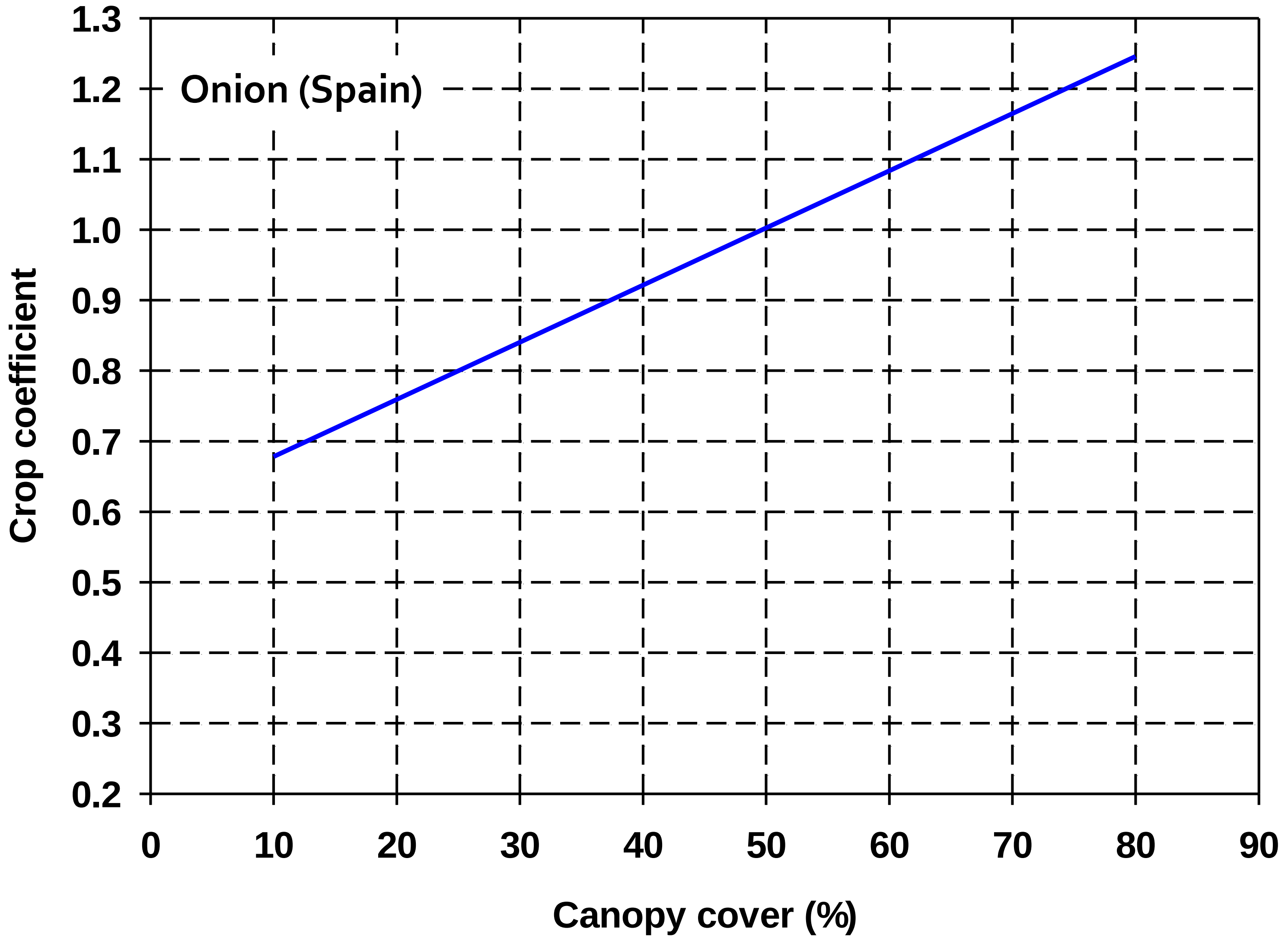


Broccoli
Crop coefficient
1.2
1.0
0.8
0.6
0.4
0.2
10
20
30
40
50
60
70
80
90
100
Canopy cover (%)
Grattan relationship
Five Points
Brawley

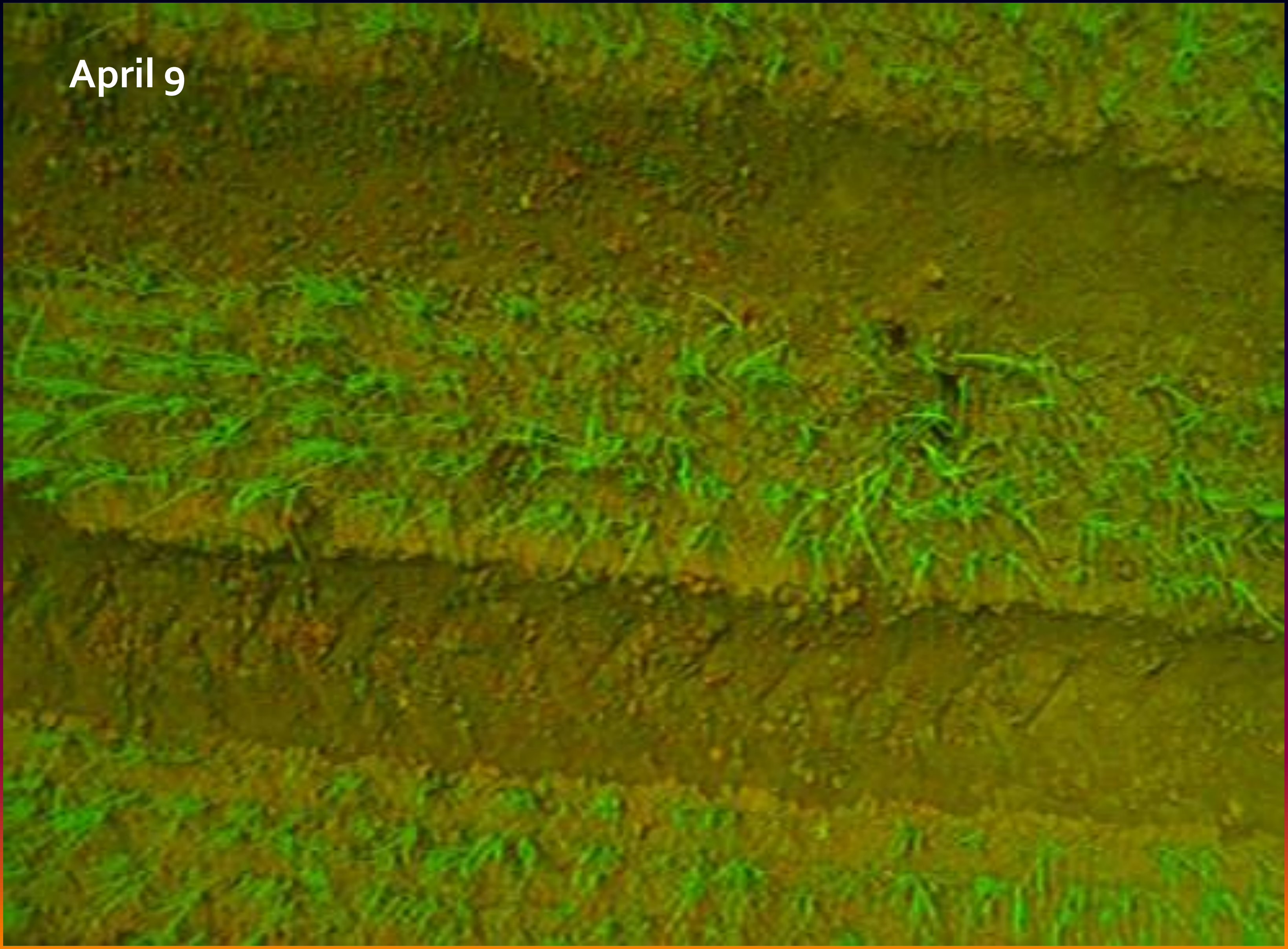

Pepper (T. Trout)
Crop coefficient
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
Canopy cover (%)

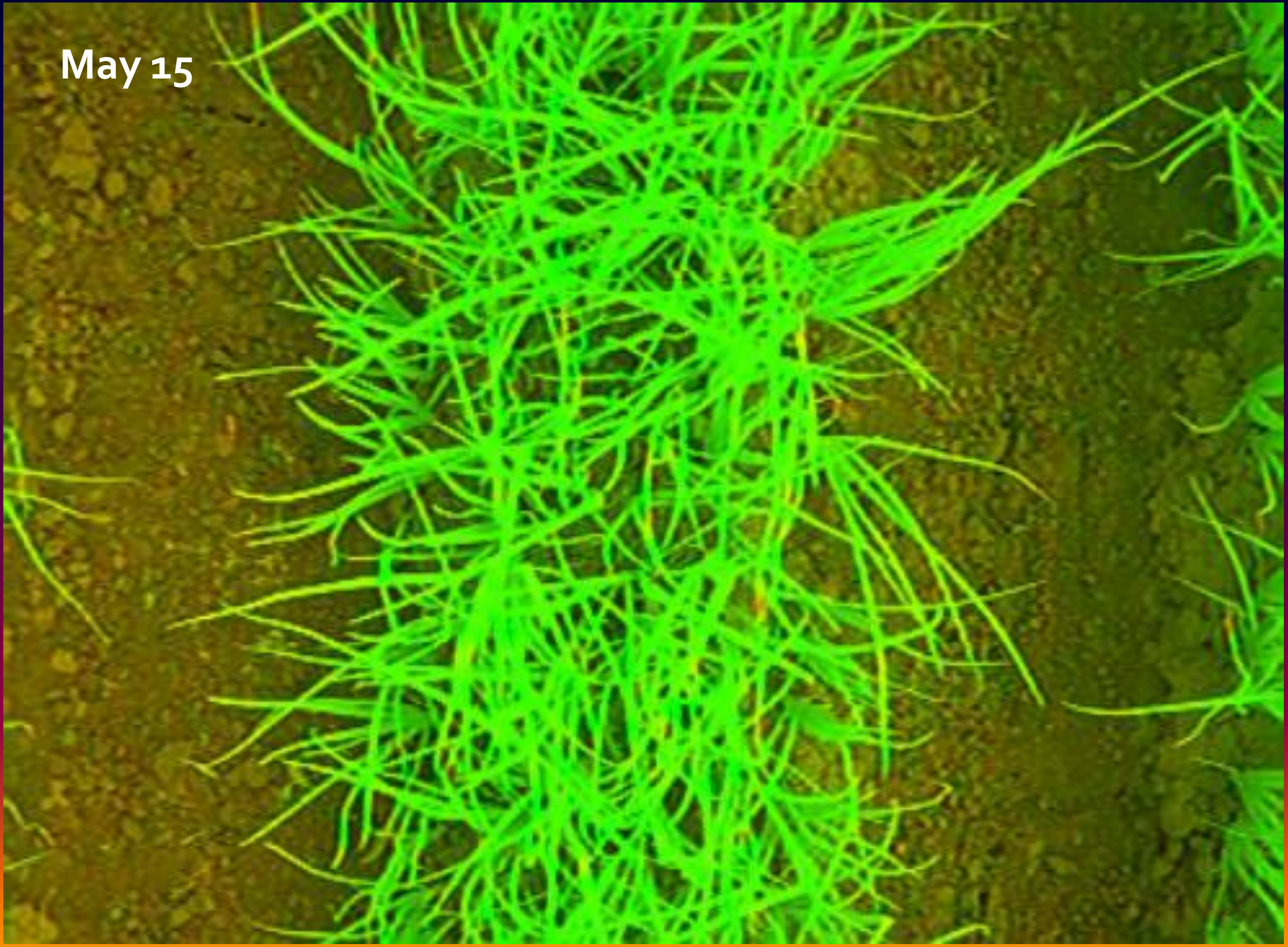


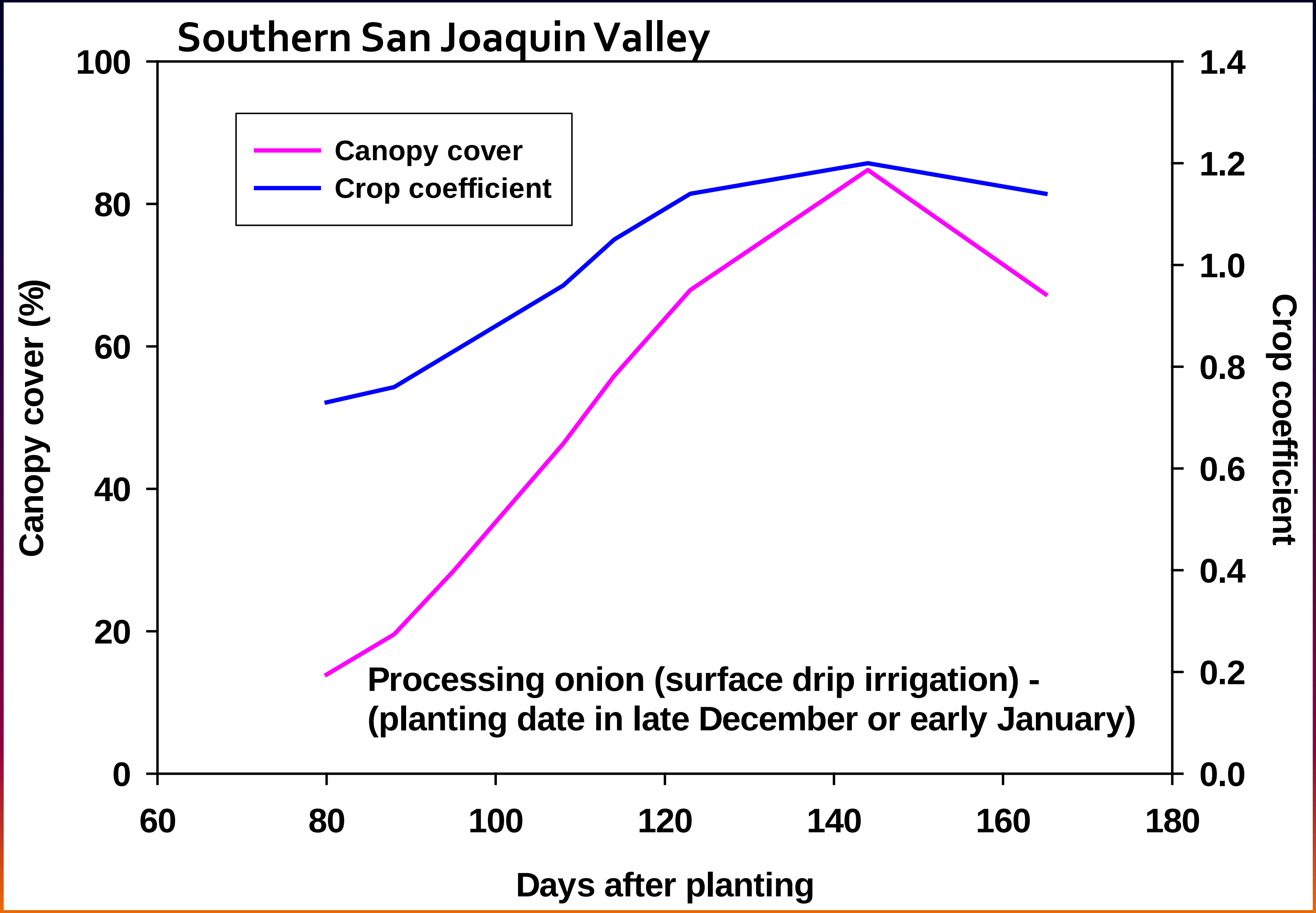
Cotton (R. Hutmacher)
GC510 1992
Pima 1992
GC510 1993
Pima 1993
Regression line
Crop coefficient
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
90
100
Canopy cover (%)

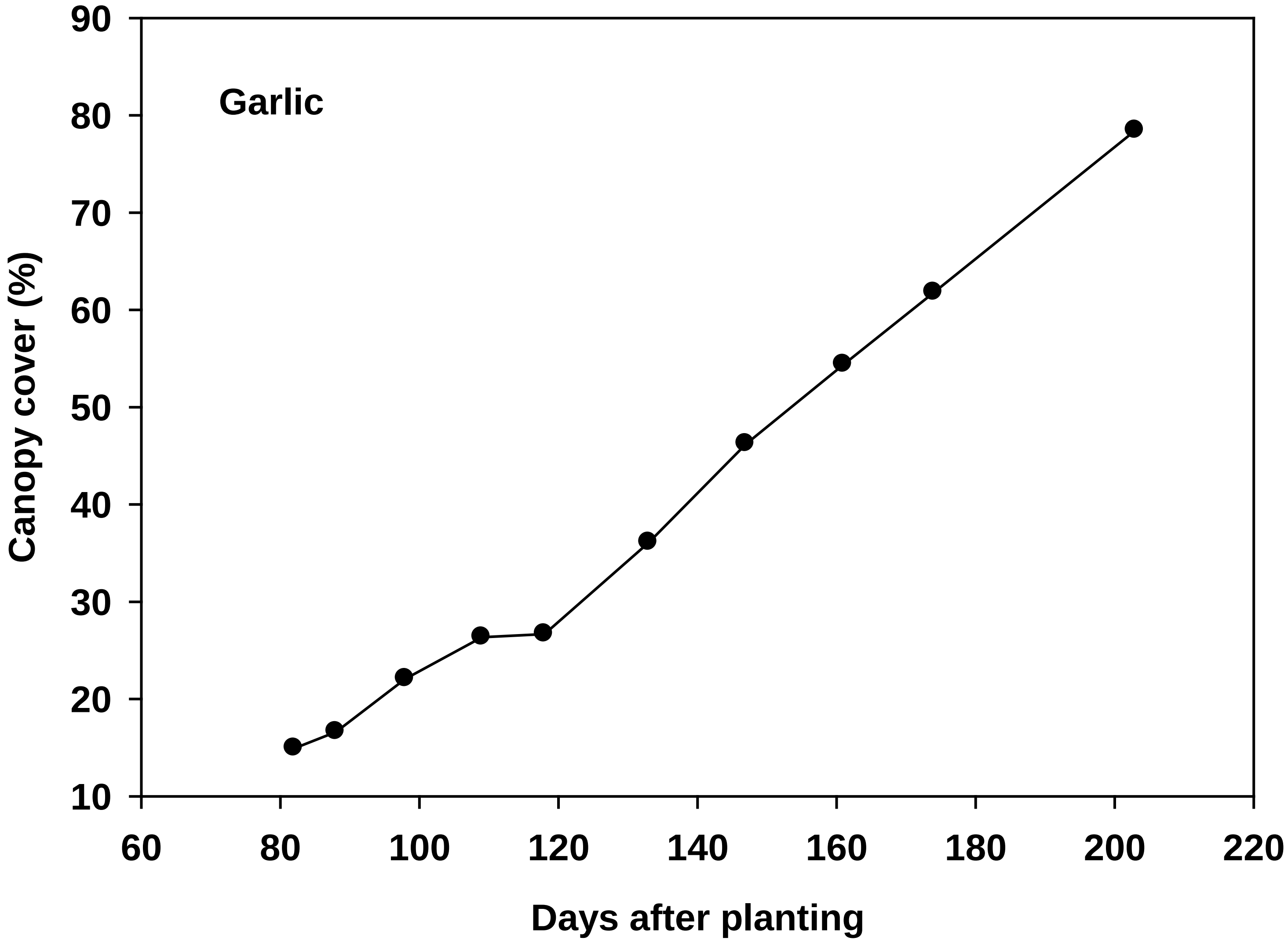


Onion (Spain)
Crop coefficient
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
10
20
30
40
50
60
70
80
90
Canopy cover (%)

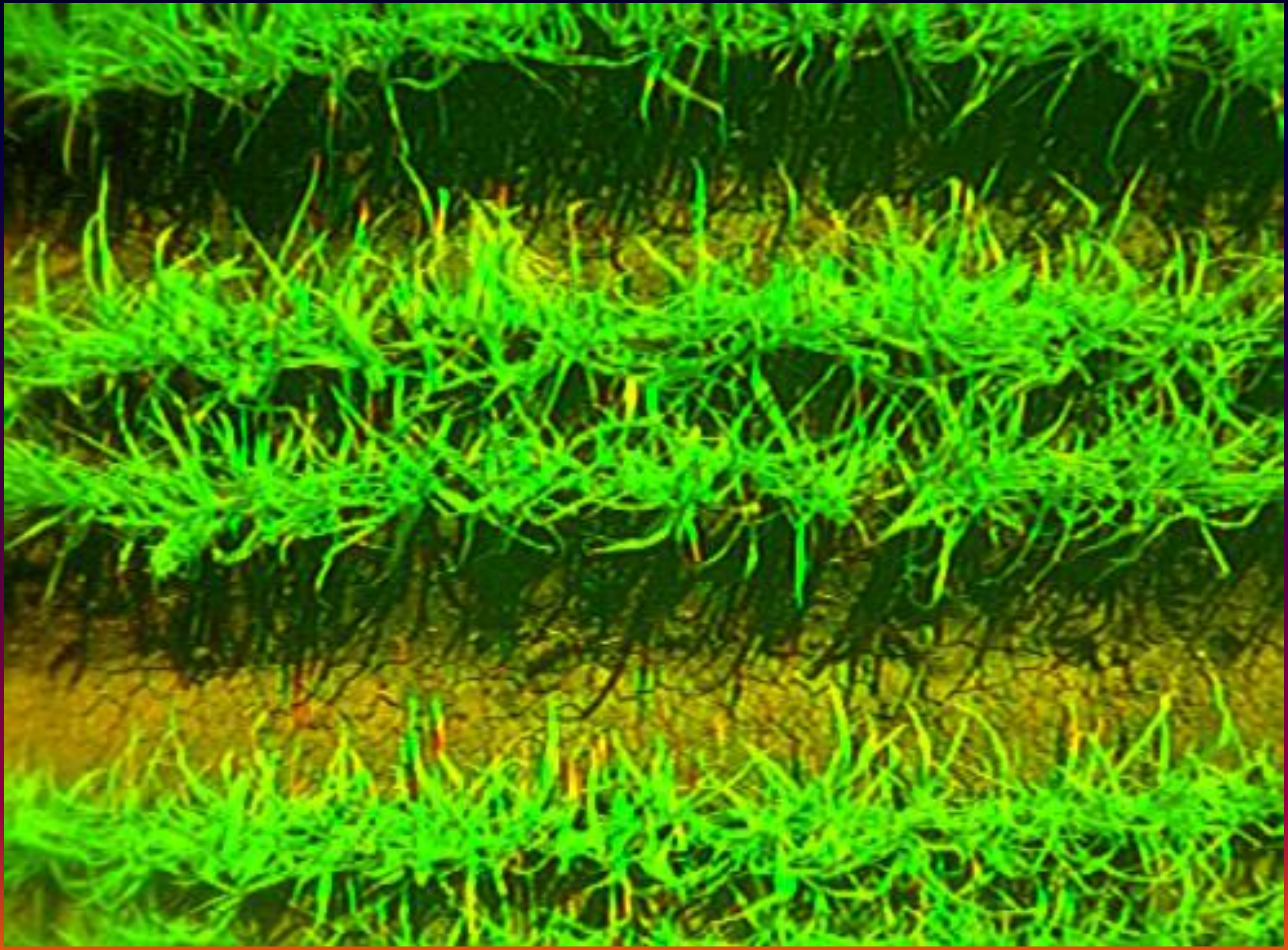

April 9

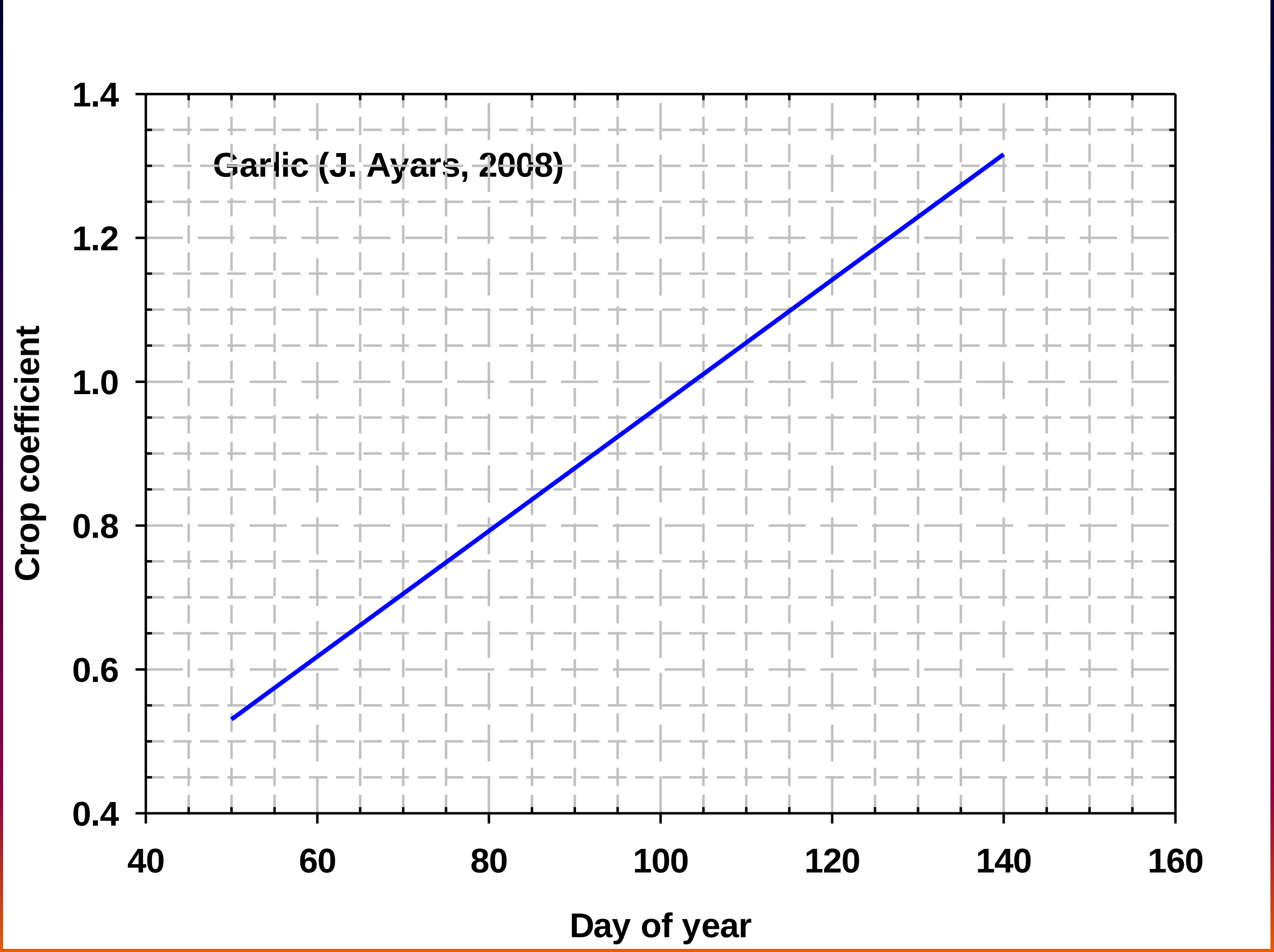

May 15


Southern San Joaquin Valley
Canopy cover
Crop coefficient
Canopy cover (%)
Crop coefficient
Processing onion (surface drip irrigation) -
(planting date in late December or early January)
Days after planting
100
80
60
40
20
0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
60
80
100
120
140
160
180


Garlic
Canopy cover (%)
Days after planting
90
80
70
60
50
40
30
20
10
60
80
100
120
140
160
180
200
220

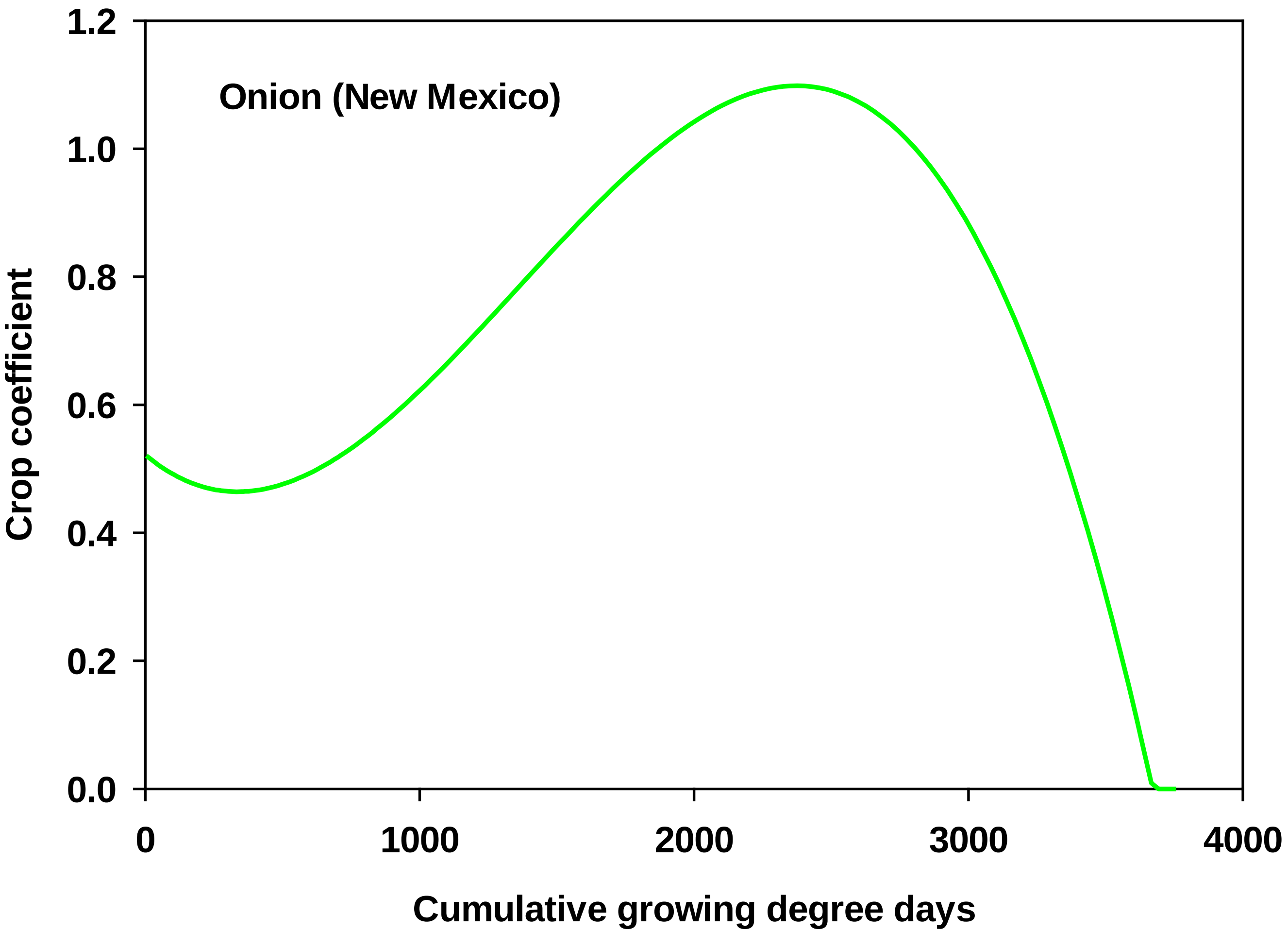
Garlic (February 25)

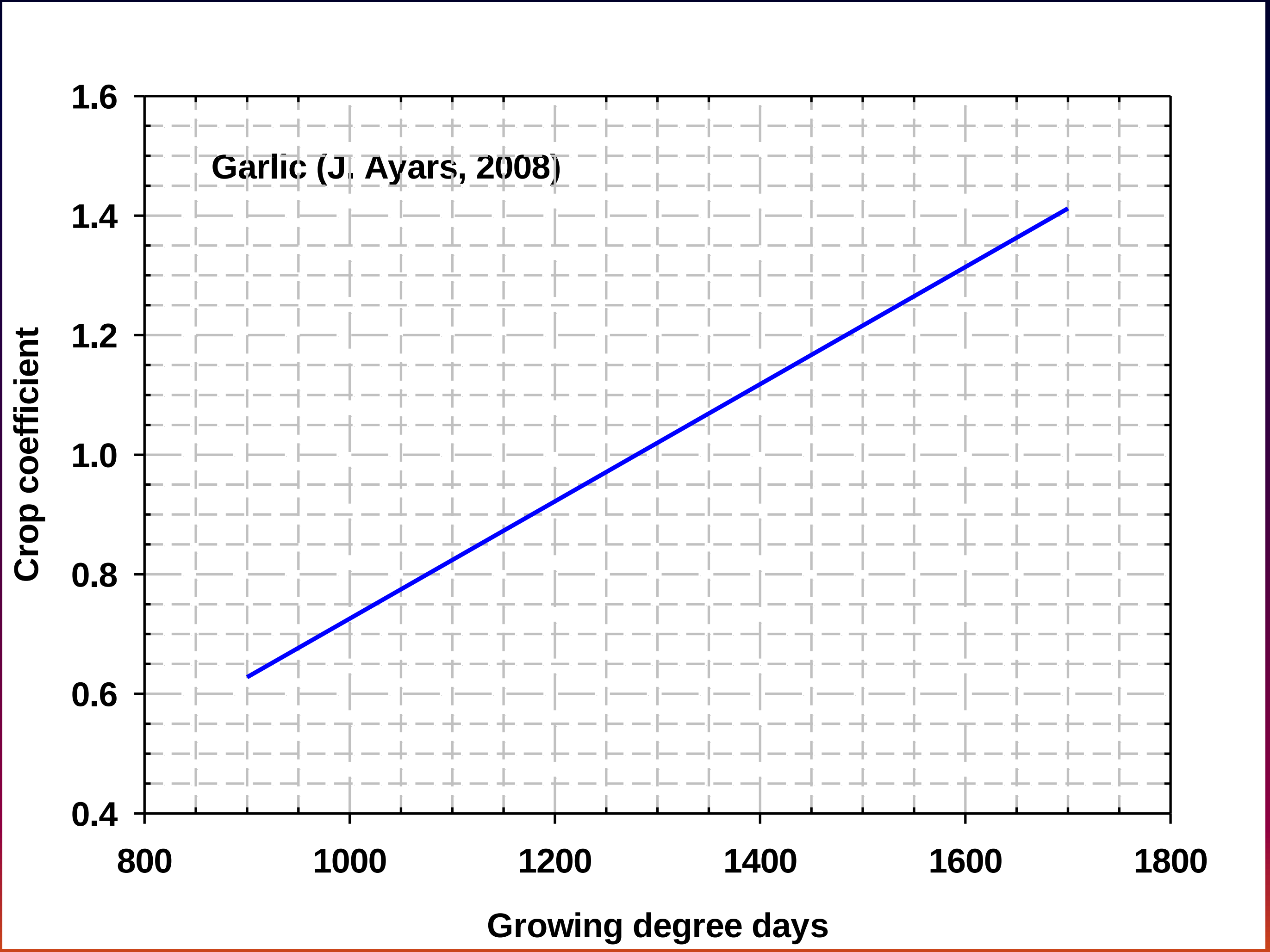



Garlic (J. Ayars, 2008)
Crop coefficient
1.4
1.2
1.0
0.8
0.6
0.4
40
60
80
100
120
140
160
Day of year

Kc – growing degree days relationships

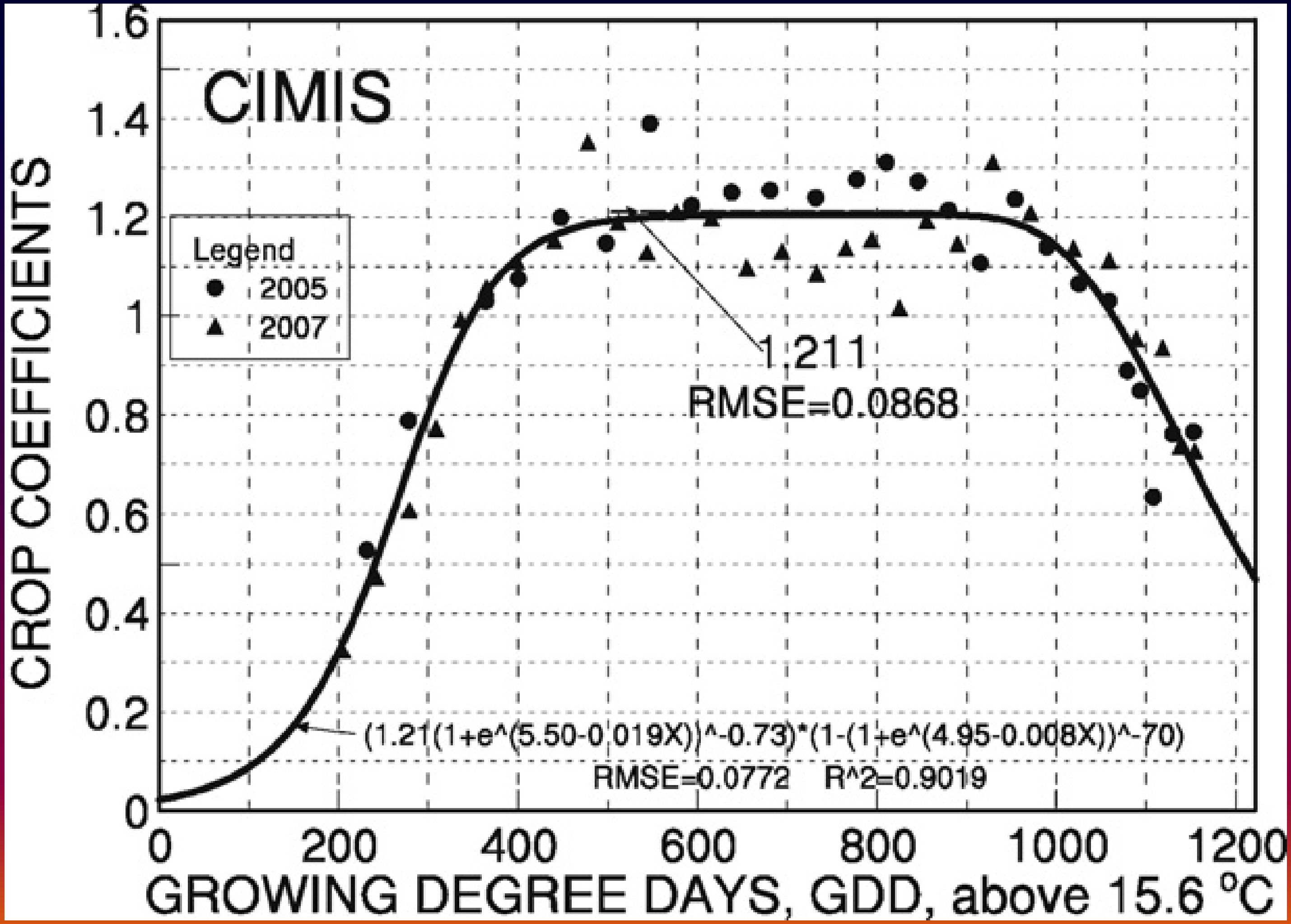
Kc – growing degree day



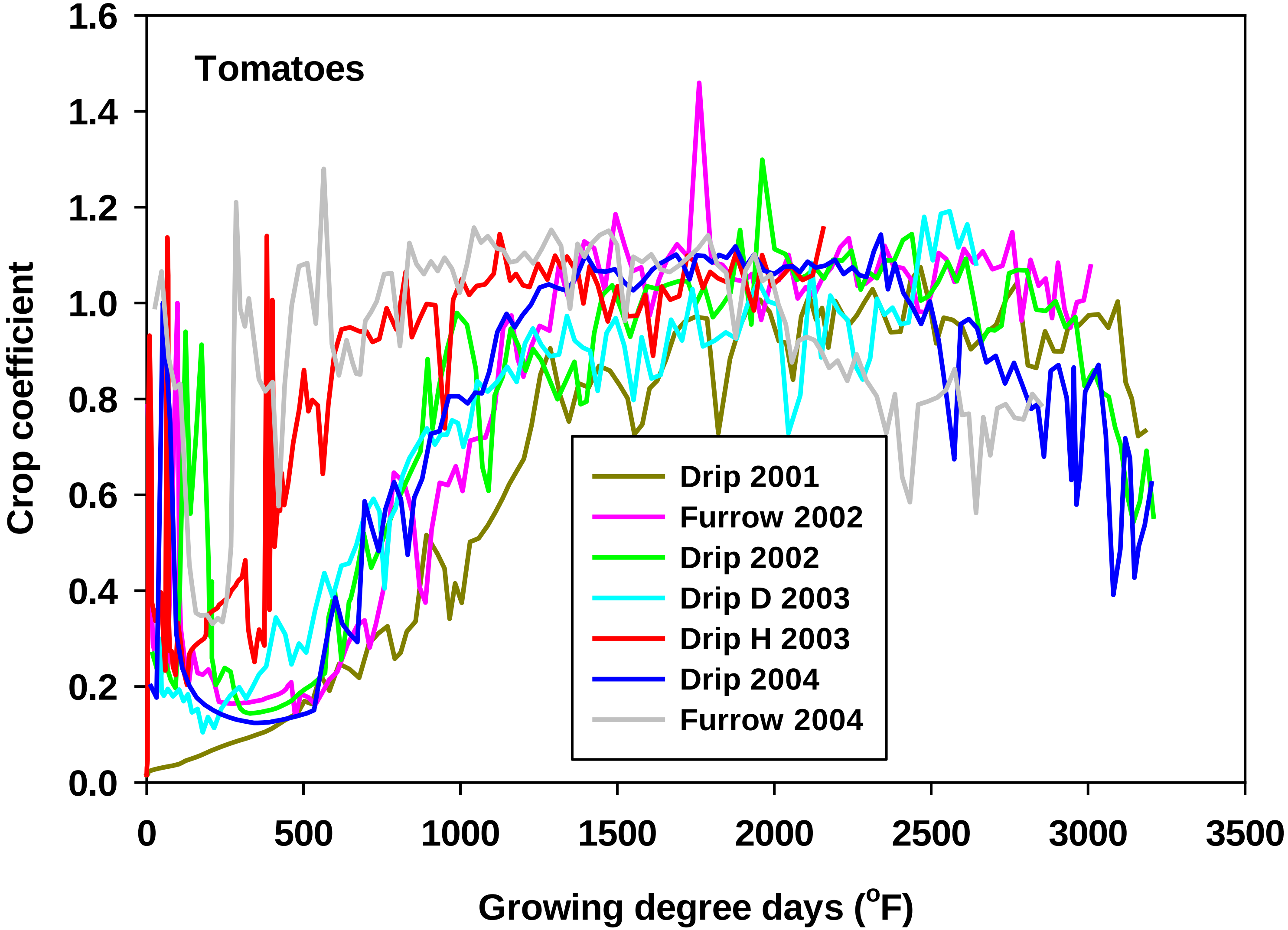


Garlic (J. Ayars, 2008)
Crop coefficient
1.6
1.4
1.2
1.0
0.8
0.6
0.4
800
1000
1200
1400
1600
1800
Growing degree days

Cowpea (W. R. DeTar, 2009)



Crop coefficients – growing degree days



Is enough water being applied?

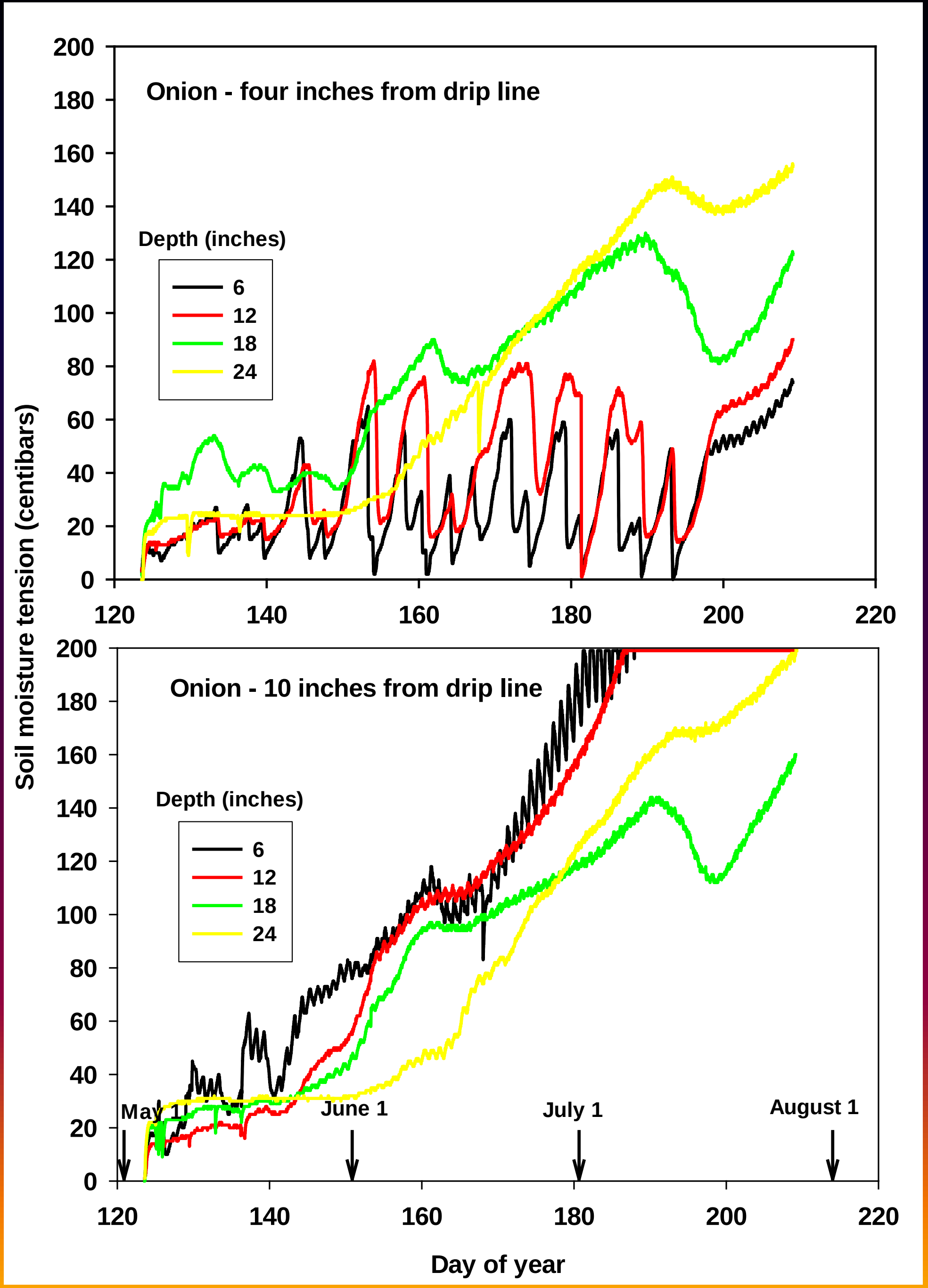
- How much water should be applied?
  - ET between irrigations = Kc x ETo x days between irrigation
  - Desired depth = ET between irrigations ÷ irrigation efficiency (best guess – 80 to 90 %)
- How much water was applied during an irrigation?
  - Applied depth (inches) = (flow rate in gallons per minute x hours of irrigation) ÷ (449 x irrigated acres)
- Compare desired depth with applied depth

Concerns

- The science part of irrigation water management
  - ET and ETo data, crop coefficients
  - Site and time specific
  - Limited number of experiments
  - Kc – canopy cover relationships appear to be more universal than other crop coefficient relationships
- Problems
  - Effect of field to field variability on ET and Kc – climate , soil, cultural practices
  - Effect of year to year variability on ET and Kc – year to year climate changes, cultural practices
- The art and guess of irrigation water management
  - Trying to make limited scientific data developed under a particular time/site-specific situation fit a particular farm

Recommendation

- Use ETo and crop coefficients to determine how much water should be applied
- Use flow meters to determine if enough water was applied
- Monitor soil moisture status with Watermark sensors
  - Determine adequacy of irrigation
  - Wetting patterns



Onion - four inches from drip line
Depth (inches)
6
12
18
24
Onion - 10 inches from drip line
Depth (inches)
6
12
18
24
May 1
June 1
July 1
August 1
Soil moisture tension (centibars)
Day of year
0
20
40
60
80
100
120
140
160
180
200
120
140
160
180
200
220

Life is Good

Have a good day!