Recommended Blaney-Criddle TR-21 Procedures: crop coefficients, elevation adjustment, calibration

COLORADO
Division of Water Resources
Department of Natural Resources

Dean Santistevan, P.E.
Assistant Division Engineer, Water Division 1

Colorado ET Conference – October 13, 2016

Blaney-Criddle TR-21

1. SCS modified the monthly B-C Equation from TB 1275
   - Introduced *Crop Growth Stage Coefficient (k_c)*
   - Not a “crop coefficient”
2. Provided k_c for 24 different crops in western U.S.
3. Source of coefficients was likely TB 1275 (Woodward 1963)

Tech. Bull. 1275

1. Blaney & Criddle (1962)
2. Second revision to B-C Equation
3. Summarized studies of monthly consumptive use
    - SCS needed monthly estimates
    - Introduced monthly time step
    - Provided monthly consumptive-use coefficients (k)

Timeline:

1945 - B-C Equation First Published
Blaney, H.F. and Criddle, W.D. (1945). "A method of estimating water requirements in irrigated areas from climatological data: Washington." U.S. Soil Cons. Service

1950 - First Revision to B-C Equation (SCS-TP-96)
Blaney, H.F. and Criddle, W.D. (1950). "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data." SCS-TP-96

1959 - Provisional Supplement to SCS-TP-96
Blaney, H.F., Haise, H.R. and Jensen, M.E. (1959). "Monthly Consumptive Use by Irrigated Crops in Western United States, Provisional Supplement to SCS-TP-96

1962 - Second Revision to B-C Equation (TB-1275)
Blaney, H.F. and Criddle, W.D. (1962). "Determining Consumptive Use and Irrigation Water Requirements." Tech. Bull. 1275, USDA-ARS

1963 - Woodward
"A Modification of the Blaney-Criddle Method for Computing Consumptive Use." ASAE annual meeting of Pacific NW Section in October 1963

1967 - SCS Modified B-C Equation
USDA – Soil. Cons. Service. (1967). "Irrigation Water Requirements." Tech. Release No. 21

1970 - Revision to TR-21

Woodward 1963

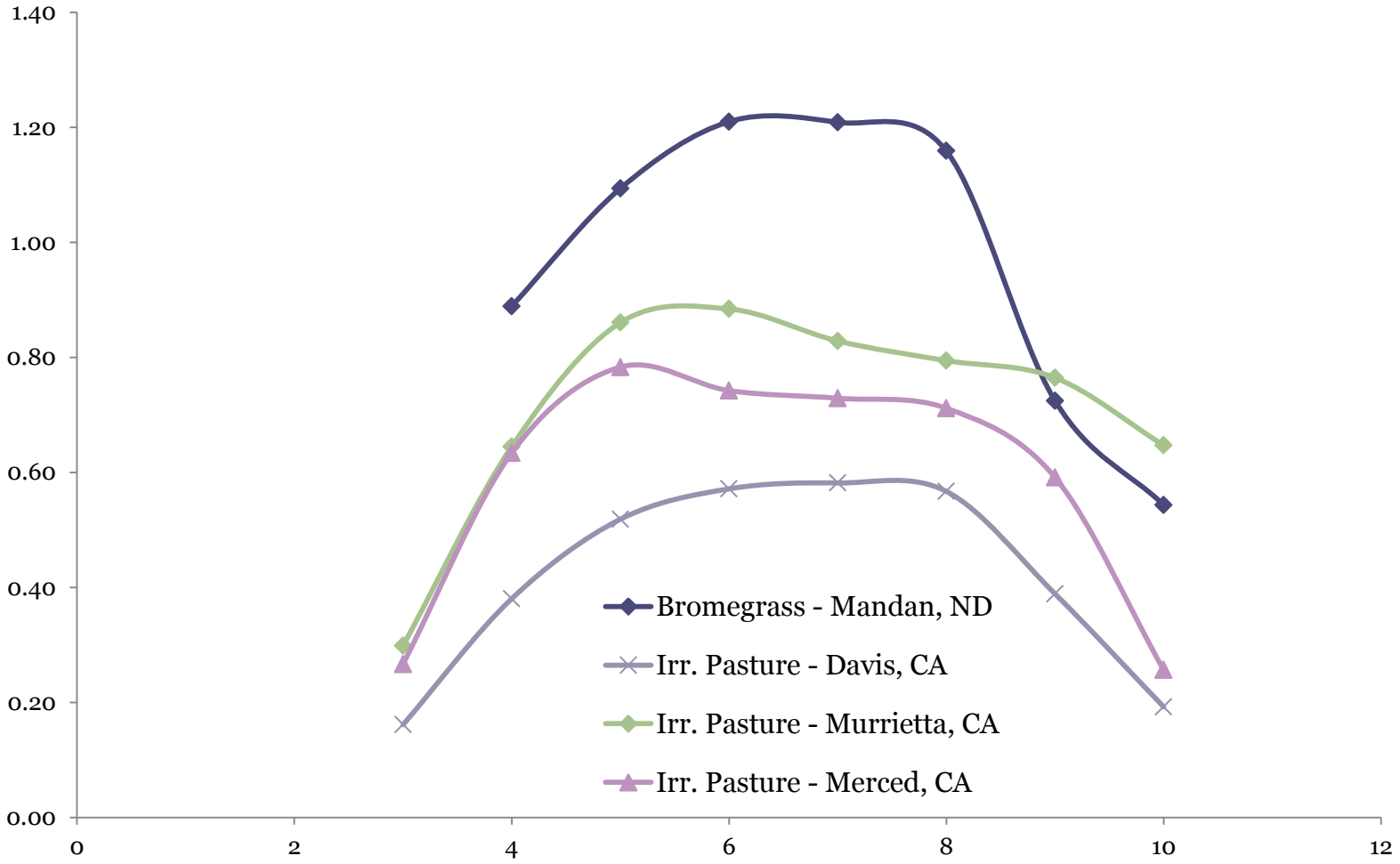
1. Hyrum Woodward, Assistant Irrigation Engineer for SCS in Portland, OR
    - The SCS is using a modification of the Blaney-Criddle method, need for monthly estimates
    - Suggest values of k for a number of crops are listed in TB 1275
    - A procedure was developed to determine k where data were not available per Phelan (1954)
    - Tentative curves were developed for ~20 types of crops applicable to the western U.S.
    - There is a critical need for additional measurements
    - There is a significant lack of reliable measurements on most crops
    - Much of the data appears to be affected by drainage or by inadequate soil moisture during critical stages of growth

Fast Forward 50 Years…

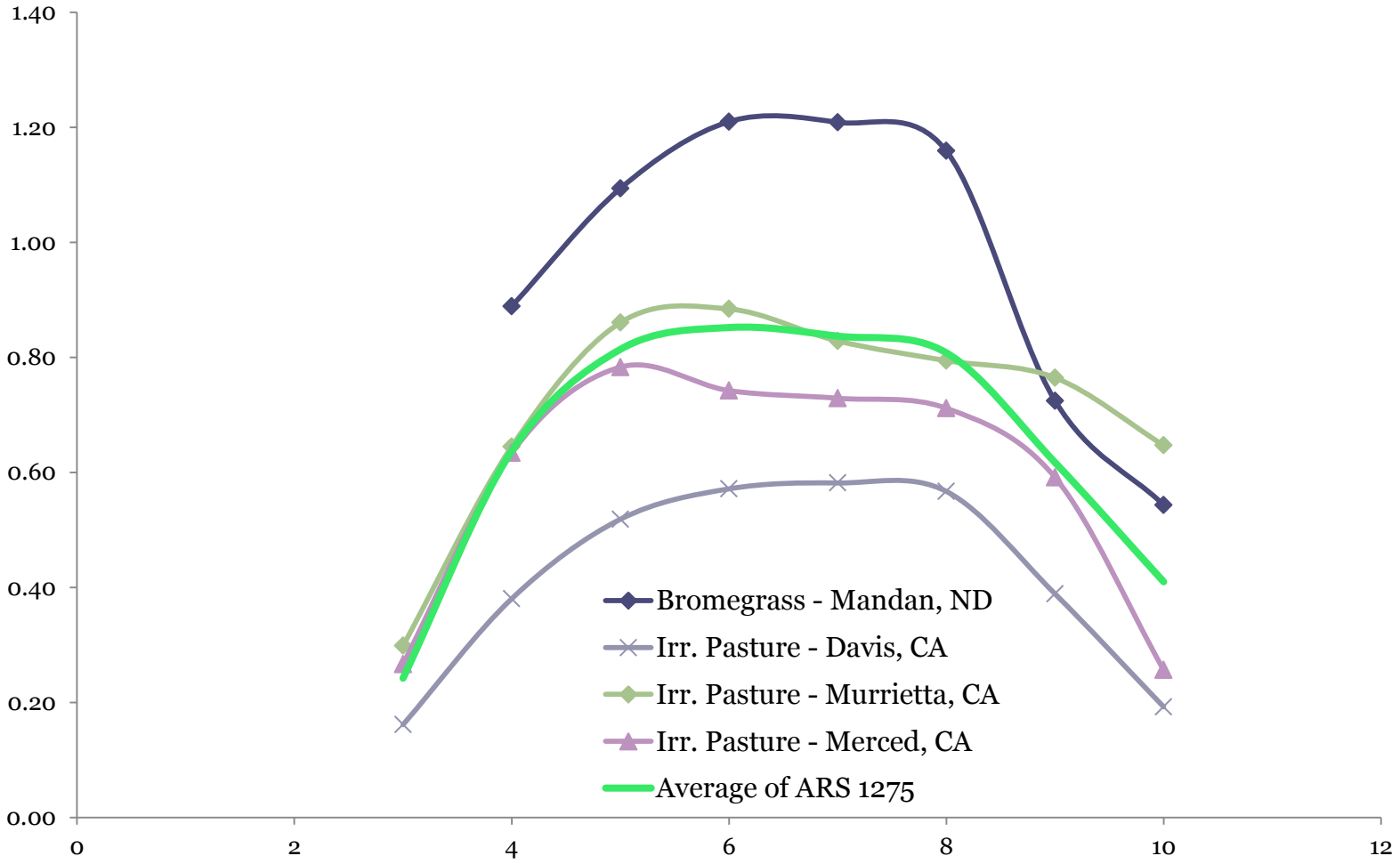
Santistevan, Coeff. Memo, unpublished, 2013

1. What happened between 1962 and 1970?
    - Development of k_c
    - Monthly crop curves
2. Objective: Evaluate TB 1275
    - Identify crop type in TR-21 (e.g., pasture grasses?)
    - Determine elevation at which TR-21 coefficients were developed at for elevation adjustment (Pochop et al. 1984)
    - Regression analysis

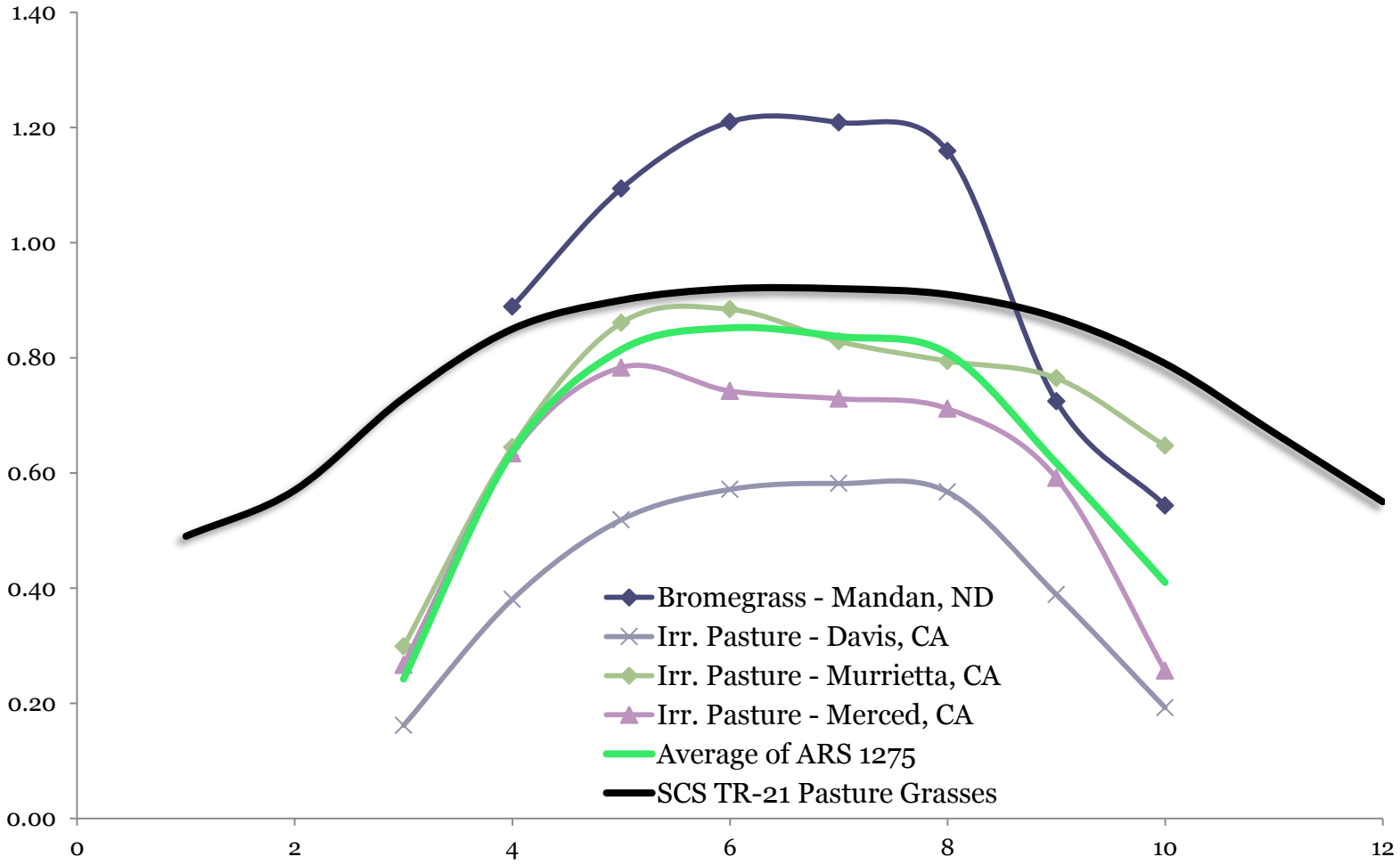
Pasture grasses:



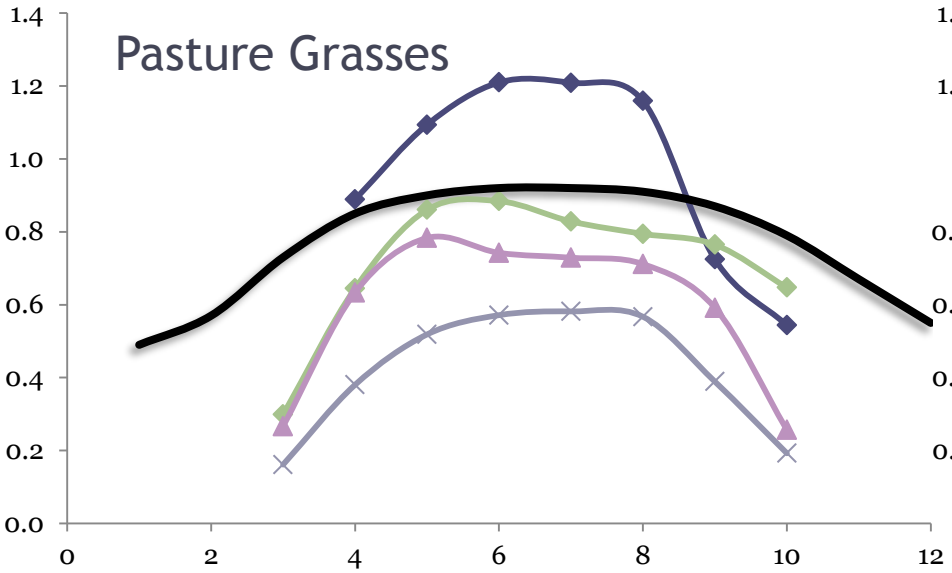
Pasture grasses:

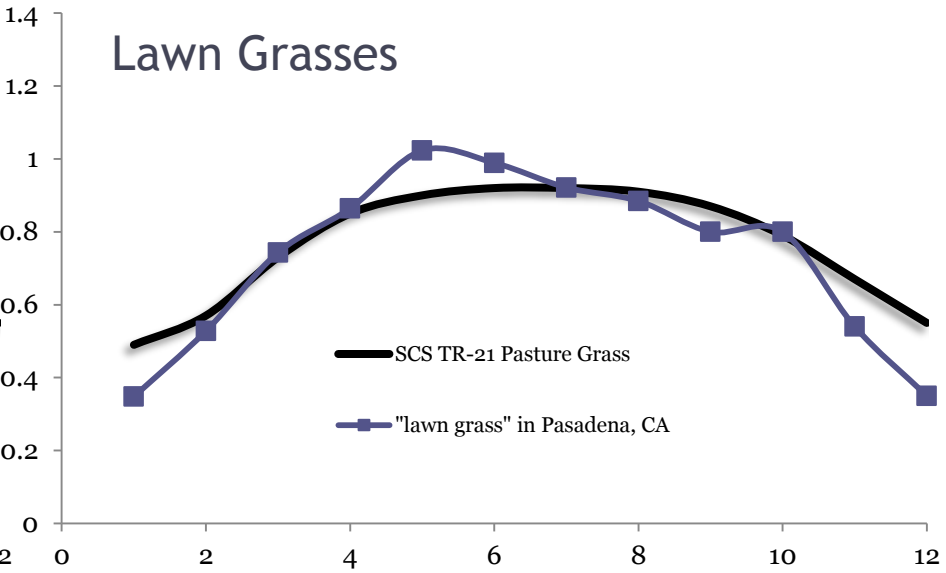


Pasture grasses:



Pasture or Lawn?

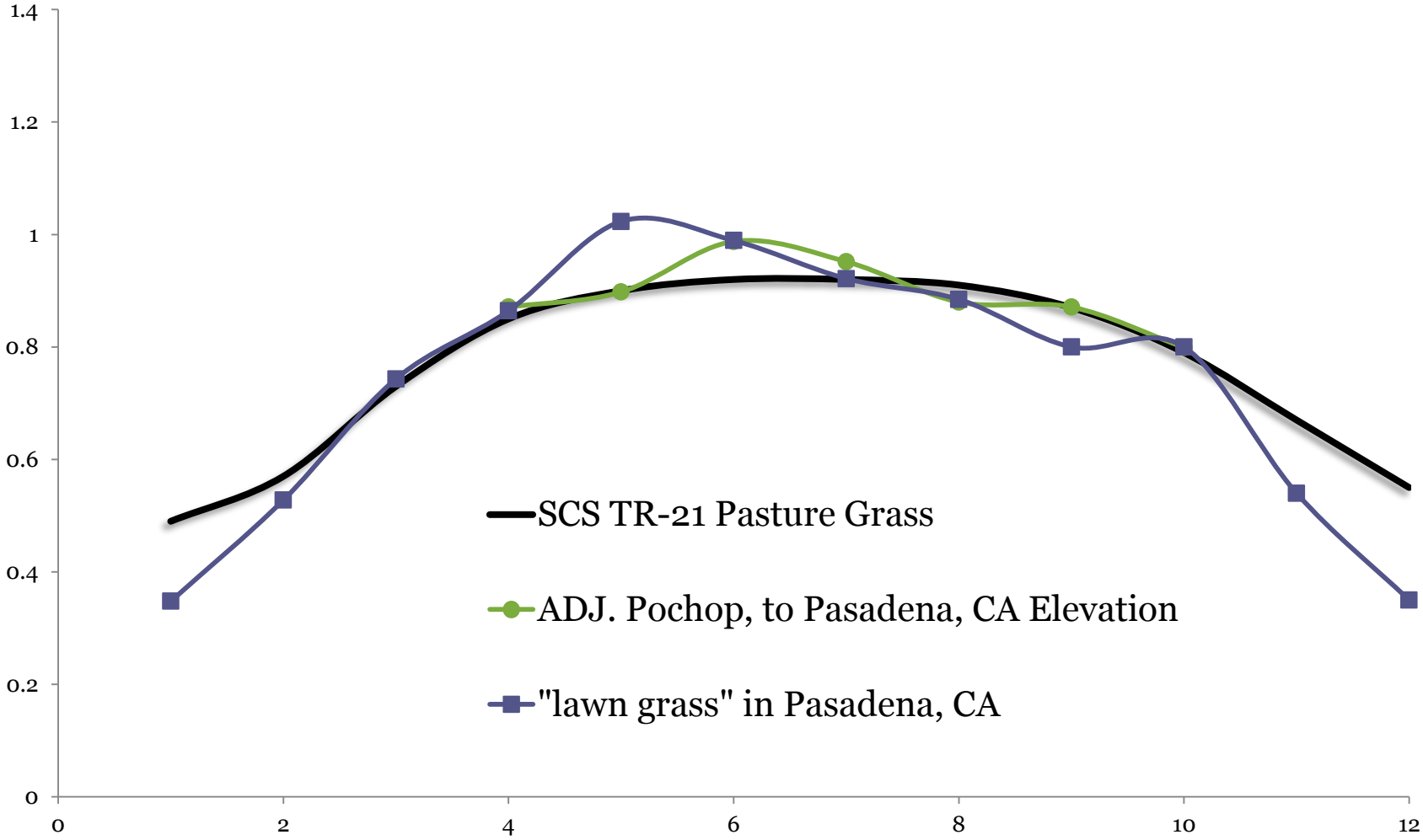




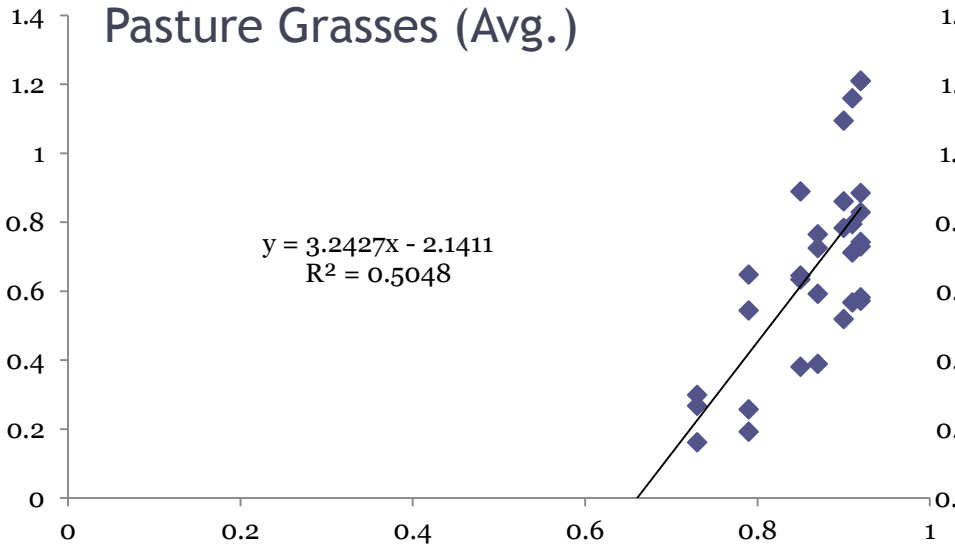
"Data for similar crops was used to guide the estimator"

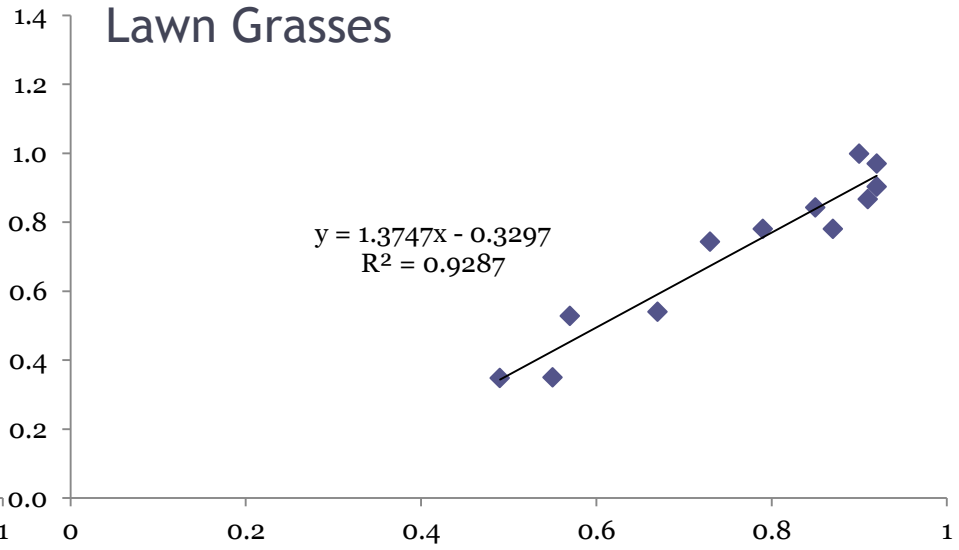
- Woodward 1963

Pasture or Lawn?



Pasture or Lawn?

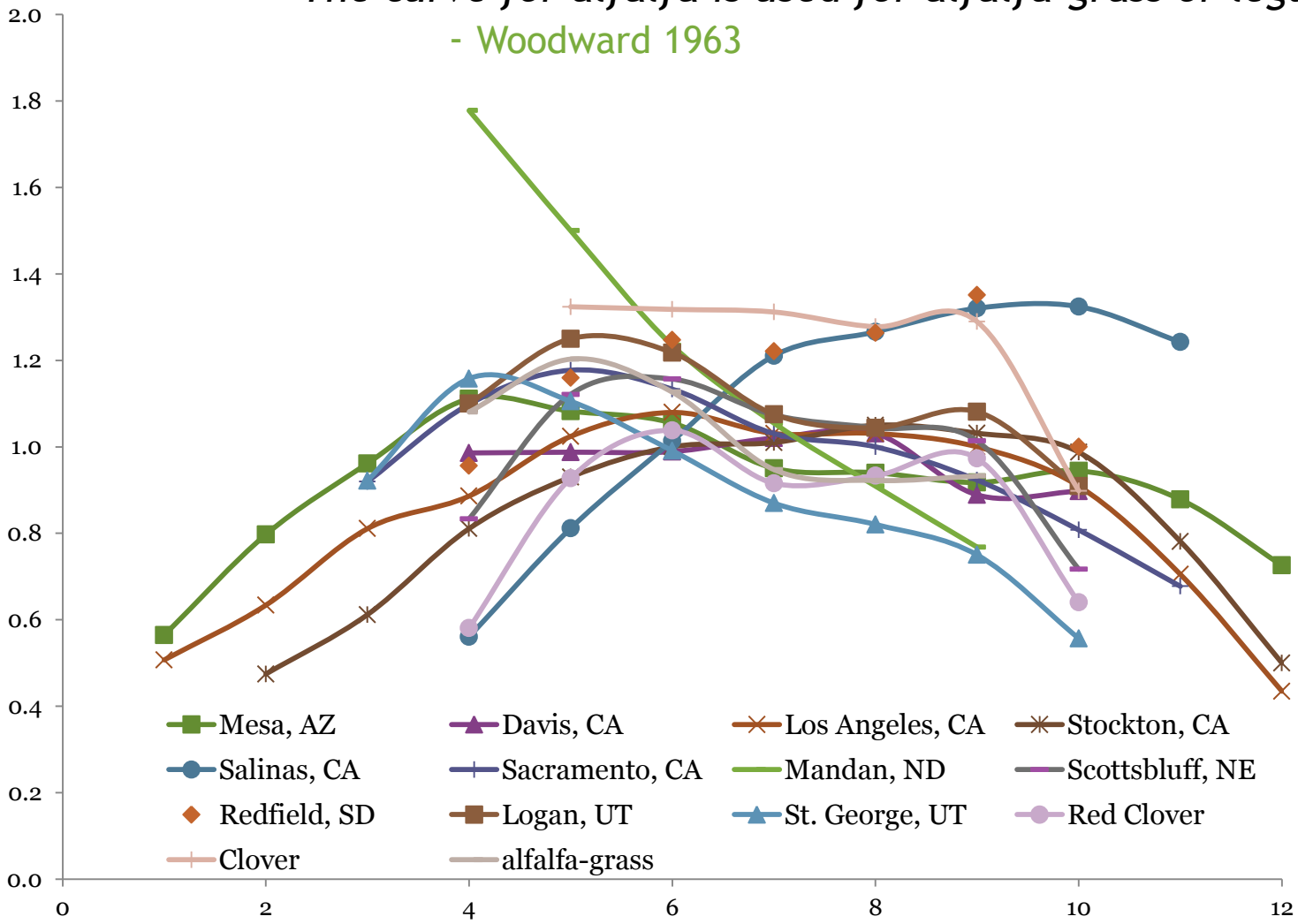




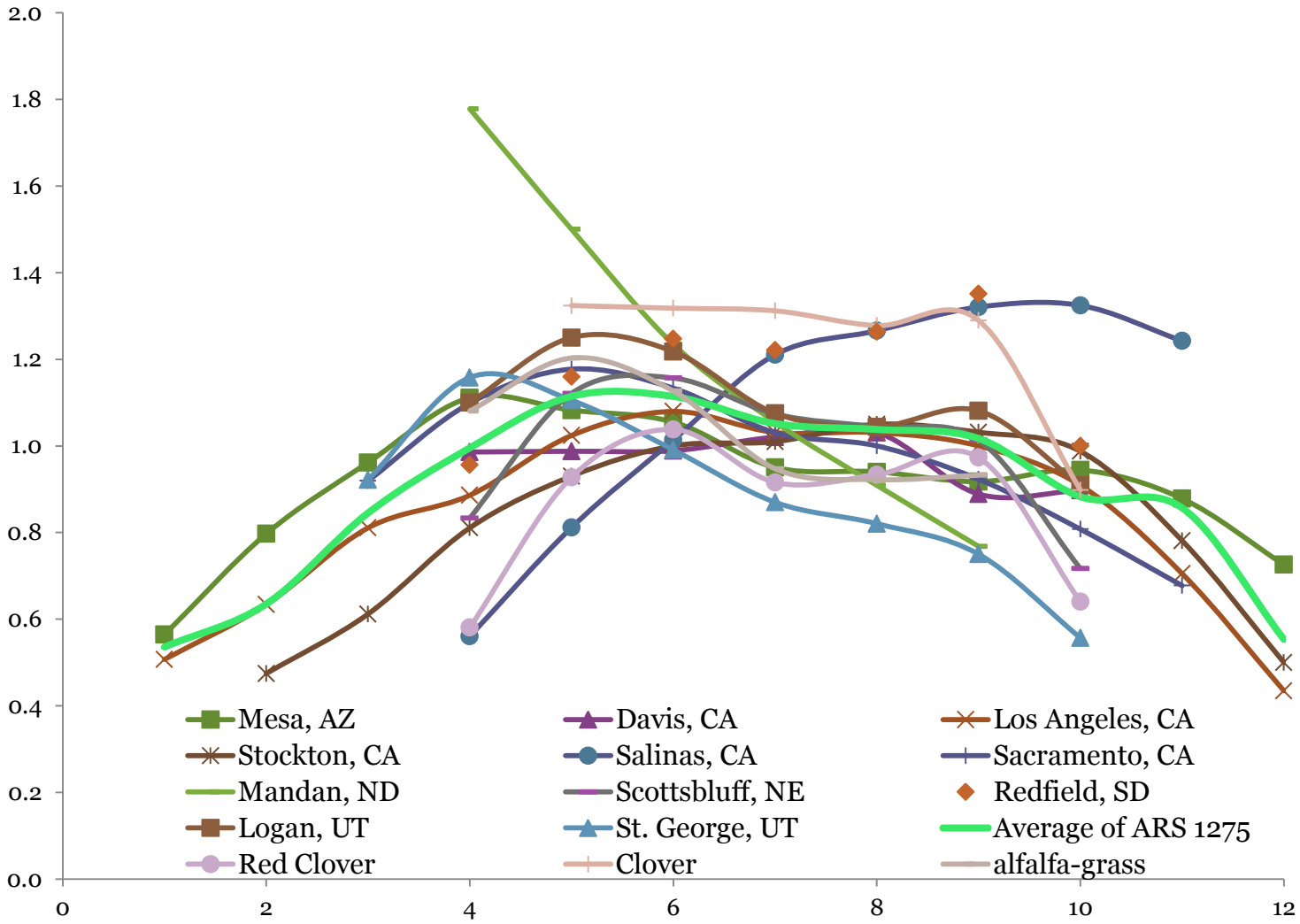
Alfalfa:

"The curve for alfalfa is used for alfalfa-grass or legume-grass."

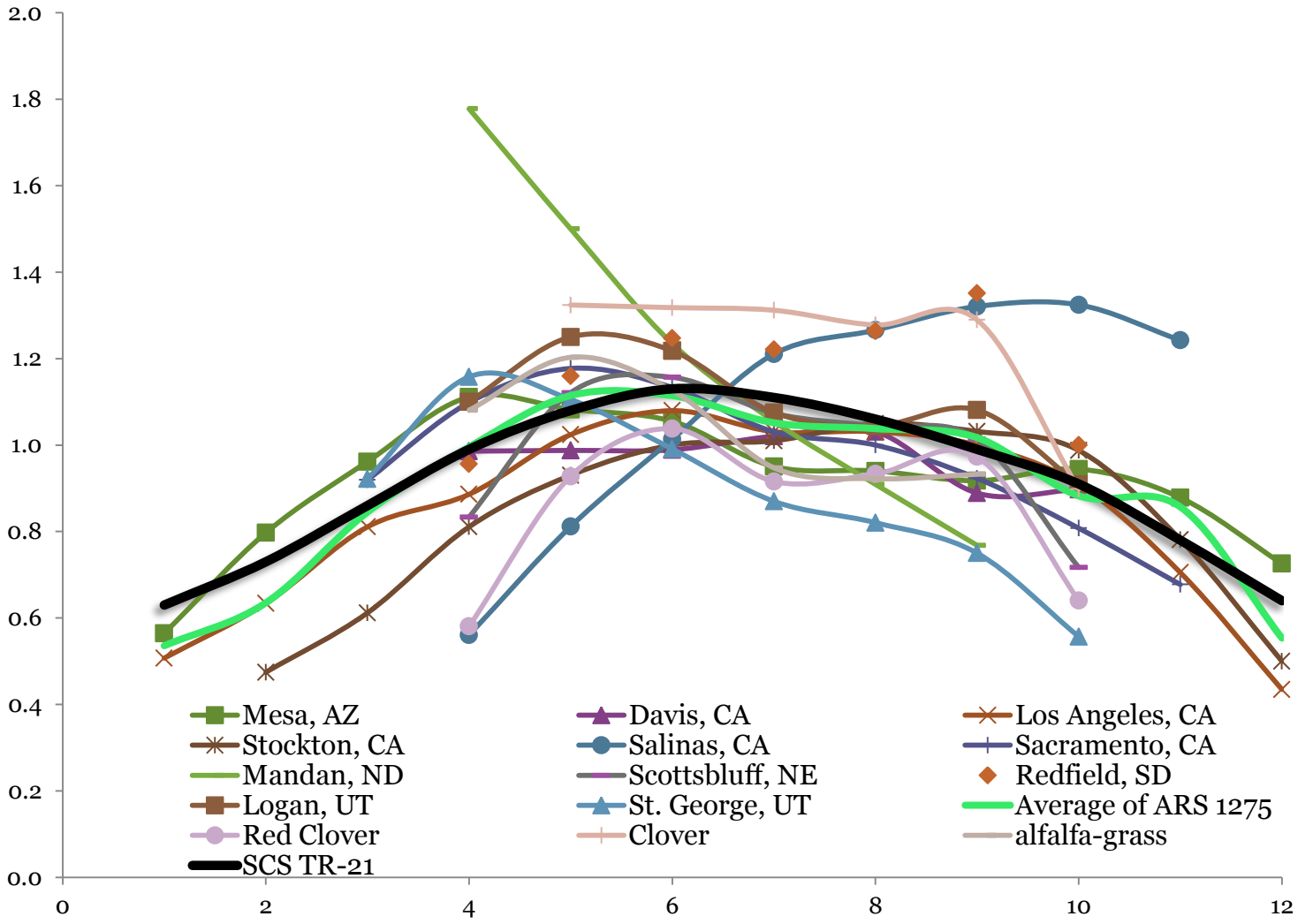
- Woodward 1963



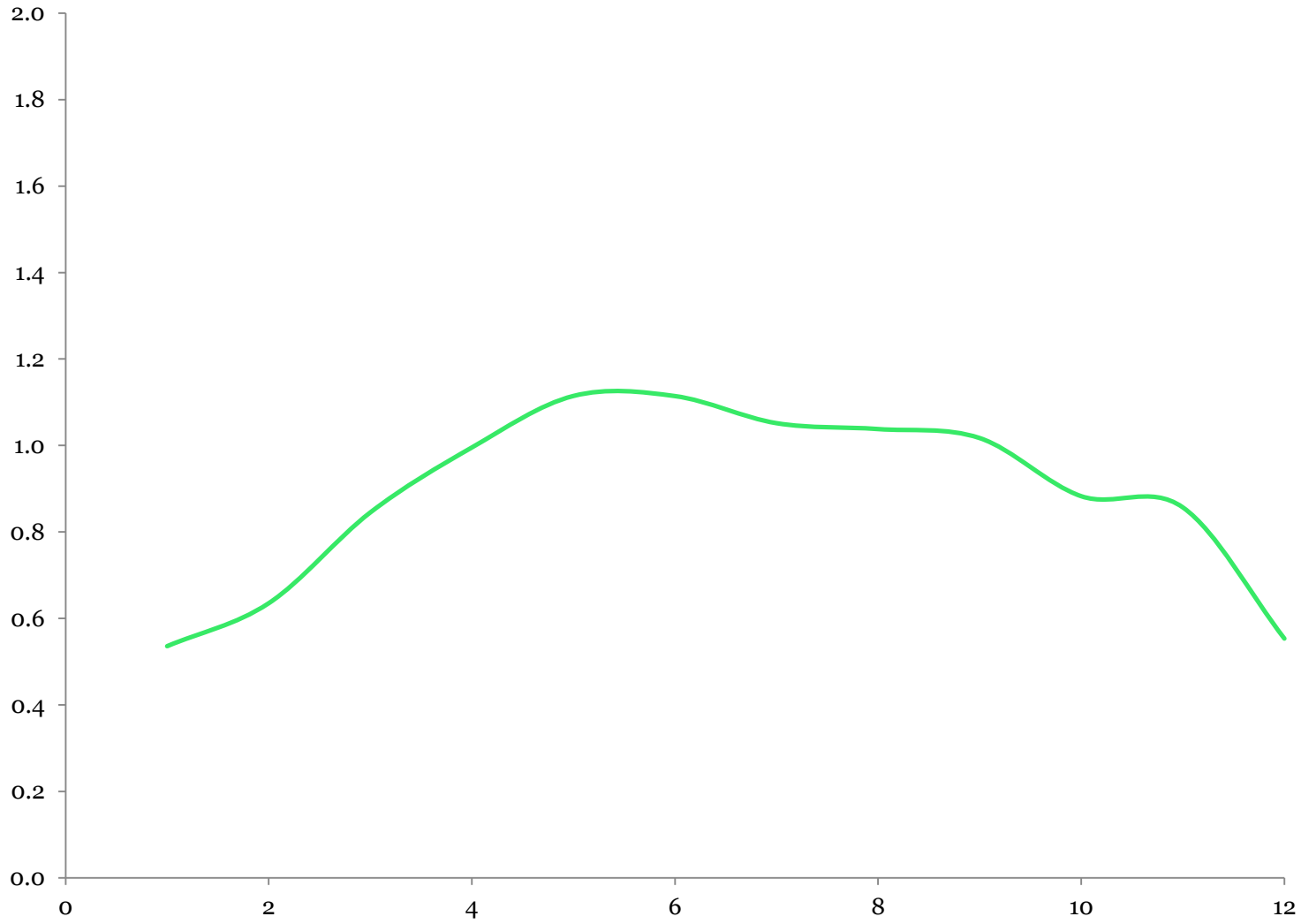
Alfalfa:


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
Mesa, AZ
Davis, CA
Los Angeles, CA
Stockton, CA
Salinas, CA
Sacramento, CA
Mandan, ND
Scottsbluff, NE
Redfield, SD
Logan, UT
St. George, UT
Average of ARS 1275
Red Clover
Clover
alfalfa-grass

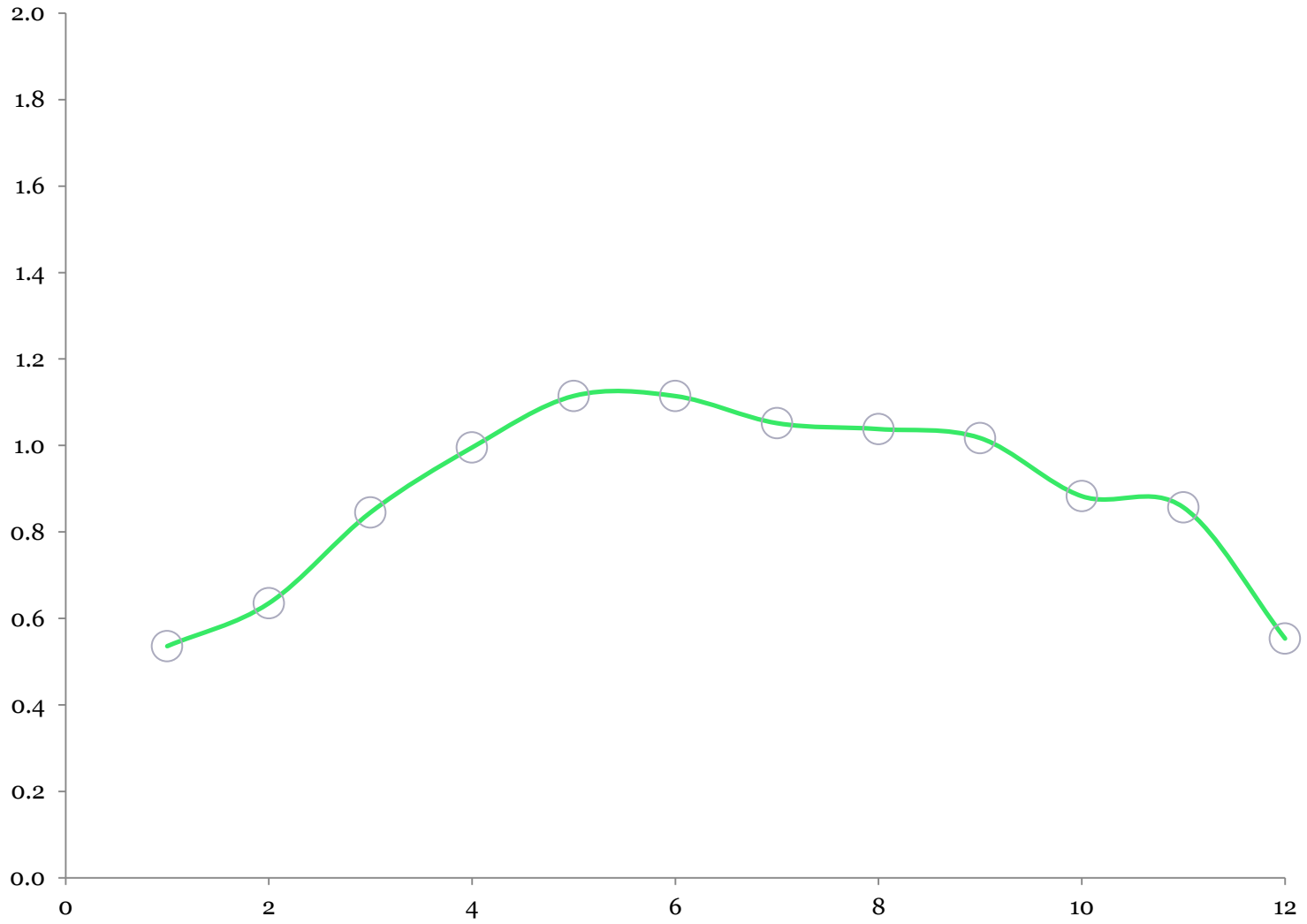
Alfalfa:


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
Mesa, AZ
Davis, CA
Los Angeles, CA
Stockton, CA
Salinas, CA
Sacramento, CA
Mandan, ND
Scottsbluff, NE
Redfield, SD
Logan, UT
St. George, UT
Average of ARS 1275
Red Clover
Clover
alfalfa-grass
SCS TR-21

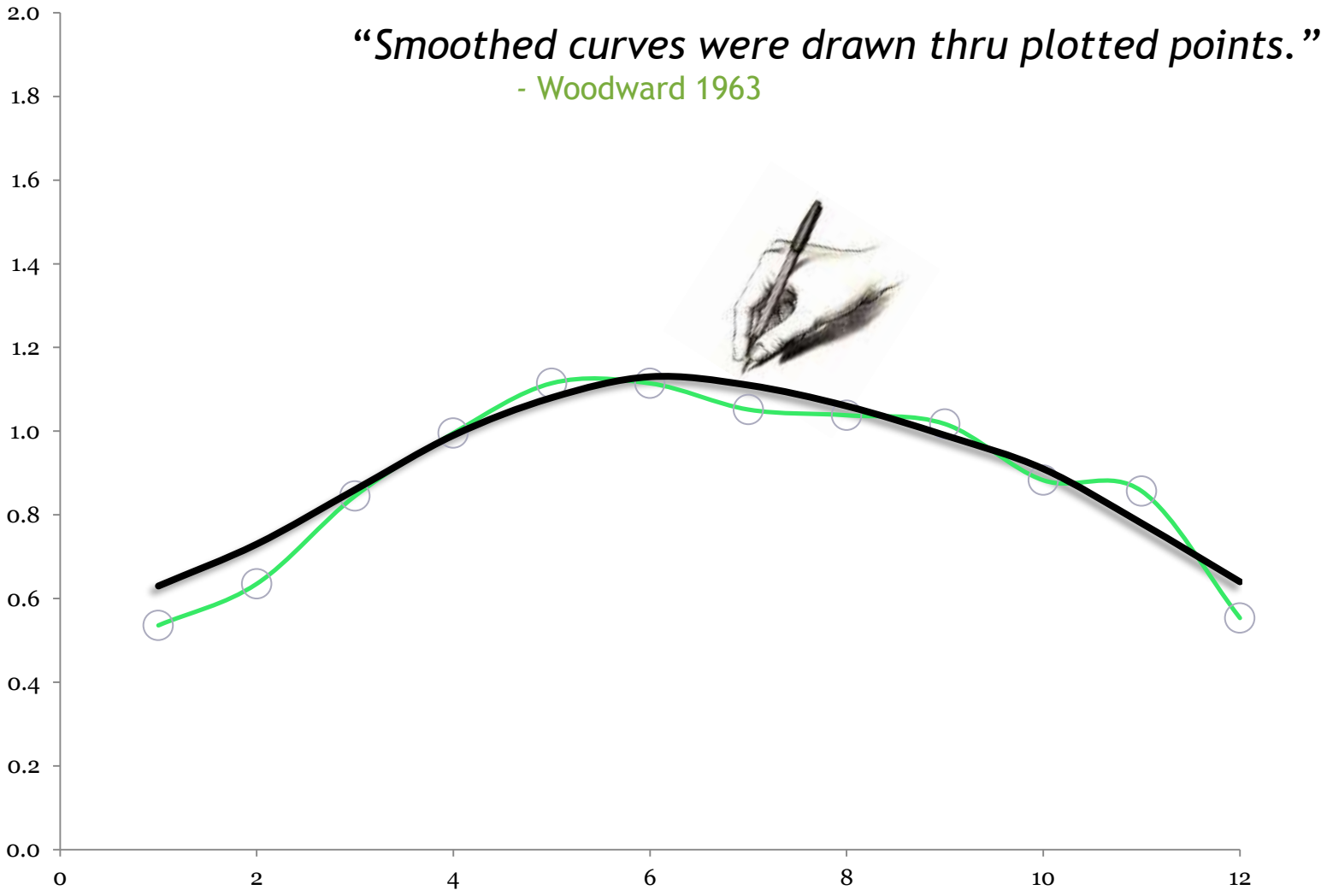
Alfalfa:



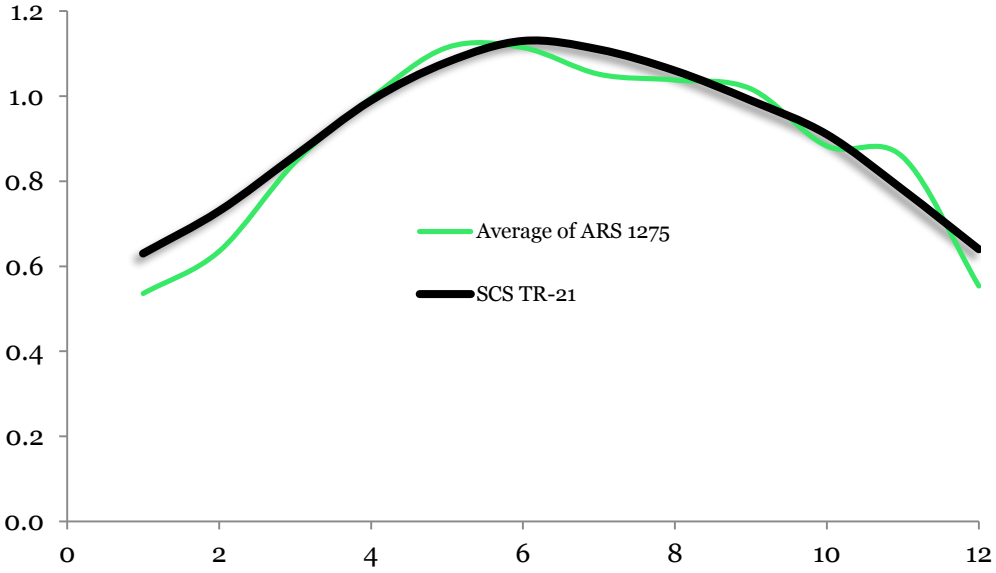
Alfalfa:

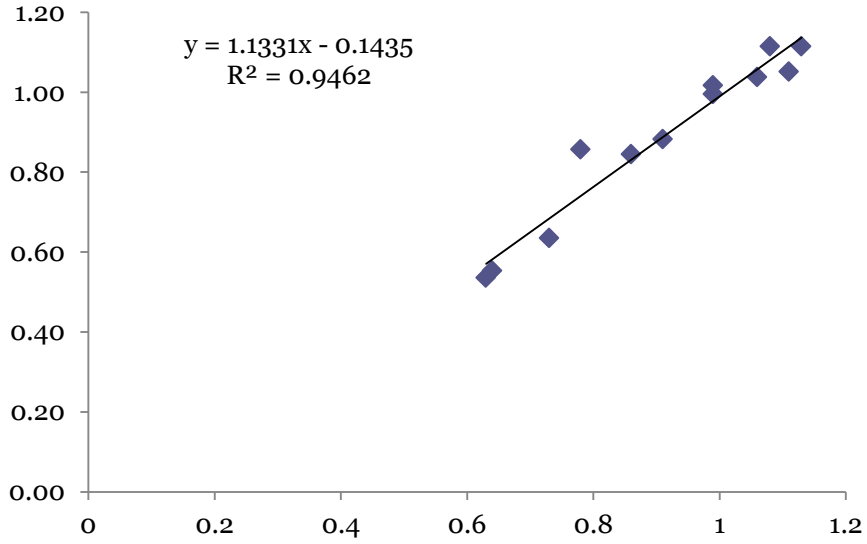


Alfalfa:

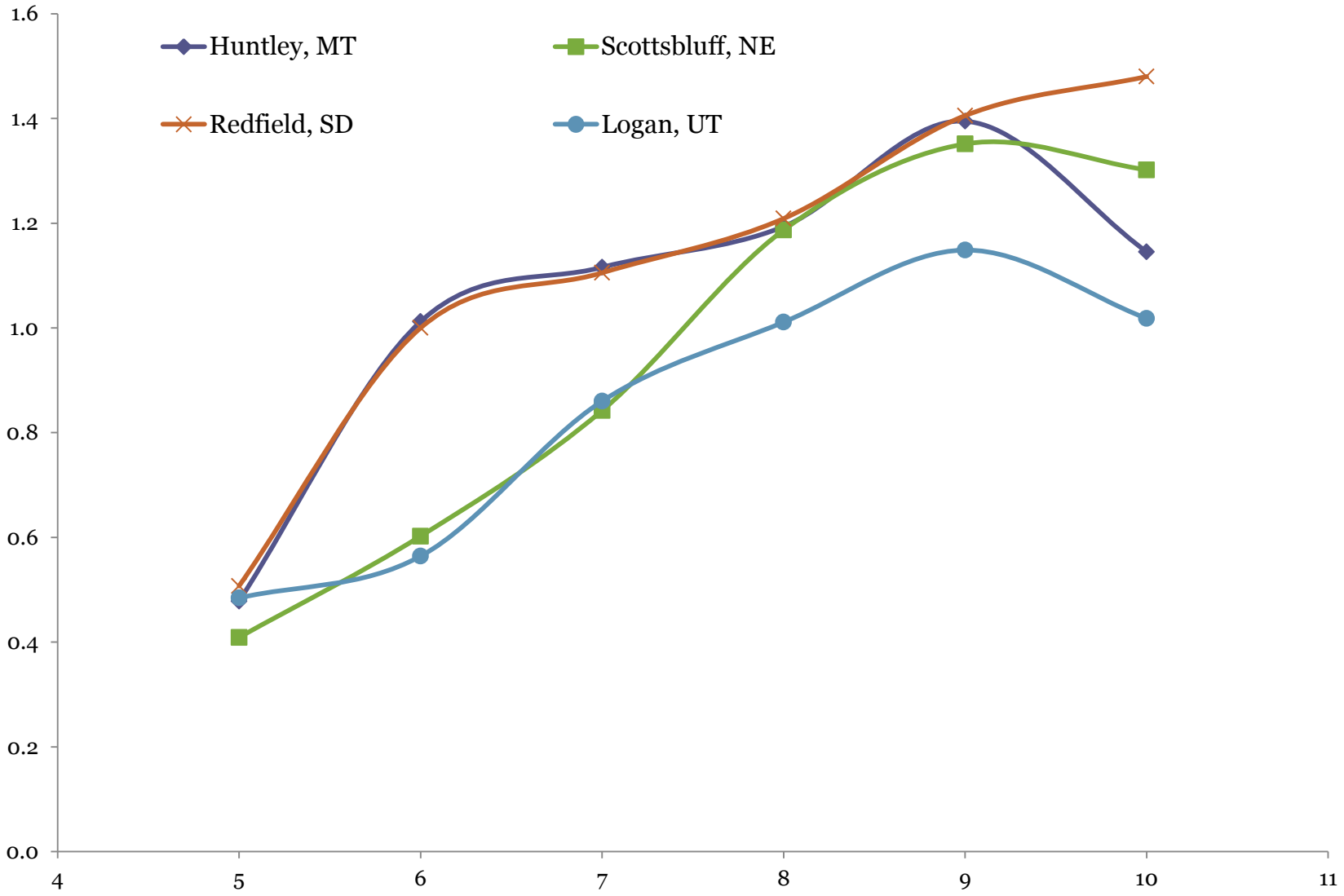

"Smoothed curves were drawn thru plotted points."
- Woodward 1963
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12

Alfalfa:

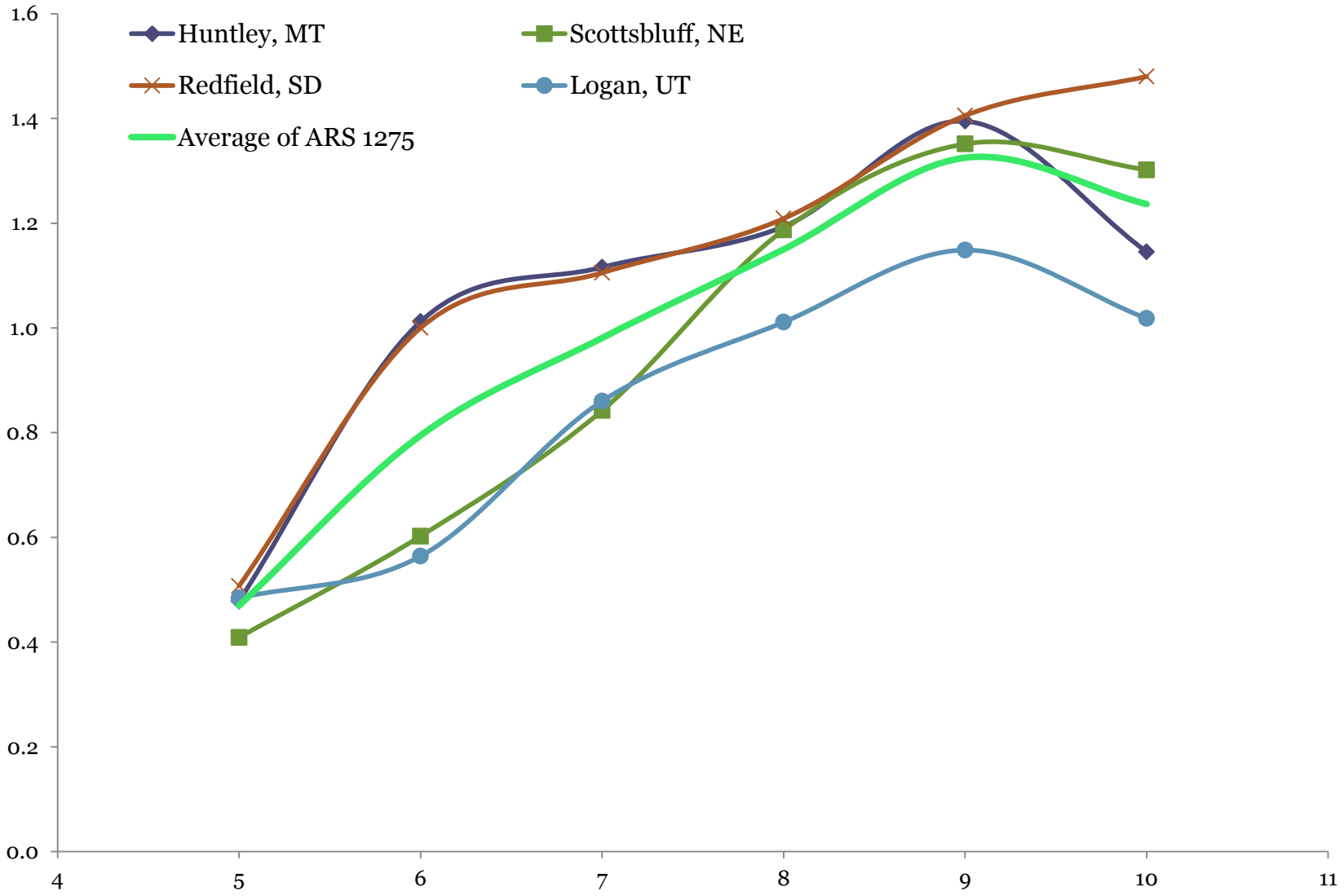

1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
Average of ARS 1275
SCS TR-21


y = 1.1331x - 0.1435
R² = 0.9462
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.2
0.4
0.6
0.8
1
1.2

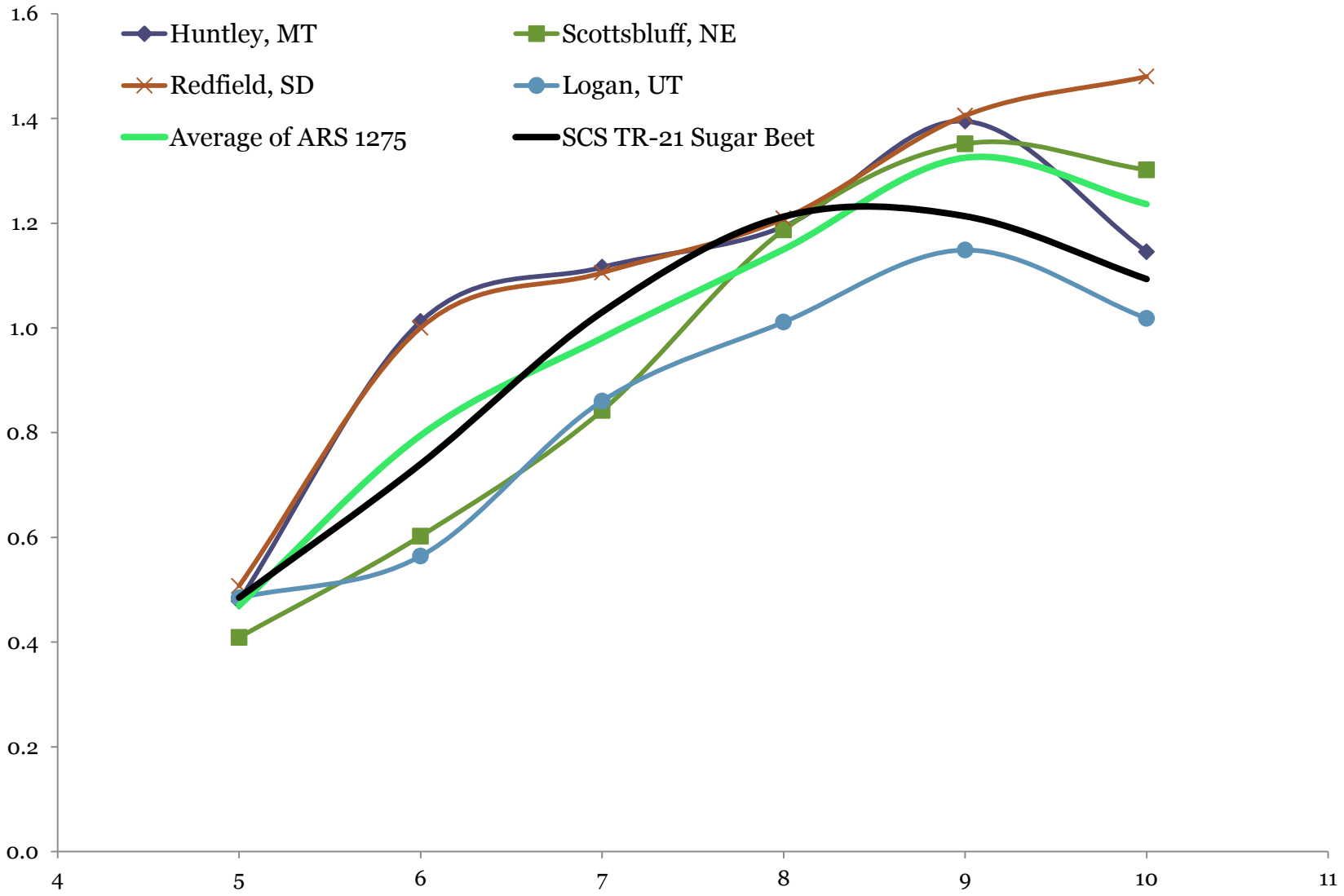
Sugar Beets:


Huntley, MT
Scottsbluff, NE
Redfield, SD
Logan, UT
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
11

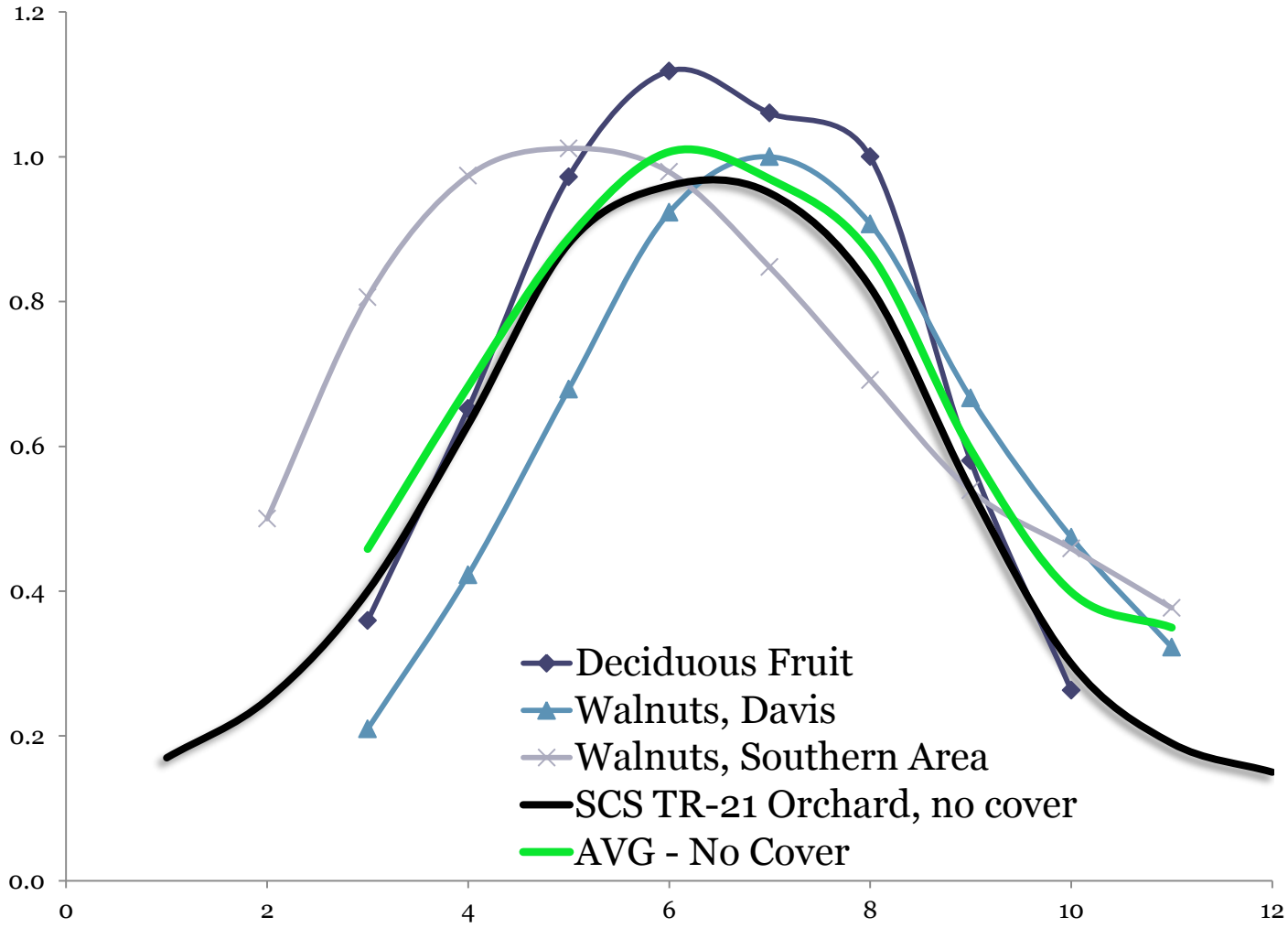
Sugar Beets:


Huntley, MT
Scottsbluff, NE
Redfield, SD
Logan, UT
Average of ARS 1275
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
11

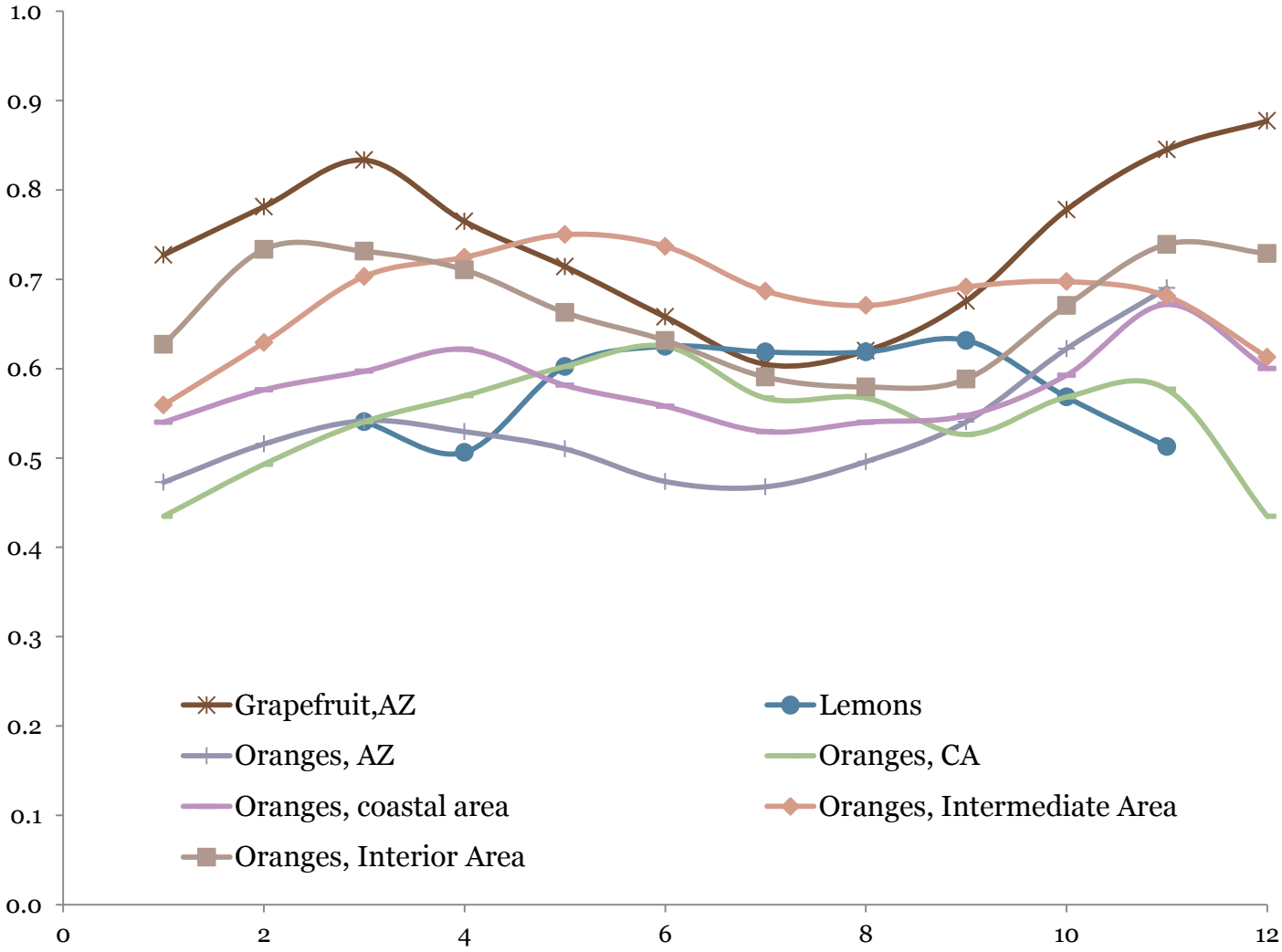
Sugar Beets:


Huntley, MT
Scottsbluff, NE
Redfield, SD
Logan, UT
Average of ARS 1275
SCS TR-21 Sugar Beet
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
11

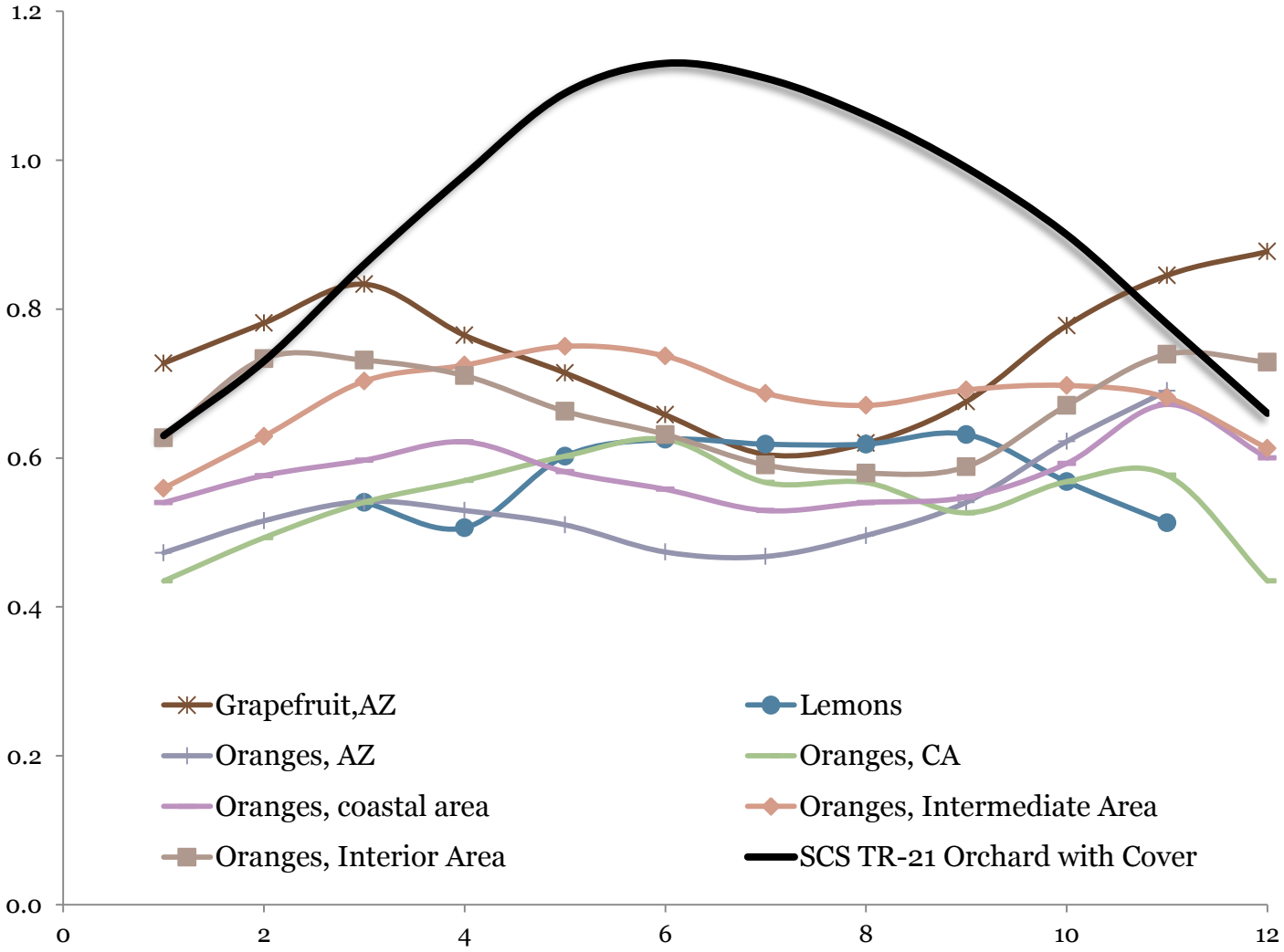
"Orchards without cover" appear to represent "deciduous fruit" and walnuts at or near sea level (in California)…



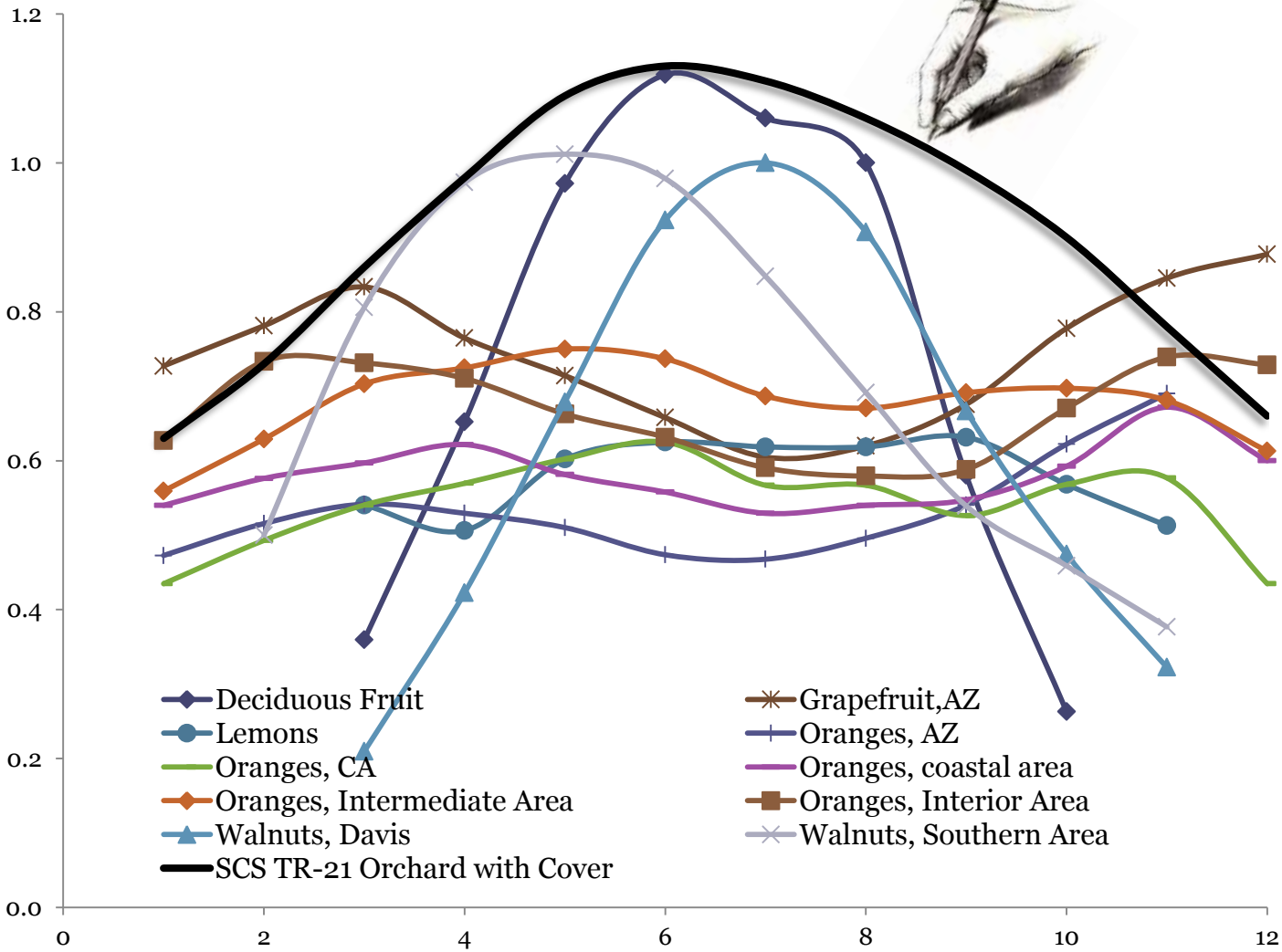
Orchards with cover:



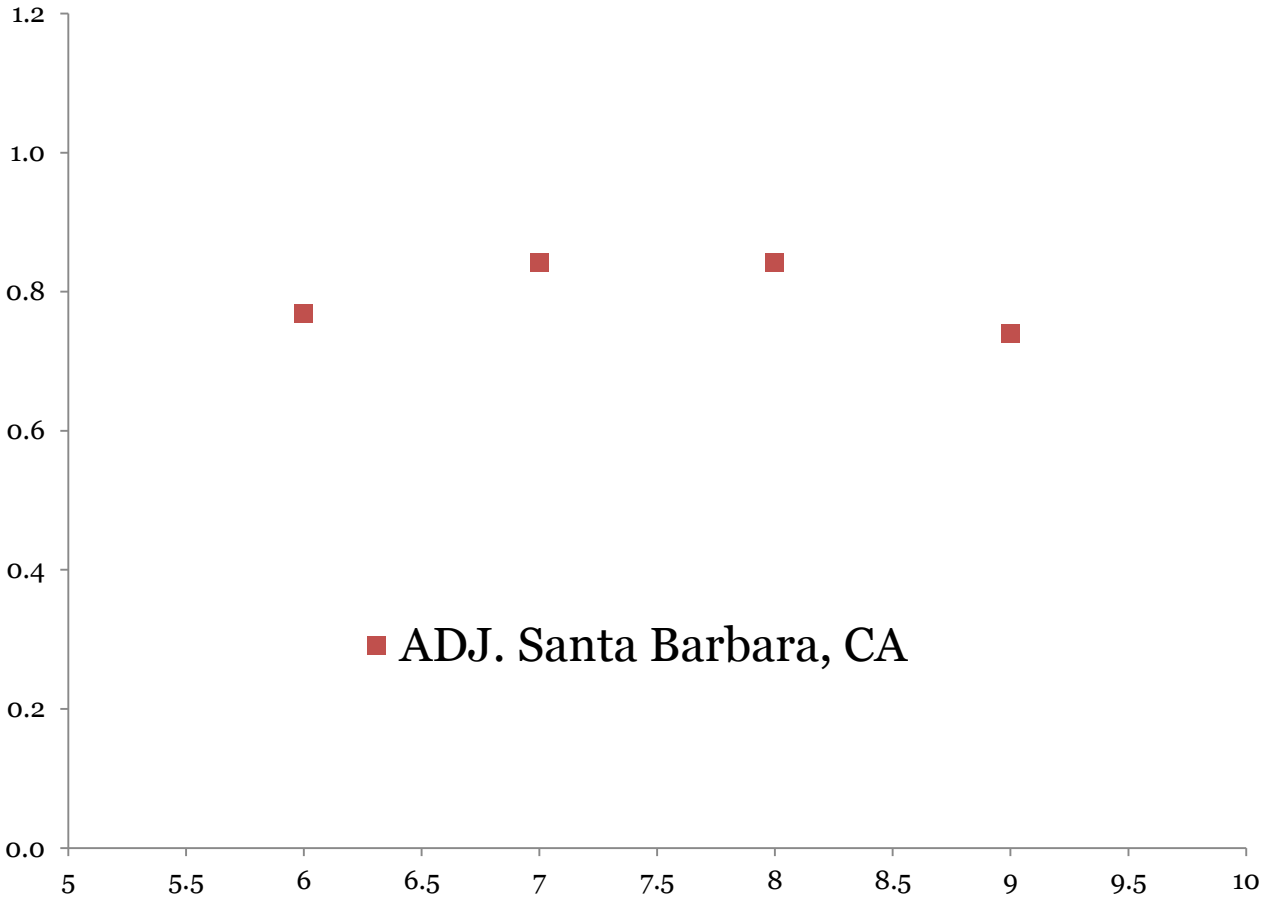
Orchards with cover:



Orchards with cover: May include Orchards without cover

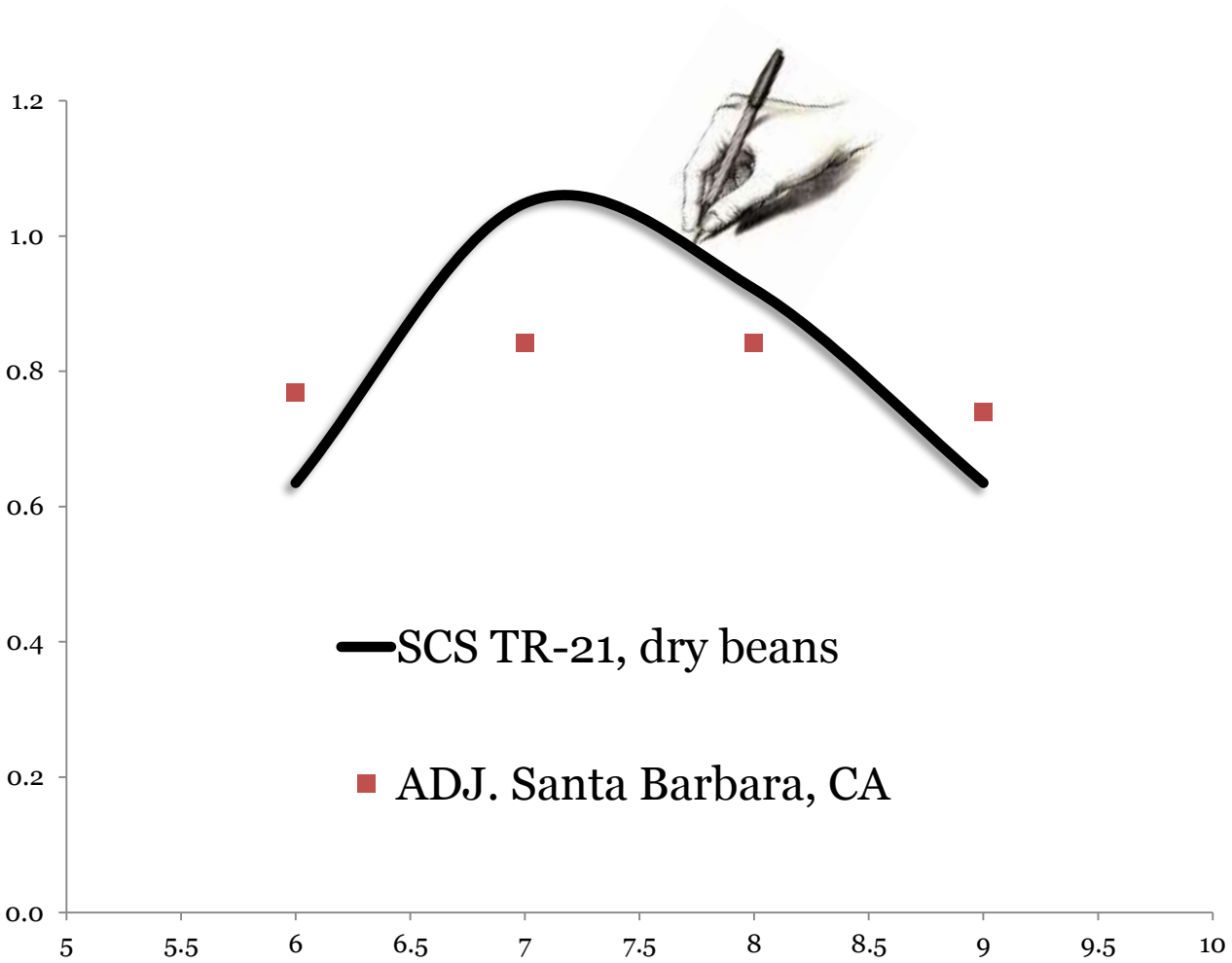


Dry beans:

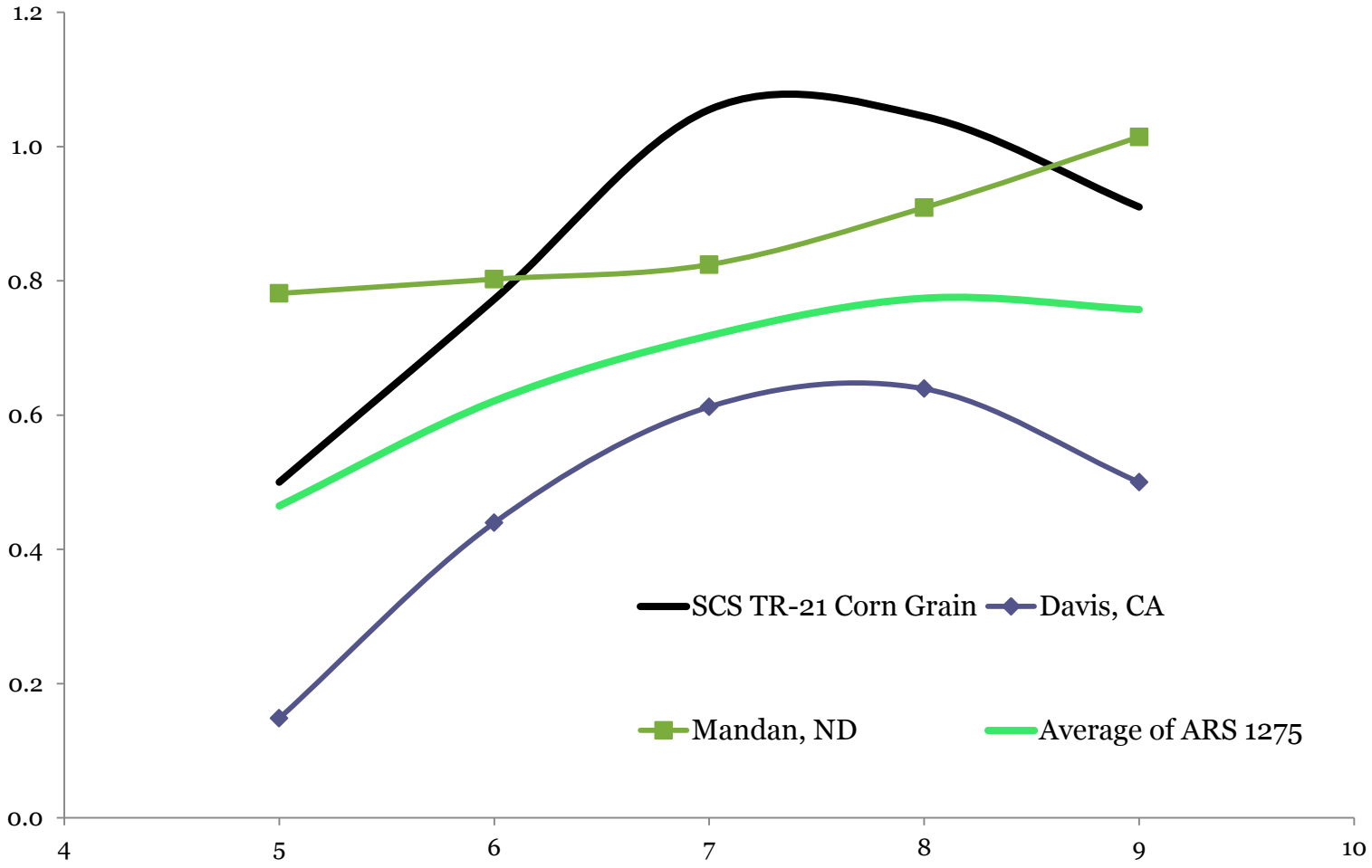


Dry beans:

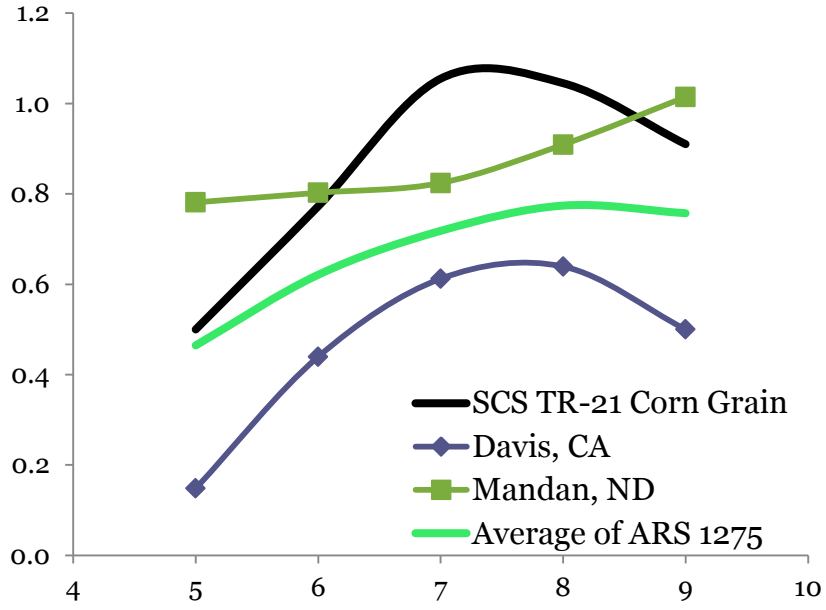
"values for some crops were estimated as no measured values of consumptive use were available" - Woodward 1963

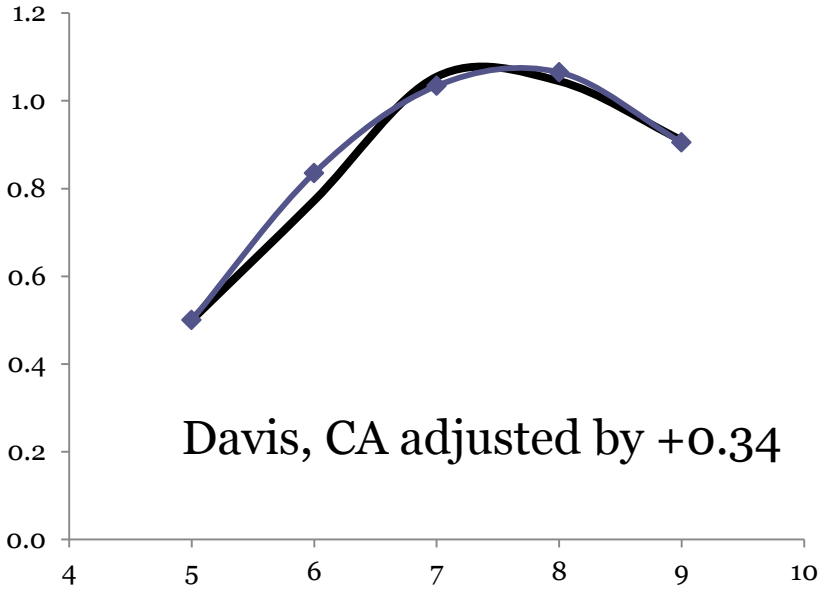


Corn:


1.2
1.0
0.8
0.6
0.4
0.2
0.0
4
5
6
7
8
9
10
SCS TR-21 Corn Grain
Davis, CA
Mandan, ND
Average of ARS 1275

Corn:





"adjustments were made . . . so that . . . *the sum of the computed monthly values . . . would approximate [the annual values] developed from the original Blaney-Criddle equation*"

- Woodward 1963

Elevation Adjustment

1. Pochop, L.O., Borrelli, J. and Burman, R. (1984). "A Bias Error in SCS Blaney Criddle ET Estimates." Transactions of the ASAE, Amer. Soc. of Agr. Eng.

2. Research indicated a trend: adjustment of 10% per 1,000m

3. Pochop et al. 1984 set out to verify if trend was true

    - Evaluated alfalfa & Kentucky Bluegrass

4. Findings:

    - An adjustment is appropriate from the elevation at which the coefficients were developed

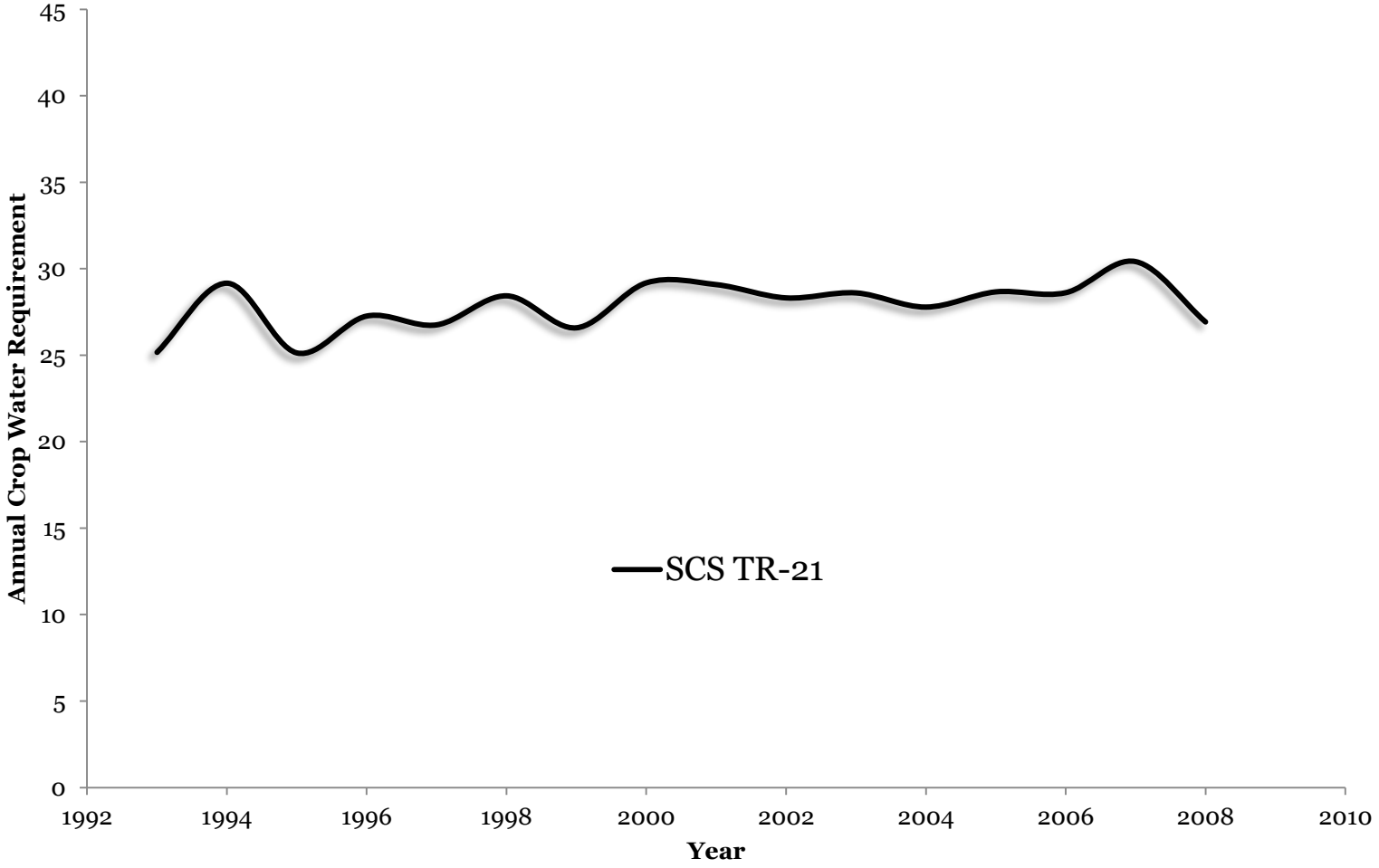
Santistevan, coefficient memo, unpublished, 2013

Crop	Elevation that k_c may represent (meters above MSL)
Bromegrass Irrigated Pasture	502 134
Lawn / KY Bluegrass	263
Sugar Beets	1382
Corn, grain	-
Alfalfa Clover Alfalfa-Grass	440 464 724
Small Vegetables	4
Small White Beans	15
Sorghum	733
Wheat	-
Barley	942
Orchard, with cover Orchard, no cover	- 134

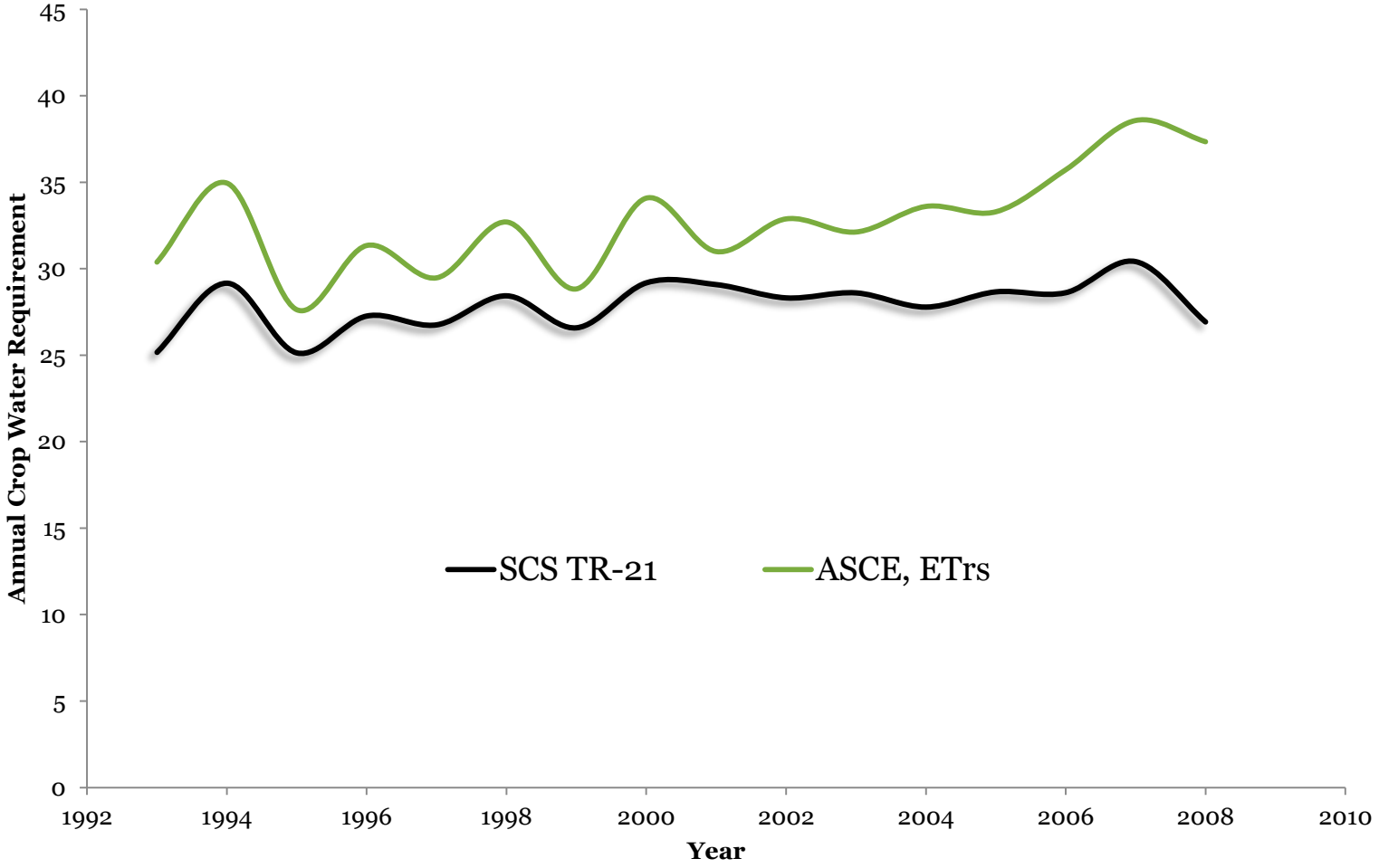
Calibration (CDSS Task Memo 59.1)

1. Before calibrating, consider:
    a. Reconstructing climate data needed for ASCE Stnd. Ref. ET Equation
    b. Hargreaves Equation
2. When calibrating, consider:
    a. CDSS Task Memo 81.2 cautions about potential temp. bias: local climate data for calibration and NOAA source for analysis
    b. What ASCE coefficient will be used? ETrs or ETos?
3. After calibrating, consider:
    a. Checking or verifying results

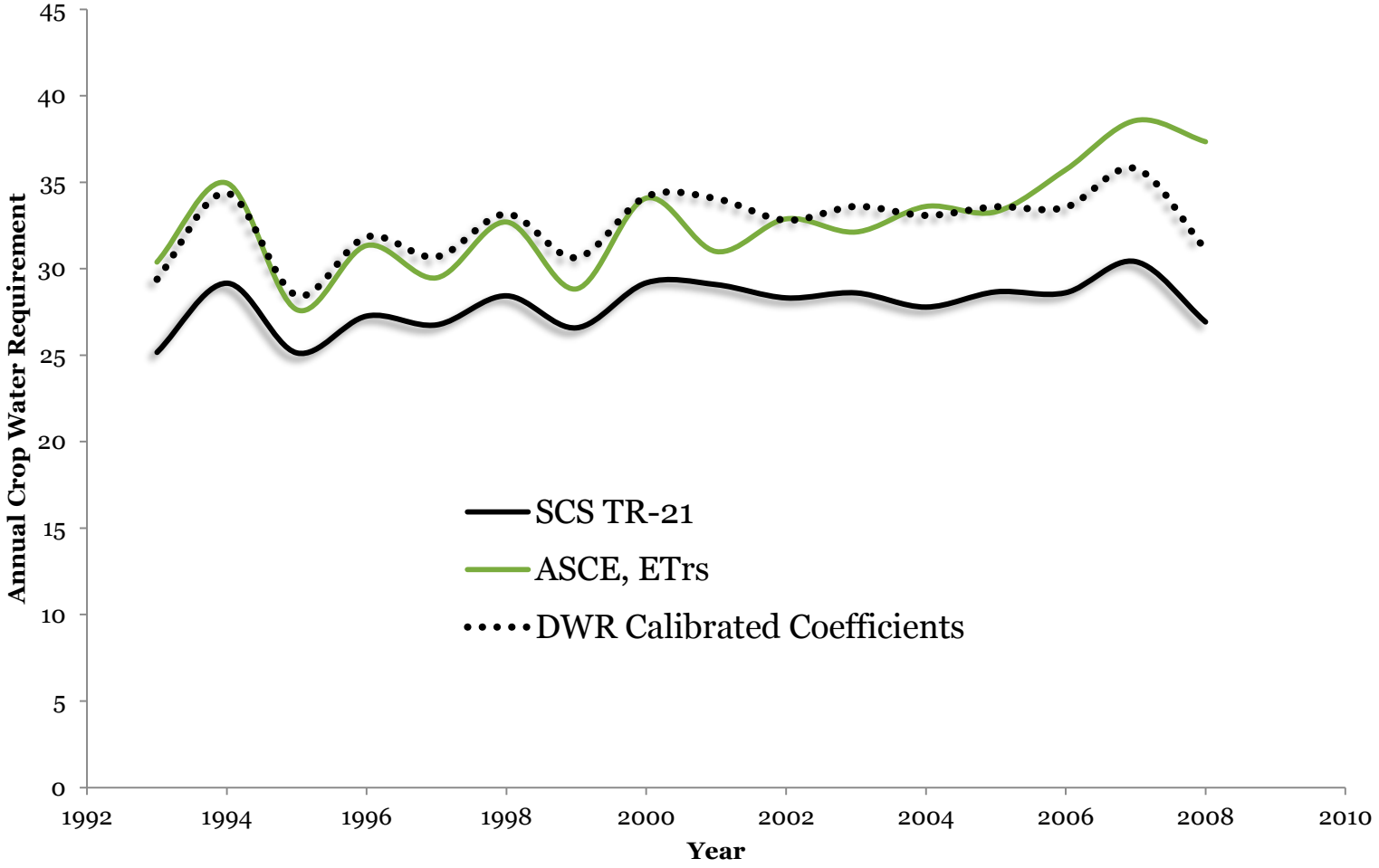
Example: Crop water requirements using B-C with SCS TR-21 coefficients



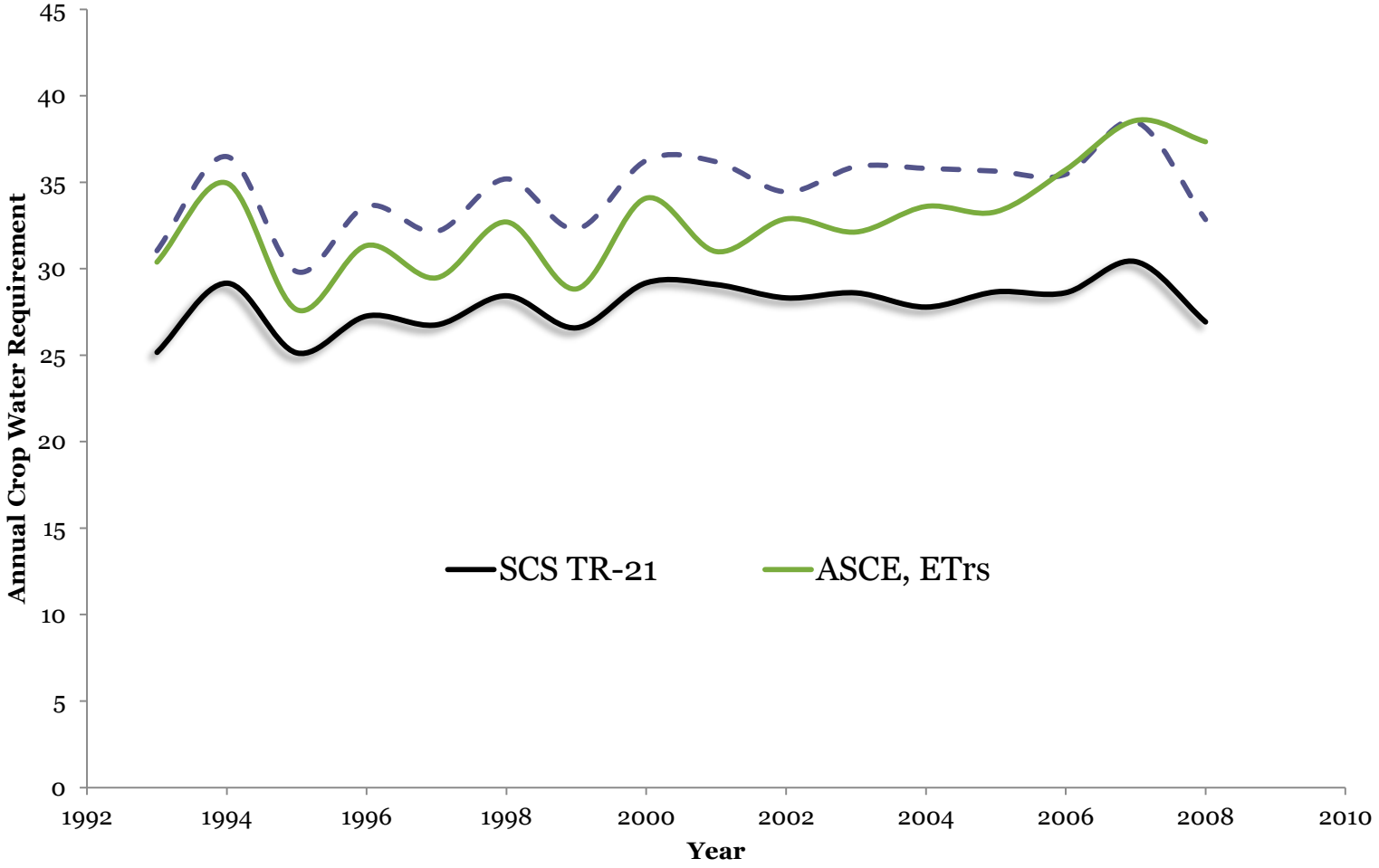
Next, crop water requirement using ASCE (ET_{rs})



B-C Calibrated to ASCE:



Verify calibrated values do not exceed ASCE:

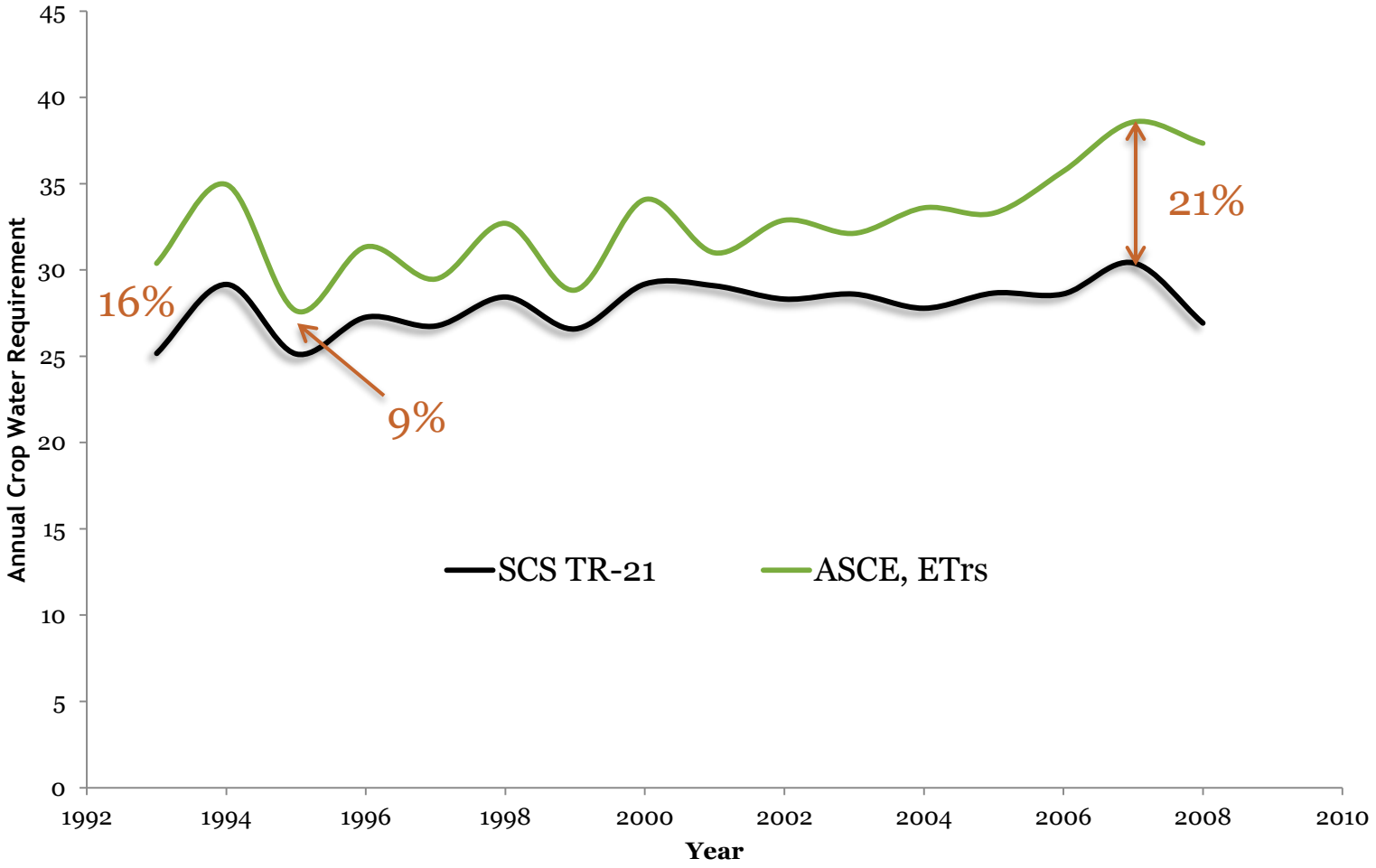


Calibration Verification:

1. Jensen and Allen (2016):
    - ASCE Penman-Montieth method provided values that were around 12 to 18 percent higher than SCS Blaney-Criddle (in arid conditions)
2. Hill 1994 (*citing*: *Hill et al. 1983*):
    - Reported a difference of 2 to 19 percent
3. Task Memo 59.1
4. Walter 1995 and Bausch 1995 (seasonal)

Crop Type	ASCE	BC	Difference	% Difference
Fort Collins (1993-2003 Average)				
Alfalfa	2.27	2.26	0.01	0%
Corn Grain	1.57	1.66	-0.09	-6%
Dry Beans	1.20	1.48	-0.28	-23%
Grass Pasture	2.50	2.10	0.40	16%
Small Grains	1.59	1.56	0.03	2%
Sugar Beets	1.69	2.00	-0.31	-18%
Fort Lupton (1993-2003 Average)				
Alfalfa	2.66	2.58	0.08	3%
Corn Grain	1.86	1.86	0.00	0%
Dry Beans	1.39	1.65	-0.26	-19%
Grass Pasture	2.88	2.32	0.56	19%
Small Grains	1.74	1.64	0.10	6%
Sugar Beets	2.17	2.32	-0.15	-7%
Greeley (1993-2003 Average)				
Alfalfa	2.67	2.53	0.14	5%
Corn Grain	1.83	1.84	-0.01	-1%
Dry Beans	1.35	1.65	-0.30	-22%
Grass Pasture	2.85	2.27	0.58	20%
Small Grains	1.80	1.66	0.14	8%
Sugar Beets	2.10	2.27	-0.17	-8%

Reproduced from Task Memo 59.1


45
40
35
30
25
20
15
10
5
0
Annual Crop Water Requirement
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year
16%
9%
21%
SCS TR-21
ASCE, ETrs

All values in acre-ft per acre

Crop	SCS TR-21	Calibrated	% Increase
Alfalfa	2.84	**3.50**	
Grass Pasture	2.53	**3.59**	42%
Sugar Beets	2.51	**2.54**	
Corn Grain	2.10	**2.35**	
Beans	1.64	**1.55**	
Small Vegetables	1.56	**2.44**	56%
Wheat (winter)	1.58	**1.49**	

Crop	SCS TR-21	TR-21 w/ Elev Adjustment	Calibrated	
Small Grains	1.15	1.23	**2.07**	80%
Alfalfa	1.99	2.23	**2.67**	34%
Small Vegetables	1.04	1.23	**2.27**	118%
Pasture Grass	1.68	n/a	**2.62**	56%

Calibration Verification:

Compared to Published Data…

Crop	SCS TR-21	TR-21 w/ Elevation Adjustment	**Calibrated**	Published Data:	
				Schneekloth & Andales, 2009 (Greeley, CO)	Ames Irrigation Handbook
Small Grains	1.15	1.23	**2.07**	1.37	1.17
Alfalfa	1.99	2.23	**2.67**	2.63	2.50
Small Vegetables	1.04	1.23	**2.27**	1.48	0.75
Pasture Grass	1.68	n/a	**2.62**	2.22	2.34

All values in acre-ft per acre