DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATER RESOURCES

MEMORANDUM

TO: DAVID NETTLES, Division Engineer in Water Division 1
KEVIN REIN, Asst. State Engineer

FROM: DEAN SANTISTEVAN, Asst. Division Engineer in Water Division 1

DATE: December 13, 2013

SUBJECT: Issues with Selecting an Appropriate Crop Growth Stage Coefficient for the SCS Modified Blaney-Criddle Equation

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EXECUTIVE SUMMARY

This memo stems from our involvement in Case No. 10CW263[1] where the Applicant relied upon the upper plains coefficients for pasture grasses in Task Memo 59.1 for their change of use analysis. The Applicant defended their use by alleging that if an elevation adjustment to SCS Blaney-Criddle coefficients was performed from sea level as referenced in Pochop[2], the result would be the same. We contested the use of the Task Memo 59.1 coefficients and argued that an elevation adjustment pursuant to Pochop would not necessarily be from sea level. This memo addresses issues with selecting an appropriate crop growth stage coefficient, and separates them into three parts.

Part I: Technical review of an elevation adjustment from Pochop (begins on p.2)

- For Kentucky Bluegrass and alfalfa, an elevation adjustment to the SCS Modified Blaney-Criddle equation is appropriate from the elevation at which the coefficients were developed (during the growing season).
  - An elevation adjustment of around 10 percent per 1,000m was confirmed

Part II: Forensic Analysis of selected SCS TR-21[3] crop growth stage coefficients (begins on p.4)

- The source of SCS TR-21 crop growth stage coefficients are data published in ARS 1275[4]
- SCS TR-21 crop growth stage coefficients for "Pasture Grasses" may better describe a "lawn" type grass, or Kentucky Bluegrass, at or near sea level (see pp.6-9)

Part III: Evaluation of "upper plains" calibrated coefficients in Task Memo 59.1[5] (begins on p.20)

- While the methodology in Task Memo 59.1 for a local calibration may be appropriate, the published upper plains coefficients for "Pasture Grasses" are suspect to error and should not be relied upon[6] (see pp.22-23)

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[1] Perry Park Water & Sanitation District, Case No. 10CW263, Water Division 1
[2] Pochop , et al. (1984), herein referred to as "Pochop"
[3] USDA-SCS (1967), rev. 1970
[4] Blaney and Criddle (1962)
[5] Wilson, et al. (2005)
[6] Testimony (deposition) from Ray Alvarado, Project Manager of SPDSS, in Case No. 10CW263 confirmed that the coefficients should not be relied upon in a legal proceeding and noted that the disclaimer inTM59.1 (p.1) states the same

NOMENCLATURE & ABBREVIATIONS

ARS	Agricultural Research Service
ASCE	American Society of Civil Engineers
CoAgMET	Colorado Agricultural Meteorological nETwork
DWR	Colorado Division of Water Resources
ET	Evapotranspiration
ET_{rs}	Evapotranspiration calculated with the ASCE Standardized Reference ET Equation using a tall (alfalfa) reference crop
f	Monthly consumptive use factor
K	Seasonal crop consumptive use coefficient
k	Monthly crop consumptive use coefficient
k_c	Crop growth stage coefficient
k_t	Climatic coefficient
KY	Kentucky
IDSCU	Integrated Decision Support Group's Consumptive Use Model
NOAA	National Oceanic and Atmospheric Administration
NEH	National Engineering Handbook
NRCS	Natural Resources Conservation Service
p	Percent daylight hours
R^2	Correlation coefficient
SCS	Soil Conservation Service
SPDSS	South Platte Decision Support System
t	Mean monthly temperature, in Farenheight
TM59.1	SPDSS Task Memo 59.1 (Wilson, et al. 2005)
TR-21	Technical Release No.21 (USDA-SCS, 1967)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WMU	Water Management Unit - Ft. Collins, CO

PART I: TECHNICAL REVIEW OF POCHOP

In Colorado, an elevation adjustment of 10 percent per 1,000m has been frequently applied in change of use cases and Pochop is most often referenced as the basis of such an adjustment. Pochop published a study on elevation adjustment based upon claims by researchers who noted that approximately 10 percent per 1,000m above sea level was warranted when using the SCS modified Blaney-Criddle equation. Potential consumptive use with the Blaney-Criddle equation has been described[7] as being biased by elevation due to solar radiation effects, and the method of calculation, which relies upon mean monthly temperature. At higher elevations in arid climates, the difference in daily maximum and minimum temperatures can be greater than at lower elevations. An average of the two neglects to consider that most of the potential consumptive use occurred when there was significant solar radiation affects. A data set for Kentucky bluegrass and alfalfa were analyzed and compared to lysimeter data in Pochop where it was concluded that an elevation adjustment "*will improve estimates of ET when using the Blaney Criddle method*" and that *"the adjustment should increase the ET estimates for sites with elevations greater than the location at which the formula is calibrated and decrease estimates for sites with lower elevations."* Pochop developed coefficients for Kentucky bluegrass that represent an average elevation of 1,350m. The appropriate calibration for these coefficients would be 9.4 percent for every 1,000m from 1,350m elevation during April through October except during June through August, when the calibration would be 7.6 percent for every 1,000m. Similarly, Pochop developed coefficients for alfalfa, for which a 6.4 percent adjustment for April through October is appropriate, except for June through August, which 9.1 percent is more appropriate for the summer months. The table below summarizes the elevation adjustments mentioned in this study.

[7] See Pochop, et al. (1984) and Jensen, et al. (1990) pp.104-107

Crop	Reference	April	May	June	July	Aug.	Sept.	Oct.
Kentucky Bluegrass	Pochop	9.4	9.4	7.6	7.6	7.6	9.4	9.4
Alfalfa	Pochop	6.4	6.4	9.1	9.1	9.1	6.4	6.4
All "other" crops	*none*	*10*	*10*	*10*	*10*	*10*	*10*	*10*

Table 1 – Elevation adjustment expressed as percent per 1,000m in elevation

In Pochop elevation corrections are only provided for months during the growing season. Neither Pochop nor the cited research suggests an elevation adjustment outside of the growing season. Based upon my personal communication with Dr. Larry Pochop[8] the purpose of the paper was to verify if the trend of 10 percent per 1,000m was true or not. The paper was not intended to be used as an application-type paper or for anything more than for what the data indicated. Dr. Pochop is not sure how one would apply this methodology to crops other than bluegrass and alfalfa or to the SCS TR-21 coefficients since he is not aware of where the coefficients were developed, or at what elevation. Dr. Pochop's research showed that an elevation adjustment of around 10 percent is reasonable. In order to apply an elevation adjustment to the SCS TR-21 coefficients, the elevation at which the coefficients were developed is needed. Dr. Pochop pointed out that if elevation was known, temperature effects would need to be considered so that any adjustment is purely a function of the calculation method. In **Part II** of this memorandum, the data source of the SCS TR-21 coefficients was researched and an analysis was performed to identify the elevation that the coefficients represent.

Side Note:

It is interesting to note that in Pochop, the adjustment for bluegrass is less during the months of June through August than for the rest of the growing season, which suggests a crop curve that does not follow the typical bell shape that peaks during the mid summer. Rather, the crop curve shows two peaks, one in the spring and one in the fall. This is consistent with cool-season grasses commonly found in temperate climates, where high temperatures can cause these types of grasses to go into dormancy. Examples of cool-season grasses include Kentucky Bluegrass, wheatgrasses (Crested Wheat), Orchardgrass, Brome (smooth), Ryegrasses, and Fescues, to name a few. Pochop's trend for Kentucky Bluegrass may not apply to warm-season grasses, which may be referred to as "drought resistant," and include Blue Grama, bluestems, and Sideoats Grama, to name a few. Alfalfa can be considered a warm-season forage, which would explain why Pochop's findings show that the elevation adjustment for alfalfa follows the traditional bell shape curve that peaks during the summer. A comparison of typical crop curves for cool and warm season grasses is shown below in **Figure 1**.

Historically in Division One, many irrigated pastures have cool-season grasses, especially Smooth Brome. These species are well suited for our climate and make good graze and good hay. Common dryland mixes in Colorado may include alfalfa and Crested Wheat, or include various mixtures of warm and cool-season grasses. Cook[9] provides recommendations of grass mixes for irrigated, non-irrigated, and sub-irrigated sites that may reflect common species of "pasture grasses" found in Colorado. Knowing what plant species are well adapted to certain soil textures under varied water supplies can be useful to help estimate the consumptive use of historically irrigated parcels in a change of use proceeding.

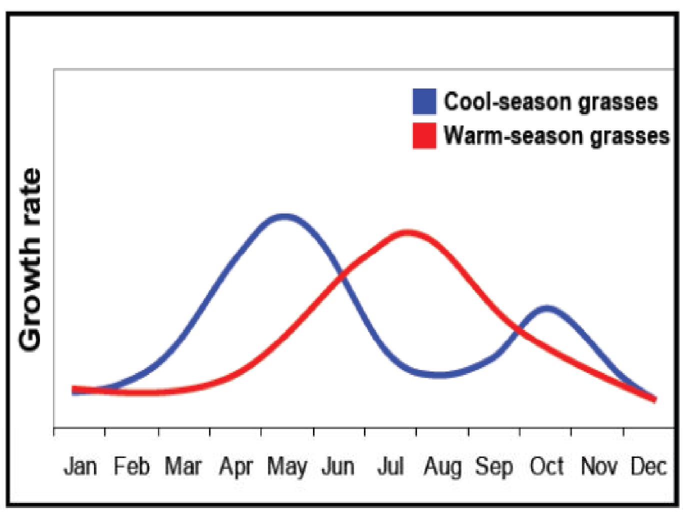

Figure 1 – Example of Crop Curves from Cook (2012) p.3 - fig. 3

[8] Personal Communication on September 25, 2013
[9] Cook, et al. (2012)

PART II: FORENSIC ANALYSIS OF SCS TR-21

Introduction:

In order to apply an elevation adjustment to the SCS Blaney-Criddle coefficients the elevation at which the curve was developed is needed. The SCS TR-21 publication provides crop growth stage coefficients for a variety of crops, but does not indicate where the curves were developed, or at what elevation. It has been my experience that within the water resources community in Colorado, no one knows where the coefficients were developed. I contacted two retired ARS researchers, Dr. Harold Duke[10] and Dr. Marvin Jensen[11], both are recognized as experts on crop water use and were working around the time SCS TR-21 was published. Neither of the two knew the source of the coefficients[12]. Dr. Marvin Jensen mentions in his 2010 paper[13] (herein referred to as “Jensen Paper”) that he worked under Dr. Harry Blaney in the 1960s. During my conversation with Dr. Jensen, he indicated that he is unaware of the work that the SCS[14] did to develop the crop curves in TR-21 or where the data came from. He believes that the best source of where the data could have come from is found in ARS 1275[15].

As part of my research, I also contacted Jerry Walker[16] and Clarence Prestwich[17] of the NRCS, both of whom are specialists within the agency in irrigation and water management. According to Mr. Walker, in the 1960s the SCS would only have relied on data provided by the ARS, a sister agency to the SCS[18]. Today, the NRCS will rely on University research and ARS work, but in prior years it was standard practice for the SCS to rely solely on ARS data. Mr. Walker indicated that any remaining SCS documentation on TR-21 would be located in Portland, Oregon at the West National Technology Support Center. Mr. Prestwich researched the SCS files in Portland and found a publication by ARS researchers Harry Blaney, Howard Haise, and Marvin Jensen entitled “Monthly Consumptive Use by Irrigated Crops in Western United States[19]” (herein referred to as “The Supplement”) and an internal SCS publication by Hyrum Woodward entitled “A Modification of the Blaney-Criddle Method for Computing Consumptive Use[20]” (herein referred to as “Woodward”).

Woodward points out that monthly crop coefficients (*k*) used in the Blaney-Criddle equation were first shown in an internal SCS document, SCS-TP-96, and later published in ARS 1275, a revision of SCS-TP-96. The Supplement is a provisional supplement to SCS-TP-96 that associates the data to ARS researchers from the Western United States. Included in the document are *k* values and information on specific years when data were collected. It is interesting to note that the data in The Supplement don’t quite match up with the ARS 1275 data, which suggests that there must have been some adjustment by the authors (notably H. Blaney[21]) between publications.

Woodward also mentions that the k_c values were taken from smoothed curves plotted from available measured consumptive use data. The smooth curves were drawn thru plotted points with minor adjustments made so that the sum of the computed monthly values would approximate the seasonal values developed for the original Blaney-Criddle equation. Woodward describes the procedure used for determining the location of the end dates, which was done by “laying a straight edge across the curve between the end points and balancing visually the areas between the straight edge and the curve.” It is important to note that Woodward points out that k_c values for some crops were estimated since no measured consumptive use values were available and data from similar crops were used to “guide the estimator.”

Since learning that the source of the data used in SCS TR-21 was ARS 1275, we should be able to identify what plant species the generalized crop curves represent, where the data was developed, and at

[10] Category I (lead) Scientist from1967-2002, USDA-ARS-WMU
[11] Category I (lead) Scientist from1955-1987. Dr. Jensen was inducted in to the ARS Hall of Fame in 2000
[12] Dr. Duke did mention that data were collected from around the Western US primarily from soil core samples
[13] Jensen (2010)
[14] In 1994 the SCS became the NRCS
[15] Blaney & Criddle (1962), Table 18, pp.49-52
[16] Irrig. Engr., Central National Techn. Support Cntr., Ft Worth, TX and a primary reviewer of the NRCS NEH Part 652 – Irrig. Guide
[17] Water Management Engr., W. National Techn. Support Cntr., Portland, OR
[18] Today the SCS and ARS are sister agencies within the USDA. During my conversation with Dr. Harold Duke he indicated that in the 1950s, and prior to, ARS was a branch of the SCS
[19] Blaney, et al. (unk)
[20] Woodward (1963)
[21] Dr. Harry Blaney is the only author common to both ARS 1275 and The Supplement

what elevation. However, after reviewing the data in ARS 1275, it is still not entirely clear what some of the SCS TR-21 curves truly represent. For example, the crop curve for “Pasture Grasses” is ambiguous and can be interpreted to mean entirely different plant species across the Western United States. Pasture grasses in South Texas is commonly irrigated coastal Bermuda grass, or on non-irrigated lands, Buffel grass. In Colorado, cool-season grasses like smooth brome, timothy, or orchard grasses are more common. Neither the SCS TR-21, Woodward, nor The Supplement specifies what the curve for “Pasture Grasses” truly represents. This information is important, especially when calculating historical consumptive use in a change of use case. If the SCS TR-21 curve for “Pasture Grasses” represents something more similar to a coastal Bermuda grass, then the curve may not be appropriate for evaluating Bromegrass in Colorado. Furthermore, it is not clear if the SCS TR-21 curve represents data from a particular location or an average of the entire data set.

Background:

A forensic analysis was performed where SCS TR-21 crop growth stage coefficients (herein referred to as “SCS TR-21 coefficients” or “k_c”) were compared to ARS 1275 in an attempt to determine what plant species represented by the SCS TR-21 crop curves and the location and elevation of the data that the crop curves represent.

As mentioned in Woodward, there was some qualitative and visual interpretation in the development of the SCS TR-21 curves, which may cause confusion in determining what data set they originated from. As such, the findings and observations from this study rely on some visual interpretation and a simple regression analysis[22]. The ARS 1275 data were evaluated by plotting them against monthly crop coefficients from the SCS TR-21 curves. In theory, if the data in ARS 1275 were the sole source of the SCS TR-21 coefficients, then a correlation coefficient of close to one should be achieved. Taking into account the fact that the curves were smoothed between data points, it is reasonable to expect that some correlation coefficients may be less than one. The data were analyzed for each crop to explain and identify a data set that achieved a correlation coefficient of 0.90 or higher. In some case, this included the average of multiple data points. In other instances, a single data set was used to achieve the optimal correlation coefficient.

The crop growth stage coefficients are provided in the Appendix of SCS TR-21 and can be interpolated for monthly or daily values (i.e., alfalfa and pasture grass). However, ARS 1275 data used to develop the SCS TR-21 crop growth stage curves were developed from monthly data points. When provided, the monthly data were used directly (i.e., SCS TR-21 Curve No. 2) or calculated as a monthly average when plotted out against percent of growing season (i.e., SCS TR-21 Curve No. 1).

Temperature Correction. During our conversation, Dr. Pochop pointed out that the effects of temperature need to be corrected for a proper elevation adjustment. The coefficients provided in ARS 1275 are not independent of meteorological effects and represent monthly empirical consumptive-use crop coefficients (k) for use with the Blaney-Criddle equation. The SCS attempted to modify the original Blaney-Criddle equation to isolate the meteorological effects from k_c by adjusting k as a function of a climatic coefficient (k_t), that is dependent of mean monthly temperature (t), and an independent growth stage coefficient (k_c) that reflects the influence of the crop growth stage on consumptive use rates.

$$k = k_t \times k_c$$

$$where,\ \ k_t = 0.0173t - 0.314$$

$$when\ 36^0 \leq t \leq 100^0\ Farenheight$$

$$or, 0.300\ when\ t < 36^0\ Farenheight$$

If the mean monthly temperature for a particular site is known, then k_c can be determined. Mean monthly temperatures used in this study were calculated or obtained from referenced sources. Since the SCS TR-21 curves were developed some time in or prior to 1967, the mean monthly temperature data would reflect some period of record that did not extend past 1967. When available, the mean monthly

[22] Results from the regression analysis are shown in Charts 1 through 15 as found in Appendix B, pp.31-35

temperature was calculated from reported monthly consumptive use factors, *f*, in The Supplement and percent daylight hours, *p*, from Table 1 in SCS TR-21.

$$f = \frac{t \times p}{100}$$

$$t = \frac{f(100)}{p}$$

Otherwise, mean monthly temperature data were taken from Woodward or, as a last resort, obtained from *TheWeatherChannel.com* website[23] and are shown in **Table 2** (Appendix A). Mean monthly temperatures calculated from *TheWeatherChannel.com* include data since 1967 and may yield different values from ARS 1275 since 40 years of additional data are included. However, any discrepancy when calculating k_c is expected to be small, less than five degrees. For instance, if the mean monthly temperature varied by five degrees, the resulting k_c will be within ten percent[24].

Corresponding values of k_t for mean monthly temperatures between 36 and 100 degrees Farenheight, were calculated for the locations and from the data in **Table 2** and are shown in **Table 3.** Specific k_t values for various mean air temperatures are also shown in Table 4 of TR-21. To obtain a monthly k_c value, the *k* coefficients in ARS 1275 can be divided by the representative k_t value.

$$k_c = \frac{k}{k_t}$$

$$k_c = \frac{k}{0.0173t - 0.314}$$

Elevation Correction. In addition to a temperature correction, an adjustment for elevation based upon Pochop was considered for some data. The Pochop correction for Kentucky Bluegrass was used when evaluating pasture grasses and lawn grass. The Pochop correction for alfalfa applies only to alfalfa. Any other adjustment of 10 percent per 1000m in elevation is not based upon Pochop.

Estimated elevations for the locations specified in ARS 1275 were obtained primarily from *Wikipedia.com* and are presented in **Table 4** (Appendix A). Some bias may exist due to the reported average elevation of a particular location rather than using the exact elevation of the site where the ARS 1275 data were developed. Any bias is expected to be very small since 100 feet in elevation will only affect the k_c curve by approximately 0.3 percent.

Growing Season Adjustment. In order to compare the SCS TR-21 coefficients to ARS 1275, the growing season for SCS TR-21 coefficients were adjusted when necessary. The length of growing season was taken from SCS TR-21 with the start dates adjusted to match the data provided by ARS 1275.

<u>Observations, Data, Findings, & Results:</u>

Pasture Grasses. As previously mentioned, interpretation of what "pasture grasses" represents is subjective and not clearly stated in TR-21. The SCS TR-21, Woodward, nor The Supplement specifies what the curve for "Pasture Grasses" really represents. However, Woodward does indicate that the curve for alfalfa includes alfalfa-grass and legume-grass. As such, the data for clovers and alfalfa-grass were not considered in the analysis of "pasture grasses."

The SCS TR-21 coefficients for pasture grasses were compared to "Bromegrass" and "Irrigated Pastures" as provided in ARS 1275.[25] Lawn grass data from Pasadena, CA were not included since common turf grasses can be distinguished from native grasses. Four data points from ARS 1275 were plotted, along

[23] Due to the government shutdown at the time of this analysis, data from NOAA were not available. However, the source of data presented by *The Weather Channel.com* is the National Climate Data Center, a part of NOAA
[24] When evaluating at temperatures of 55 and 60 degrees
[25] Data for clover from Prosser, WA in June was believed to be reported in error and the average value from the prior and post month replaced the reported value.

with their average, and the SCS TR-21 curve for pasture grasses as shown in **Figure 2**. Data from ARS 1275 were reported from the following locations:

Location	State	Crop	Elevation (m)	(ft)
Mandan	ND	Bromegrass	502	1,647
Davis	CA	Irrigated Pasture	16	52
Murrietta	CA	Irrigated Pasture	334	1,096
Merced	CA	Irrigated Pasture	52	171
Pasadena	CA	"lawn grass"	263	864

Table 5 – Locations of pasture grass data from ARS 1275

The ARS 1275 coefficients represent an average elevation of 742 feet above sea level. As shown in **Chart 1** (Appendix B), average data from ARS 1275 did show a strong relationship to TR-21 (R^2 = 0.505). Visually this is evident as well. The curve for "pasture grasses" in SCS TR-21 is not represented well by Bromegrass and "irrigated pasture."

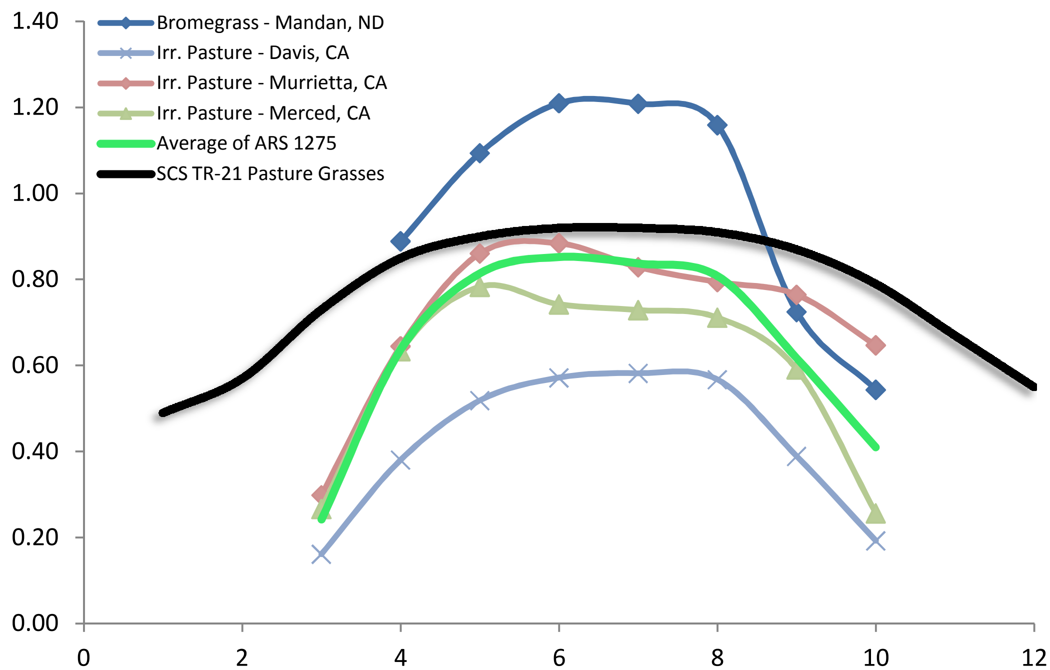

Figure 2 - k_c vs. month for Pasture Grasses

Change-of-use analyses that evaluate irrigated pasture or lands that were historically hayed might consider using the crop growth stage coefficients directly from ARS 1275 depending on site specific conditions. **Table 5** includes these k_c coefficients, which have been adjusted from the published *k* values.

Location	State	Crop	Elevation (m)	Elevation (ft)	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
Mandan	ND	Bromegrass	502	1,647		0.89	1.09	1.21	1.21	1.16	0.72	0.54
Davis	CA	Irrigated Pasture	16	52	0.16	0.38	0.49	0.55	0.57	0.56	0.38	0.19
Murrietta	CA	Irrigated Pasture	334	1,096	0.30	0.64	0.86	0.88	0.83	0.79	0.76	0.65
Merced	CA	Irrigated Pasture	52	171	0.24	0.61	0.76	0.74	0.74	0.71	0.58	0.25
		AVG:	226	742	0.24	0.64	0.81	0.85	0.84	0.81	0.62	0.41

Table 6 - k_c values for Bromegrass and "Irrigated Pasture"

Lawn Grass / Kentucky Bluegrass. A further investigation of SCS TR-21 coefficients for "pasture grasses" suggests that they may be better represented as a "lawn" type grass that is closely related to Kentucky Bluegrass as shown in **Figure 3**.

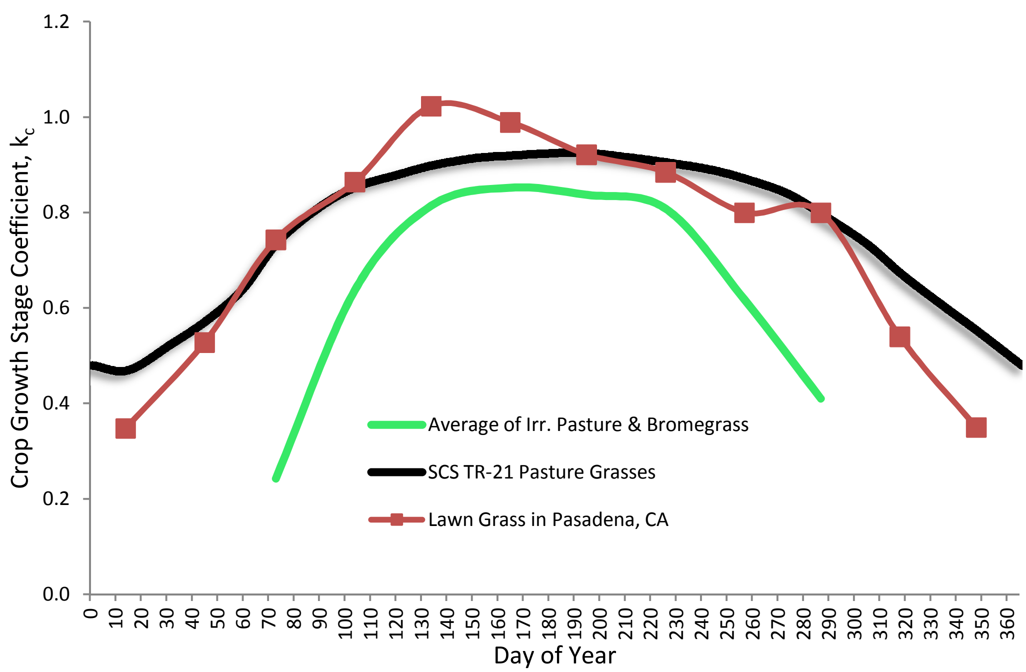

Figure 3 - k_c vs. month for ARS 1275 "pasture grasses," SCS TR-21 "pasture grasses," and "lawn grass" in Pasadena, CA

"Lawn grass" in Pasadena, CA and Kentucky Bluegrass from Pochop were compared to SCS TR-21 for "pasture grasses." The Pochop data set was adjusted to reflect an elevation of 864 feet, the approximate elevation in Pasadena. A regression analysis of ARS 1275 data from Pasadena compared to SCS TR-21 showed a strong correlation (R^2 = 0.929) as shown in **Chart 2**, which suggest that it closely represents lawn or Kentucky Bluegrass at or near an elevation of 864 feet above sea level. It seems reasonable to assume that the SCS may have smoothed the SCS TR-21 curve to eliminate the peaks and valleys of the Pasadena curve.

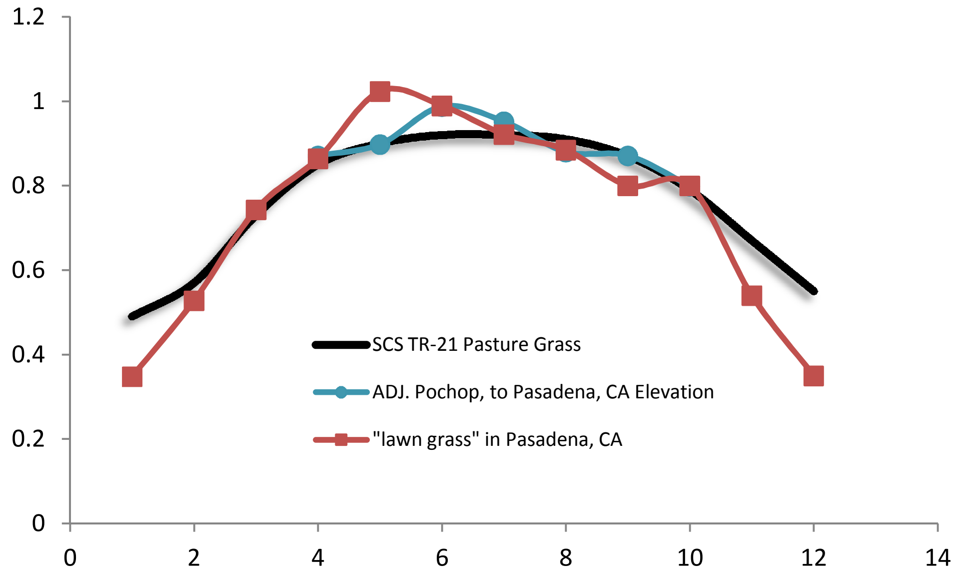

Figure 4 - k_c vs. month for lawn & Kentucky Bluegrass

Crop	Elevation		Month											
	(m)	(ft)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lawn Grass	263	864	0.348	0.528	0.743	0.864	1.023	0.989	0.922	0.885	0.800	0.800	0.54	0.35
KY Bluegrass	1,350	4,428				0.97	1.00	1.10	1.06	0.98	0.97	0.89		

Table 7 - k_c values for lawns

Sugar Beets. The crop growth stage coefficients in SCS TR-21 for sugar beets were compared to four data sets provided in ARS 1275. Data from ARS 1275 were reported from the following locations:

			Elevation	
Location	State	Crop	(m)	(ft)
Huntley	MT	sugar beets	921	3,022
Scottsbluff	NE	sugar beets	1,186	3,891
Redfield	SD	sugar beets	398	1,305
Logan	UT	sugar beets	1,382	4,534

Table 8 – Locations of sugar beet data from ARS 1275

The data from ARS 1275 suggest that there is a correlation (R^2 = 0.764) to the SCS TR-21 coefficients as shown in **Chart 3** and suggests that the SCS TR-21 coefficients were developed from ARS 1275 data. It appears that the SCS TR-21 curve may follow the average of the four data sets from May through August, then approached a value near the average of Huntley, MT and Logan, UT in October (R^2 = 0.978, **Chart 4**).

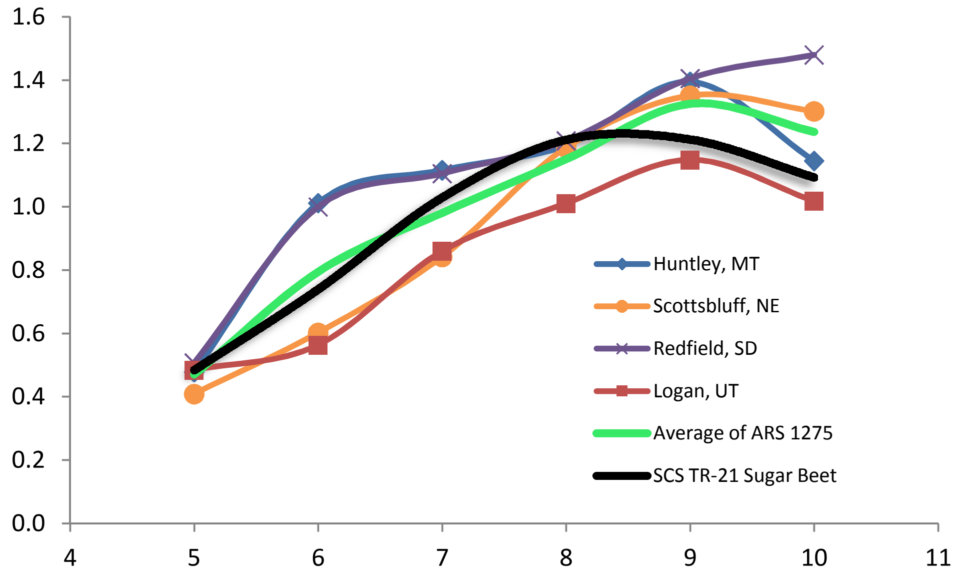

Figure 5 - k_c vs. month for Sugar Beets

However, further analysis indicates that the data from Logan, UT may better represent sugar beets in Division One. SPDSS Task Memo 59.1 suggests that the SCS TR-21 method over-estimates consumptive use for the upper plains region. When plotted together, the data from Logan, UT trends with the Task Memo 59.1 curve below the SCS TR-21 curve. It appears that the SCS TR-21 curve has been shifted to the left along the x-axis.

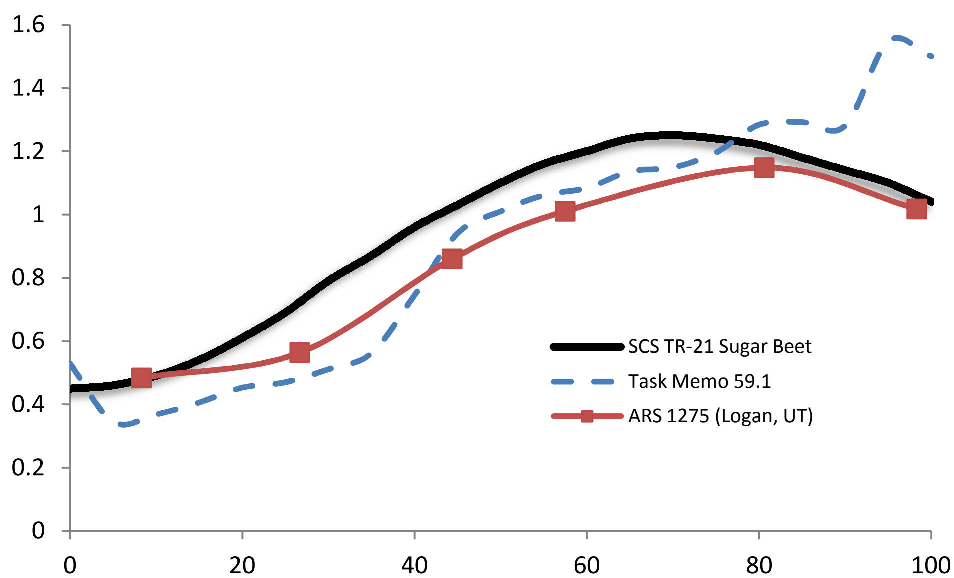

Figure 6 – Crop curves for Sugar Beets

Data from Logan, UT could be used in many portion of Division 1 without an elevation adjustment. Logan, UT has an approximate elevation of 4,534 feet above sea level (1,382m).

Location	State	Crop	Elevation (m)	Elevation (ft)	Month MAY	JUN	JUL	AUG	SEP	OCT
Logan	UT	Sugar Beets	1,382	4,534	0.484	0.557	0.860	1.022	1.149	1.077

Table 9 - k_c values for sugar beets, taken from ARS 1275

Corn (Grain). The crop growth stage coefficients in TR-21 for grain corn were compared to two out of three data sets provided in ARS 1275, identified as only "corn." Data from ARS 1275 were reported from the following locations:

			Elevation	
Location	State	Crop	(m)	(ft)
Phoenix	AZ	corn	340	1,117
Davis	CA	corn	16	52
Mandan	ND	corn	502	1,647

Table 10 – Locations of corn data from ARS 1275

IDSCU reports the growing season for silage corn as being around 110 days. ARS 1275 data from Phoenix, AZ shows a growing season of up to 120 days, which may reflect silage corn. The data from Arizona were excluded from the analysis. The data from ARS 1275 did not show a substantial relationship to SCS TR-21 (R^2 = 0.198) as shown in **Chart 5**.

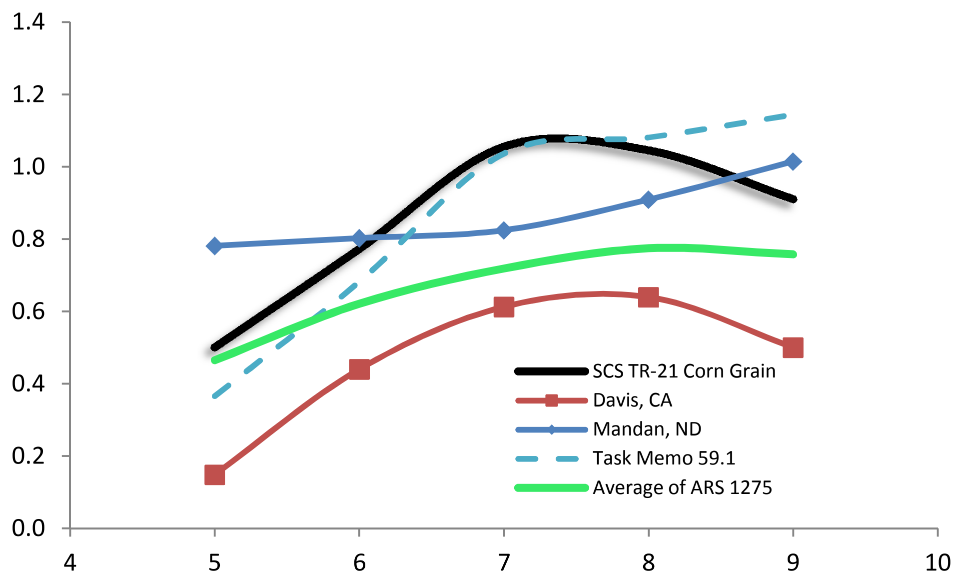

Figure 7 - k_c vs. month for Corn (grain)

The SCS TR-21 crop curve for corn closely resembles the curve from Davis, CA and a simple regression analysis shows a strong correlation (R^2 = 0.980) as shown in **Chart 6**. If the Davis, CA curve is shifted upwards by 0.34, the curves follow closely with one another. It is interesting to note that the k value for corn from Mandan, ND was reported to be 0.5 in May. This is the same value that the SCS TR-21 curve starts at. It would appear that the SCS felt it was necessary to shift this curve upward. A comparison with Task Memo 59.1 suggests that the SCS adjustment upwards may have been warranted. The Davis, CA data shows a stronger relationship to SCS TR-21 when shifted upwards and may suggest that it is more probable that the TR-21 coefficients reflect corn with adjustment.

It is interesting to note that the SCS TR-21 curve does not trend with the Davis, CA data for the first part of the growing season. In fact, the first part of the growing season trends more closely with the Task Memo 59.1 data presented for the upper plains coefficients.

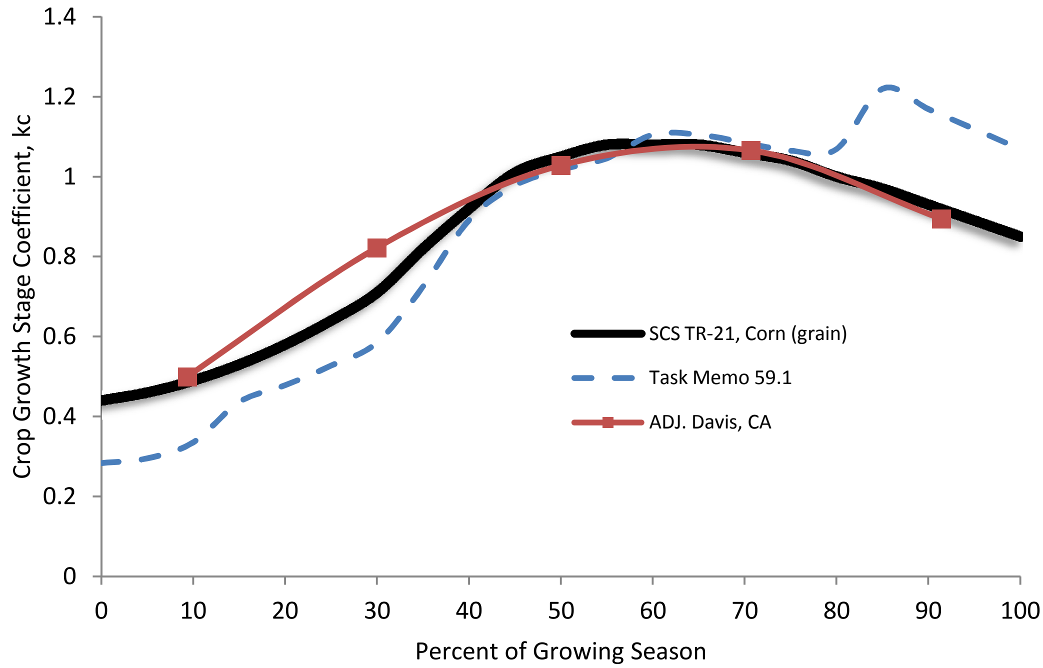

Figure 8 – Crop curves for Corn (grain)

Alfalfa. Woodward indicated that the curve for alfalfa is used for alfalfa-grass or legume-grass. The alfalfa-grass and clover data in ARS 1275 were included in our analysis of alfalfa. The crop growth stage coefficients in TR-21 for alfalfa were compared to 14 data sets from ARS 1275. Data from ARS 1275 were reported from the following locations:

			Elevation	
Location	State	Crop	(m)	(ft)
Mesa	AZ	Alfalfa	378	1,243
Davis	CA	Alfalfa	16	52
Los Angeles	CA	Alfalfa	71	233
Stockton	CA	Alfalfa	4	13
Salinas	CA	Alfalfa	16	52
Sacramento	CA	Alfalfa	9	30
Mandan	ND	Alfalfa	502	1,647
Scottsbluff	NE	Alfalfa	1,186	3,891
Redfield	SD	Alfalfa	398	1,305
Logan	UT	Alfalfa	1,382	4,534
St. George	UT	Alfalfa	872	2,860
Caldwell	ID	Alfalfa-Grass	724	2,375
Caldwell	ID	Red Clover	724	2,375
Prosser	WA	Clover	203	666

Table 11 – Locations of alfalfa data from ARS 1275

The data from ARS 1275 show a strong relationship (R^2 = 0.946) to TR-21, as shown in **Chart 7**, and suggests that it is probable that the TR-21 coefficients reflect alfalfa (and grass, or legumes) at an average elevation 1,520 feet above sea level.

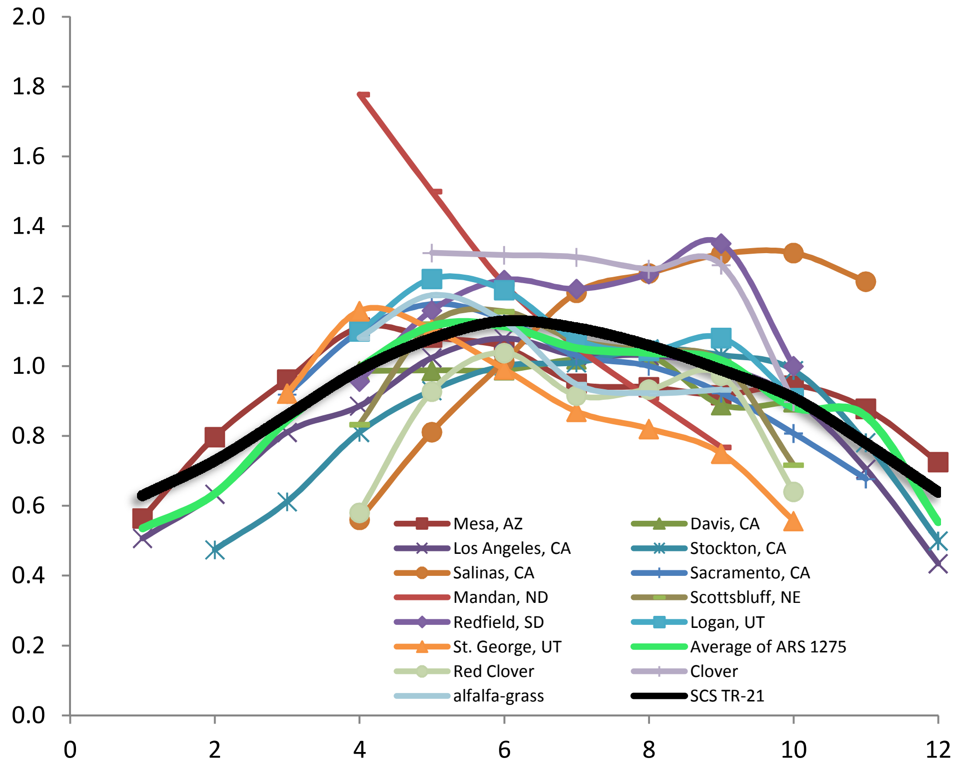

Figure 9 - k_c vs. month for Alfalfa

The data sets in **Figure 9** were removed and only the average value was compared to SCS TR-21 in **Figure 10** to show how close the two compare. It seems reasonable to assume that the SCS may have smoothed the SCS TR-21 curve to eliminate the peaks and valleys of the average curve.

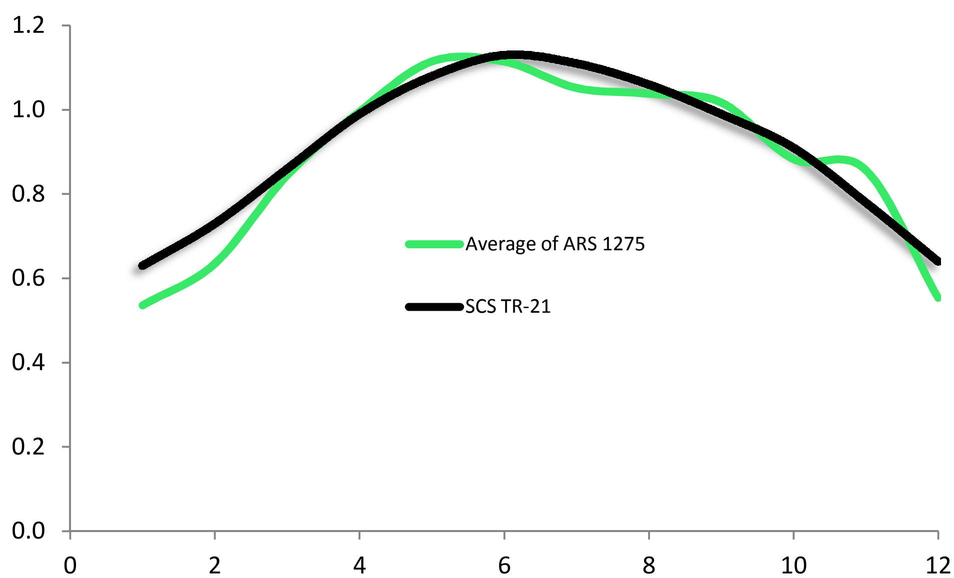

Figure 10 – k_c vs. month for alfalfa

Small Vegetables. The SCS TR-21 coefficients for small vegetables were compared to one data set from ARS 1275. A single data set representing "vegetables, truck garden" in Stockton, CA was available from ARS 1275. The SCS TR-21 coefficients were adjusted to reflect a 200 day growing season to compare with the values presented in ARS 1275. The data from ARS 1275 did show a strong relationship (R^2 = 0.953), as shown in **Chart 8**, to TR-21 and may suggest that it is probable that the TR-21 coefficients reflect small vegetables in Stockton, CA at or near sea level.

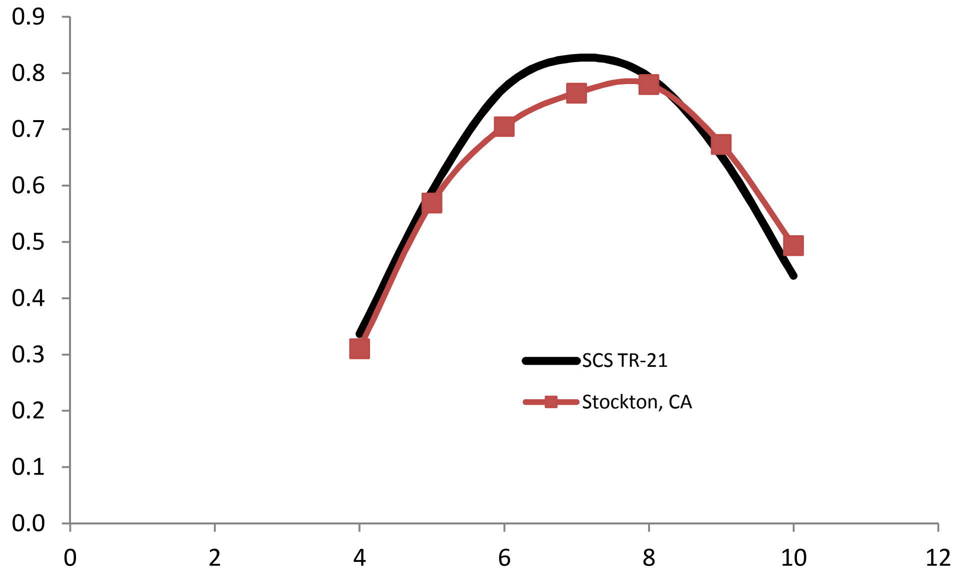

Figure 11 - k_c vs. month for small vegetables

Dry Beans. The SCS TR-21 coefficients for dry bean were compared to one data set from ARS 1275. A single data set representing “small white beans” was provided from Santa Barbara, CA in ARS 1275. The data from ARS 1275 do not show a significant relationship (R^2 = 0.892), as shown in **Chart 9**, to TR-21 and may suggest that the TR-21 coefficients could have relied on this data in part, or not at all.

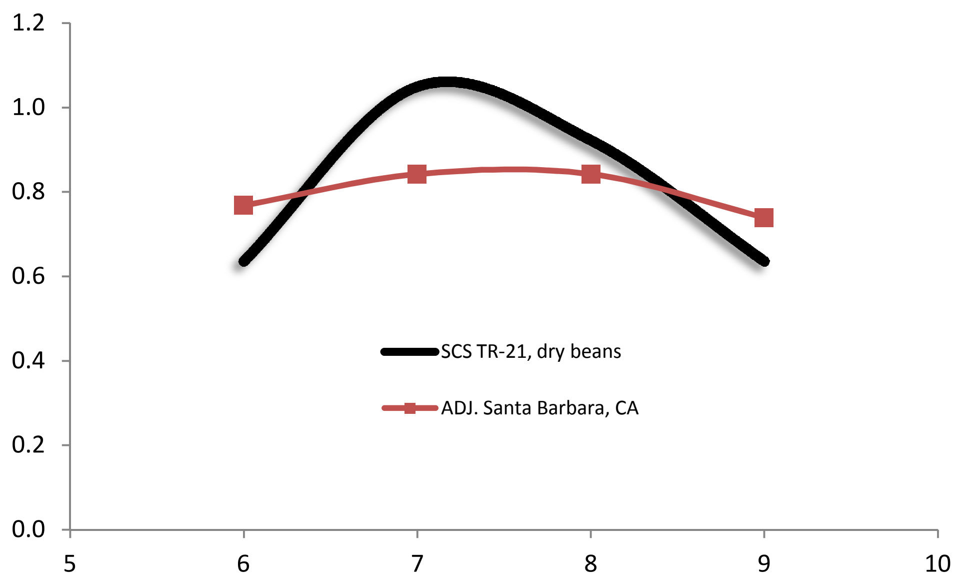

Figure 12 – k_c vs. month for Dry Beans

Sorghum. The SCS TR-21 coefficients for sorghum were compared to three data sets from ARS 1275. Data from ARS 1275 were reported from the following locations:

			Elevation	
Location	State	Crop	(m)	(ft)
Phoenix	AZ	sorghum	340	1,117
Garden City	KS	sorghum	865	2,838
Lubbock	TX	sorghum	992	3,256

Table 12 – Locations of sorghum from ARS 1275

The ARS 1275 did not show a strong relationship (R^2 = 0.851), as shown in **Chart 10**, to TR-21 and may suggest that the TR-21 coefficients do not reflect the average of the three data sets.

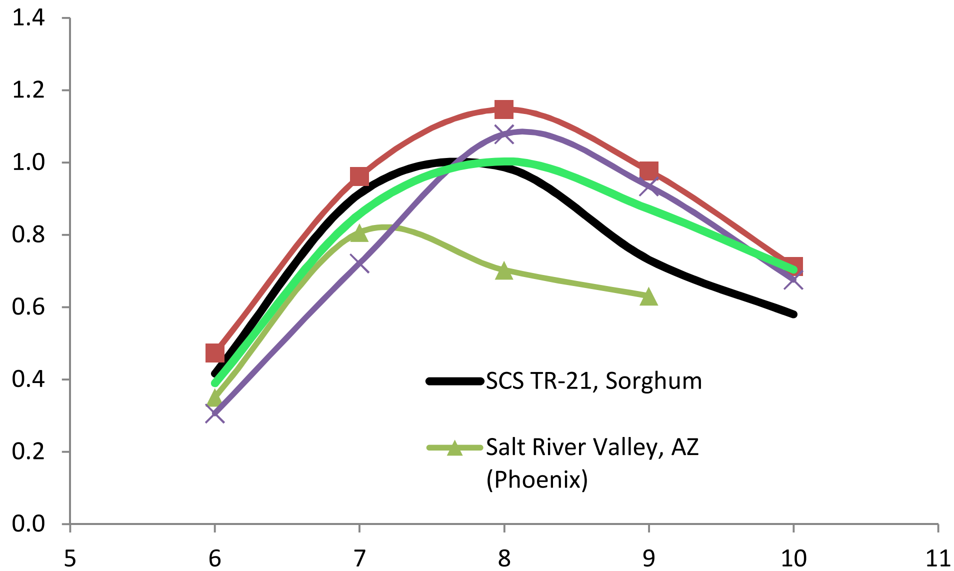

Figure 13 - k_c vs. month for sorghums

A better correlation (R^2 = 0.909) was found when the SCS TR-21 curve was compared solely to data from Garden City, KS.

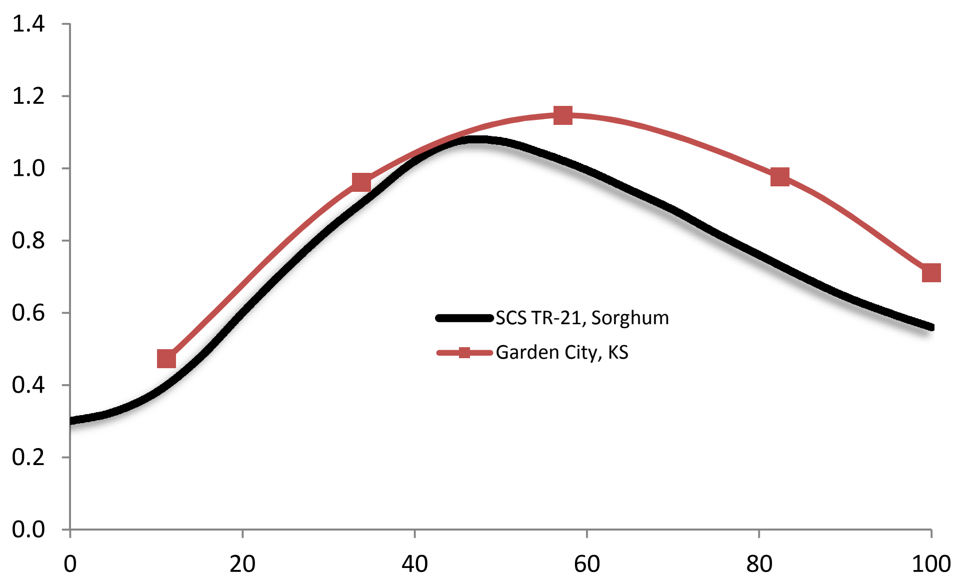

Figure 14 – Crop curves for dry beans

Winter Wheat. The SCS TR-21 coefficients for wheat were compared to three data sets from ARS 1275. Data from ARS 1275 were reported from the following locations:

Location	State	Crop	Elevation (m)	Elevation (ft)
Phoenix	AZ	wheat	340	1,117
Garden City	KS	wheat	865	2,838
Bushland	TX	wheat	1,162	3,812

Table 13 – Locations of winter wheat from ARS 1275

The data from ARS 1275 do not show any correlation to TR-21, as shown in **Chart 11**, and suggests that it is probable that other data were considered in the development of SCS TR-21 coefficients.

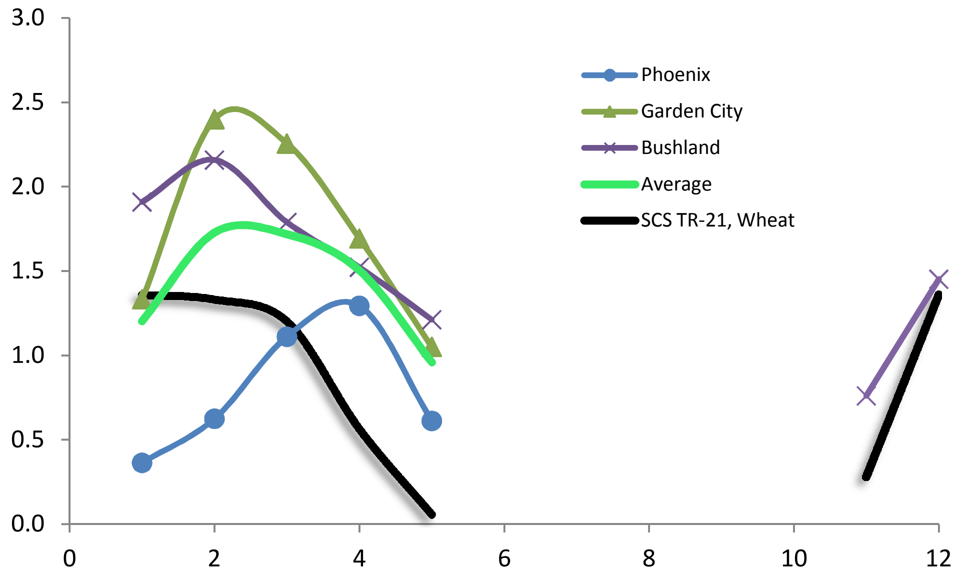

Figure 15 - k_c vs. month for winter wheat

Small Grain. The SCS TR-21 coefficients for small grain were compared to two data sets in ARS 1275. The data sets from ARS 1275 represent barley in Mandan, ND and Logan, UT reflect an average elevation of 3,091 feet above sea level. The data from ARS 1275 did not show a strong relationship (R^2 = 0.857), as shown in **Chart 12**, to TR-21 and may suggest that the TR-21 coefficients could have relied on this data in part, or not at all.

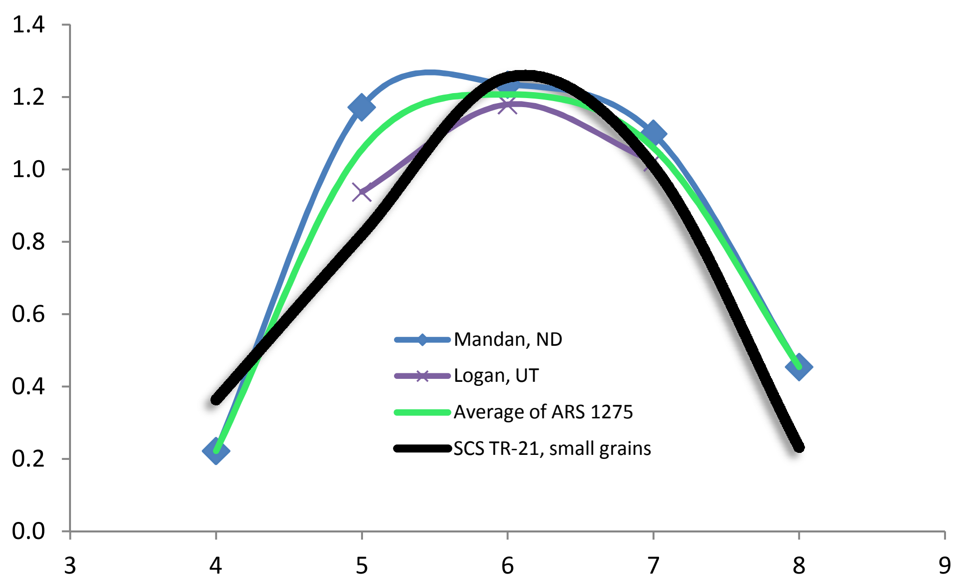

Figure 16 - k_c vs. month for Barley

Orchards. The SCS TR-21 coefficients for orchards were compared to ten data sets in ARS 1275. The data sets from ARS 1275 represent "Deciduous Fruit," lemons, grapefruit, orange, and walnut trees. TR-21 provided two curves for orchards, one with "ground cover" and one without. The SCS provides no mention of what type of ground cover, whether it is grass, alfalfa, or another legume; all of which are common. Similarly, the ARS 1275 is not clear on what was meant by "deciduous fruit." Data from ARS 1275 were reported from the following locations:

Location	State	Crop	Elevation (m)	Elevation (ft)
San Joaquin	CA	Deciduous Fruit	53	174
Phoenix	AZ	Grapefruit	340	1,117
(unknown)	CA	Lemons	71	233
Phoenix	AZ	Oranges	340	1,117
Los Angeles	CA	Oranges	71	233
Coastal	CA	Oranges	4	13
Intermediate	CA	Oranges	53	174
Interior	CA	Oranges	334	1,096
Davis	CA	Walnuts	16	52
South Area	CA	Walnuts	334	1,096

Table 14 – Locations of orchard data from ARS 1275

The average of the data from ARS 1275 did not show a strong relationship (R^2 = 0.514) to SCS TR-21, as shown in **Chart 13**. However, for orchards with cover, it does appear that the SCS may have simply made a "hand drawn" line that approximately incorporates the average of the data set. During January and February the SCS line follows the data from "Oranges, Interior Area," then along the maximum of the data sets, which includes "Walnuts, Sourthern Area" in March, and "deciduous fruit" in June, then sloping gently down to the approximate average of the data set in December (as shown below by the dots in **Figure 17**). This approximation showed a strong correlation (R^2=0.998) to the SCS TR-21 curve, as shown in **Chart 14**. The average elevation from the entire data set reflects approximately around 531 feet above sea level. However, the elevation of "Lemons" in California were estimated using data from Los Angeles, and oranges in the "coastal areas" of California were estimated using data from Stockton, oranges in "intermediate areas" of California were estimated using data from San Joaquin, the "interior areas" and the "Southern Area" of California, for oranges and walnuts respectively, were estimated using data from Murrietta.

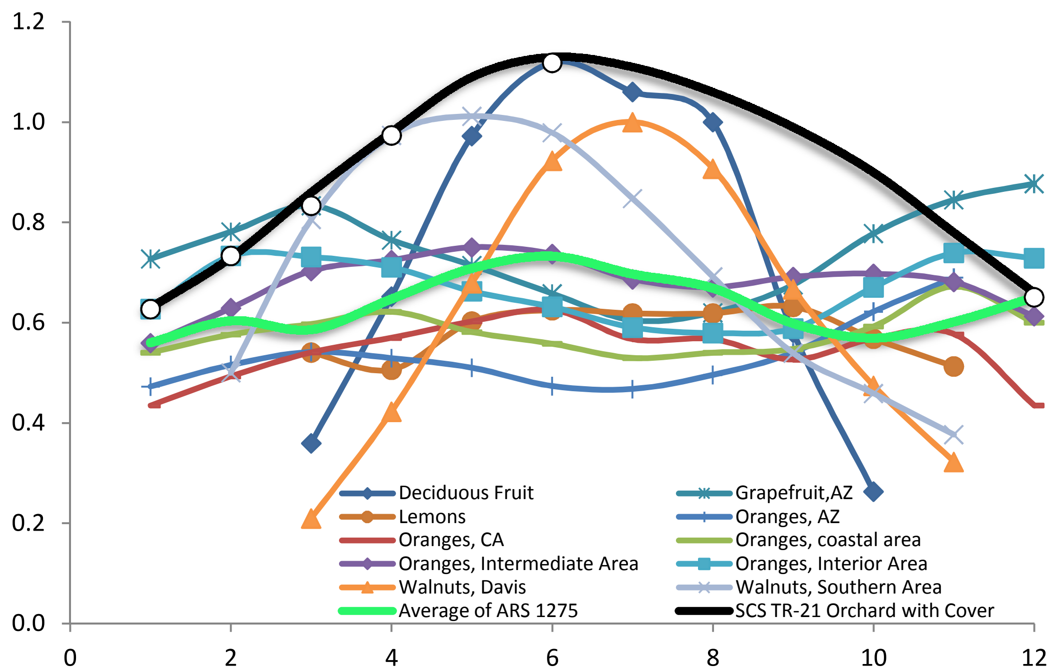

Figure 17 - k_c vs. month for Orchards with cover

For orchards without cover, it appears that the SCS relied upon the average of the "deciduous orchard" and walnut data. The data from ARS 1275 showed a strong correlation (R^2=0.991) to the SCS TR-21 curve as shown in **Chart 15**. The data suggests an average elevation of 441 feet above sea level.

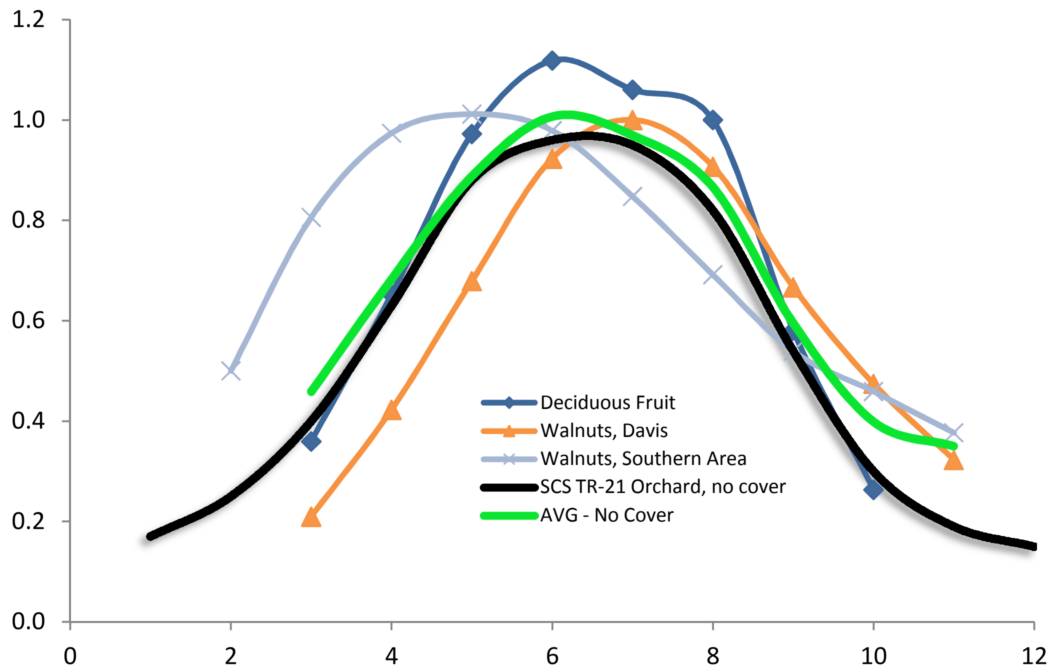

Figure 18 - k_c vs. month for Orchards without cover

Implications and Further Research:

The level of probability, or the confidence level, can be best represented by the R^2 term in the linear regression analysis. When it was shown that there was a strong correlation, it is probable that the data presented in ARS 1275 were used in the development of the SCS TR-21 coefficient curves. Disparity in the data, which result in a lower correlation coefficient, could be due to assumptions in the mean monthly temperature data used in this study, or in the interpretation of monthly crop growth stage coefficients from the SCS TR-21 data, or from other data. Woodward indicated that "*smoothed curves were drawn thru plotted points*" indicating that they were not mathematically interpolated. In addition, "*minor adjustments were made in the smooth curves so that for a number of locations the sum of the computed monthly values…would approximate the…values developed from the original Blaney-Criddle equation*," which may explain some variability. Furthermore, Woodward indicates that the values were adjusted so that the sum of monthly values would equal the previously calculated seasonal amounts developed for the original Blaney-Criddle equation. This may explain why some crop curves like sorghum, wheat, and small grains (Barley) track below the ARS 1275 data set. The crop curve for small vegetables had a strong correlation to the ARS 1275 data, and may have been adjusted upward to fit a seasonal amount. The same may be true for sugar beets and corn as there is no other clear explanation.

The SCS TR-21 curve for pasture grasses appears to better describe lawn grass at or near sea level. Alfalfa and orchard without cover appear to represent the average of ARS 1275 data. Orchard with cover appears to represent the high-end of the data set during peak use and at or near the average of the data set during the winter months. Dry beans were the only crop where a rational explanation couldn't be provided.

Based upon the work performed in this study, it is recommended that the information in **Table 15** be considered when performing calculations of consumptive use with the SCS modified Blaney-Criddle equation. Further research and analysis should be performed to validate the appropriateness of specific crop growth stage coefficients when quantifying the historical consumptive use in a change of use analysis. For example, is it appropriate to use the SCS TR-21 crop coefficients for orchards in Colorado when they are based upon data for "deciduous fruit," citrus, and walnuts in California and Arizona? The

SCS TR-21 coefficients should not be taken at face value and judgment should be applied when they are relied upon.

Crop [1]	Referenced Source for k_c [2]	Confidence Level (R^2) [3]	Elev. that k_c may represent [4]	Adjustment Required? [5]	Adjustment Amount [6]
"Pasture Grass" *Bromegrass* *"Irr. Pasture"*	 *ARS 1275* *ARS 1275*	 *N/A* *N/A*	 *1,647'* *440'*	 *Yes* *Yes*	 *9.4%, 7.6%* *9.4%, 7.6%*
Lawn / KY Bluegrass *	Pochop (1984) SCS TR-21 "pasture grasses" ARS 1275	- 0.929 -	4,428' 0' 864'	Yes Yes Yes	9.4%, 7.6%
Sugar Beets **	SCS TR-21 ARS 1275	0.930 0.928	3,188' 4,534'	No Yes	N/A 10%
Corn, grain	SCS TR-21	0.980	N/A	N/A	N/A
Alfalfa *Clover* *Alfalfa-Grass*	SCS TR-21 *ARS 1275* *ARS 1275*	0.946 - -	1,442' *1,521'* *2,375'*	Yes Yes Yes	6.4%, 9.1% 6.4%, 9.1% 6.4%, 9.1%
Small Vegetables	SCS TR-21	0.953	13'	Yes	10%
Dry Beans *Small White Beans*	SCS TR-21 *ARS 1275*	0.802 *N/A*	N/A *49'*	N/A *Yes*	N/A *10%*
Sorghum	SCS TR-21	0.851	2,404'	Yes	10%
Wheat	SCS TR-21 ARS 1275	0.373 N/A	N/A varied	N/A varied	N/A 10%
Small Grains *Barley*	SCS TR-21 *ARS 1275*	0.860 *NA*	3,091'	Yes	10%
Orchard with cover[26] no cover[27]	 SCS TR-21 SCS TR-21	 0.998 0.991	 - 441'	-	-

Table 15 – Sources of k_c for use in SCS modified Blaney-Criddle equation.

* Refer to Table 3; ** Refer to Table 6

[1] Crop type
[2] Referenced source of k_c for crop in [1]
[3] Level of probability that the crop presented in [1] is represented by the reference source in [2]
[4] Elevation that k_c was developed at (or may represent)
[5] Elevation adjustment required below 6,400 feet in elevation above sea level
[6] Recommended elevation adjustment amount. Refer to Table 1

[26] Data references "deciduous fruit" during the peak of the year and lemons, grapefruit, and oranges in California and Arizona for the shoulder months
[27] Data references "deciduous fruit" and walnuts in California

PART III: EVALUATION OF TASK MEMO 59.1

Background:

Task Memo 59.1 presented a methodology for calibrating the SCS Modified Blaney-Criddle equation to the ASCE Standardized Reference ET Equation[28] (herein referred to as "The ASCE"). This methodology will often increase the historical consumptive use of a water right when compared to TR-21. An analysis using data from Kersey, CO was performed to show how applicable the upper plains coefficients for pasture grasses are to a specific site, such as in a change of use analysis. This evaluation also compares the findings of Task Memo 59.1 to those of Pochop using an elevation adjustment, and published Blaney-Criddle coefficients from ARS 1275. In addition, an independent calibration was performed in attempt to duplicate the results of Task Memo 59.1.

The upper plains coefficients were developed by calibrating the SCS modified Blaney-Criddle equation to The ASCE. The two equations were solved independently for a given month using CoAgMET data from the same climate station. The k_c value was determined by dividing The ASCE results by the SCS TR-21 results. The resulting factor was then applied to the k_c value and the process was repeated. A summary of the input data for the analysis is provided below.

	SCS TR-21 Blaney-Criddle	ASCE Stnd. Ref. ET Equation
Type of Climate data (1993 - 2003)	Monthly[29]	Daily
Source of crop (growth stage) coefficients	TR-21	Table 6.9 of Manual 70 [30]
Loc. where coefficients were developed	(unknown, varied)	Kimberly, ID
Growing season parameters	TR-21	TR-21
Reference Crop	N/A	Tall (f/k/a, alfalfa)

Table 16 – Input data for calibration procedure in Task Memo 59.1

It is important to note that Manual 70 references the ASCE Penman-Monteith Equation for ET and Table 6.9 has not been adjusted for use with The ASCE. A small adjustment should be made to these coefficients before using them with The ASCE. This adjustment has been done by Dr. Richard Allen and can be found in Chapter 8, Irrigation Requirements of *Design and Operation of Farm Irrigation Systems*[31] (herein referred to as "Chapter 8").

The SPDSS defines the upper plains region as District 1, 2, and the lower portions (below 6500' elevation) of 3, 4, 5, 6, 7, 8, and 9. However, the upper plains coefficients really represent an average of Ft Collins, Ft Lupton, and Greeley since that is where the data came from. Climate data from these three locations were used to develop independent coefficients, which were then averaged. Ft Collins and Greeley are located in District 3 and Ft Lupton is located in District 2. No data from Districts 1, 4, 5, 6, 7, 8, or 9 were considered.

The upper plains coefficients may have been adequate for the basin-wide planning that the CWCB was involved in, but may not represent a particular site within the upper plains basin. Since the data used was from Ft Collins, Ft Lupton, and Greeley the results may only accurately represent that area in a site specific analysis. An example of this can be seen when evaluating pasture grass in Kersey, CO.

Kersey Analysis (pasture grasses):

Kersey is located approximately 10 miles east-southeast of Greeley, CO. Climate data from CoAgMET (KSY01) were used to calculate monthly consumptive use of pasture grasses using the SCS modified Blaney-Criddle equation with TR-21 coefficients, the ASCE Standardized Equation, and SCS modified Blaney-Criddle equation with the upper plains coefficients from Task Memo 59.1. The monthly results were plotted from 1993 to 2008 and show that for pasture grasses in Kersey, CO the upper plains coefficients over estimate consumptive use when compared to the ASCE method and SCS TR-21 method. Kersey, CO may not be represented well by Ft Collins, Ft Lupton, or Greeley climate data.

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28 Allen, et al. (2005)
29 Average monthly temperature was calculated from daily max & min temperature
30 Reported mean crop coefficients were used
31 Allen, et al. (2007)

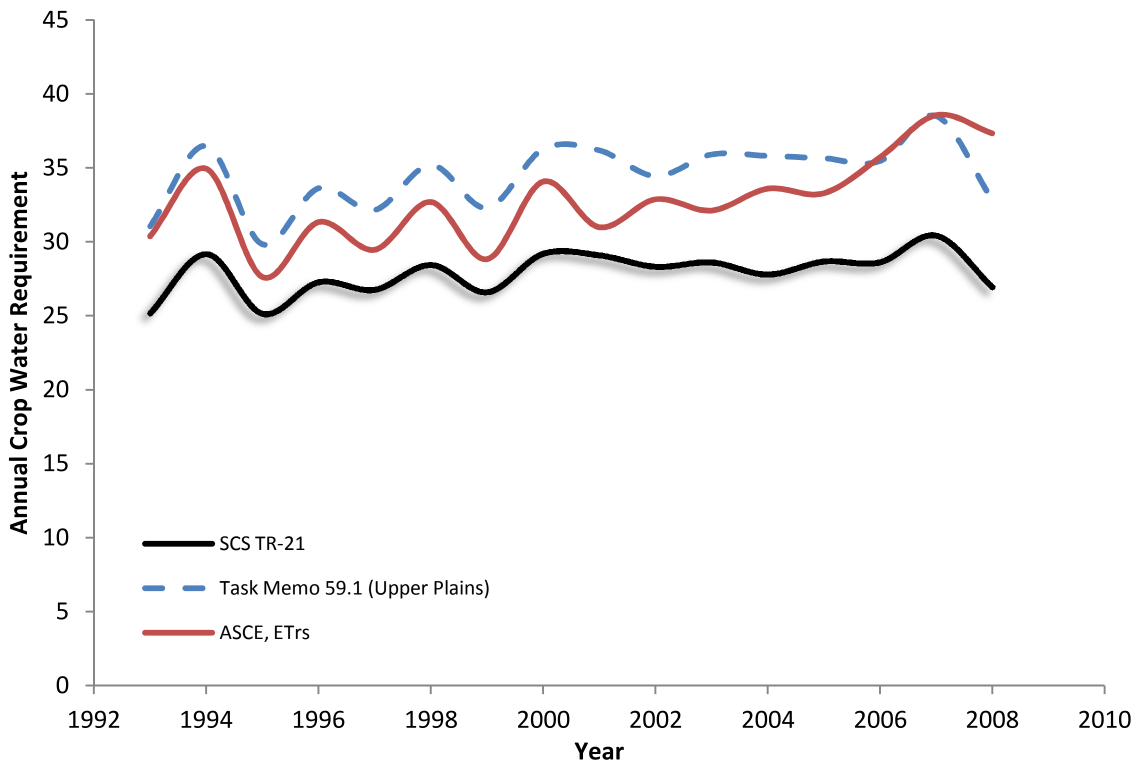

Figure 19 – Comparison of calculated irrigation requirement

Apart from overestimating consumptive use in Kersey, the Task Memo 59.1 curve has changed shape when compared to the SCS TR-21. In theory, the Task Memo 59.1 curve should mimic the SCS TR-21 in shape and only be shifted upwards to match the magnitude of The ASCE. The change in shape of the Task Memo 59.1 curve may suggest that more than the coefficients have changed in the calibration process.

DWR[32] Calibrated Blaney-Criddle Crop Coefficients (pasture grasses):

Using the procedures and data specified in Task Memo 59.1, an independent analysis was performed in an attempt to duplicate the results published in the task memo. IDSCU was used for the calculation of ASCE and Blaney-Criddle ET estimates.

Climate Data. Climate data from Ft Lupton (FTL01), Ft Collins (FTC01), and Greeley (GLY03) were automatically imported from the web into IDSCU and were weighted by 33%, 33%, and 34% respectfully. Unfilled Greeley data were used to fill both the Ft Collins and Ft Lupton data. Ft Lupton data were used to fill Greeley data as specified in the task memo (TM59.1, p.9).

ASCE Crop Coefficients. Task Memo 59.1 indicates that mean crop coefficients were taken from Manual 70[33]. In Chapter 8, Allen[34] indicated that "*it is important to establish the differences between ET equations*" when selecting appropriate crop coefficients. In other words, contrary to Task Memo 59.1, the coefficients from Manual 70 cannot be used directly "*in the ASCE Standardized method without any adjustment*." Table 8.7 in Chapter 8 provides mean crop coefficients that have been "*converted for application with the ASCE ET Equation*," which were derived from the same data set as those published in Manual 70. The updated mean crop coefficients for ryegrass from Chapter 8 were used. It is important to note that ryegrass is specified as a perennial crop 8 to 15cm (3 to 6") in height and may not accurately reflect common pasture grasses in Colorado. For example, Smooth Brome grows 2 to 4 feet tall. Tall Fescue grows 3 to 4 feet tall and Orchardgrass can grow 2 to 5 feet tall. The crop characteristics parameters in IDSCU were changed so that pasture grass reflects a perennial crop. It is important to

[32] In the context of this analysis, "DWR" represents D. Santistevan, Assistant Division Engineer in Division 1
[33] Jensen, et al. (1990), p.6
[34] Allen, et al. (2005), p.46

note that by calibrating the Blaney-Criddle equation to The ASCE we are forcing the calibrated coefficients to signify ryegrass.

Results. The methodology outlined in Task Memo 59.1 was followed (TM59.1, p.12) and convergence was achieved on the second iteration. Because pasture grasses in SCS TR-21 may actually represent a lawn type grass, ARS 1275 coefficients for pasture grasses were not considered. A comparison of the resulting curve is shown below and also in **Table 17 (**Appendix A).

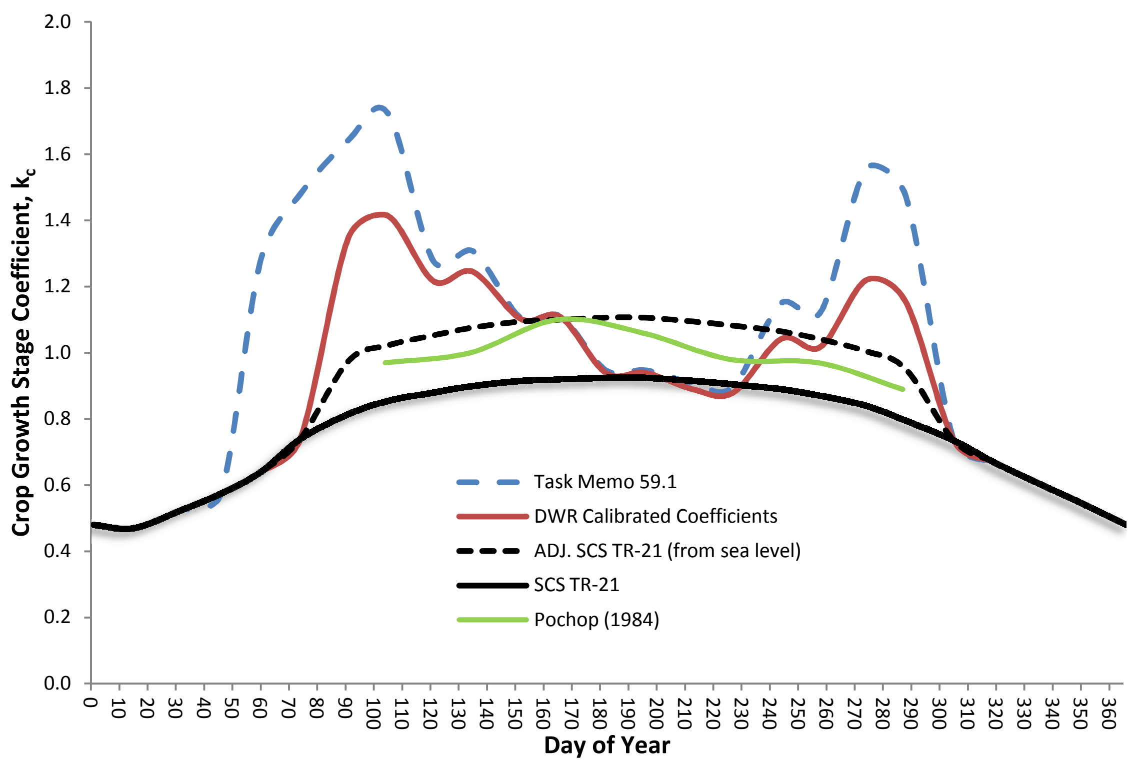

Figure 20 – Comparison of crop curves

The shape of the DWR calibrated crop curve is similar to what Task Memo 59.1 reported, although lower in magnitude. The resulting curves from the calibrated coefficients appear to follow the shape that one might expect to see for cool-season grasses, but the curve seems exaggerated during the shoulder months (spring and fall). This phenomenon may be explained, not by plant phenology, but by the plant response to high daytime temperatures and low night temperatures, similar to what has been reported at high elevation arid sites. Pochop noted that researchers have suggested the Blaney-Criddle may underestimate consumptive use when there are high daytime temperatures and low night temperatures due to the fact that the equation evenly weighs day and night temperatures. The Jensen Paper points out that originally, "*for long-time periods mean air temperature was considered to be a good measure of solar radiation*" and that "*it is unfortunate that Blaney and Criddle did not select extraterrestrial solar radiation as an index of solar energy instead percent of daytime hours [sic]*." When the SCS modified the Blaney-Criddle equation for monthly time periods, they introduced a climatic coefficient (k_t) and independent crop growth stage coefficient (k_c) to separate out the climatic effects from the phonological. However, as pointed out in Manual 70, the k_c term may still contain a meteorological component and may explain why an elevation adjustment is appropriate.

On the other hand, the ASCE Standardized equation uses solar radiation measurements and a methodology for determining net solar radiation among many other climatic parameters. It is not surprising that if there is a significant climatic effect during the shoulder months that are unaccounted for using the SCS TR-21 equation that it will differ from the ASCE equation. This may explain the spikes during the spring and fall.

The monthly results from our calibrated coefficients were compared to the Kersey Analysis and plotted along with the other curves for pasture grasses (as shown in **Figure 19**) to see if they might better represent the "upper plains."

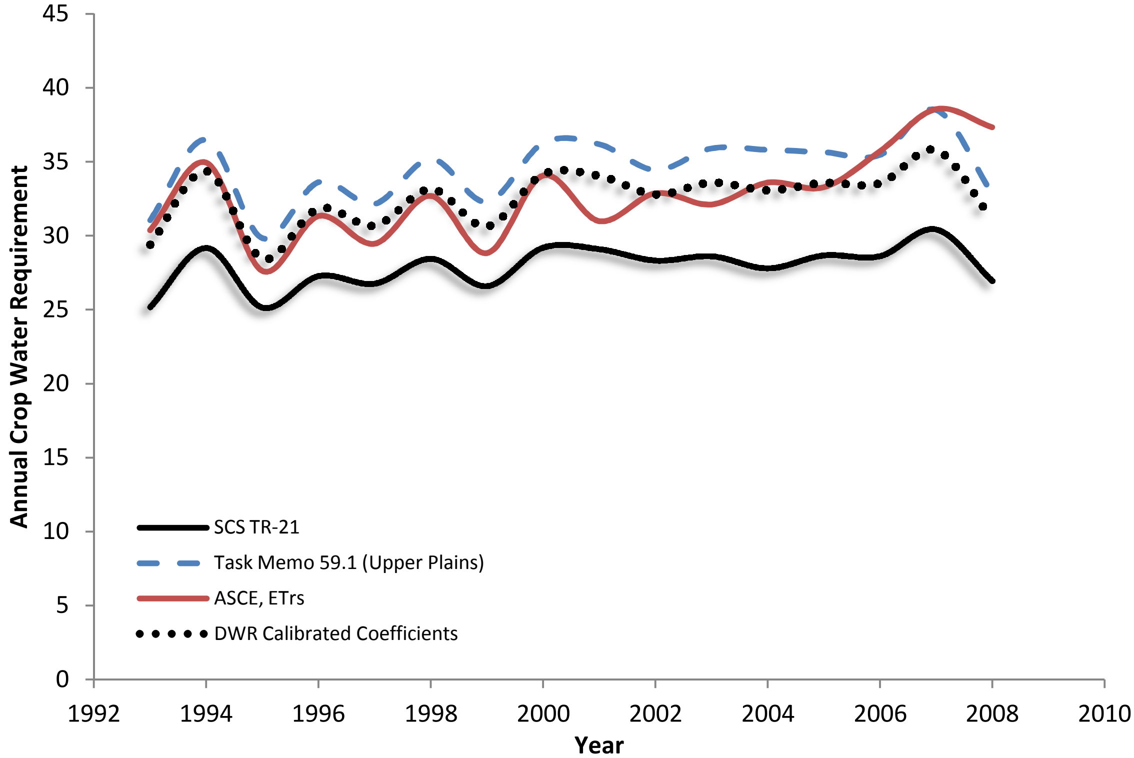

Figure 21 – Comparison of calculated irrigation requirement

The calibrated coefficients that the DWR calculated follows the same shape as the SCS TR-21 results and are shifted upwards to the magnitude of the ASCE Standardized ET. Over the 16 years analyzed in the Kersey Analysis, our calibration was within one percent of the ASCE equation while Task Memo 59.1 overestimated by more than five percent.

Year	ASCE (ETrs)	SCS TR-21	SPDSS Task Memo 59.1	DWR Calibration
1993	30.38	25.17	31.04	29.39
1994	34.95	29.16	36.48	34.37
1995	27.63	25.13	29.83	28.45
1996	31.34	27.26	33.62	31.84
1997	29.47	26.75	32.15	30.69
1998	32.7	28.43	35.19	33.16
1999	28.83	26.58	32.29	30.64
2000	34.08	29.18	36.26	34.17
2001	30.99	29.08	36.18	34.05
2002	32.88	28.31	34.44	32.8
2003	32.12	28.6	35.9	33.6
2004	33.6	27.78	35.8	33.08
2005	33.29	28.66	35.64	33.58
2006	35.72	28.61	35.46	33.55
2007	38.57	30.41	38.5	35.79
2008	37.34	26.92	32.84	31.12
AVERAGE:	32.74	27.88	34.48	32.52

Table 18 – Calculated seasonal consumptive use amounts (inches)

Further Analysis of Other Crops:

Sugar Beets. The Task Memo 59.1 crop curve for sugar beets suggests that SCS TR-21 will over-estimate consumptive use. Findings from our study of ARS 1275 suggest the same. However, the coefficients from Task Memo 59.1 present an unusual shape that is not bell shaped and is suspicious in the later portion of the growing season, which may reflect temperature effects during the fall.

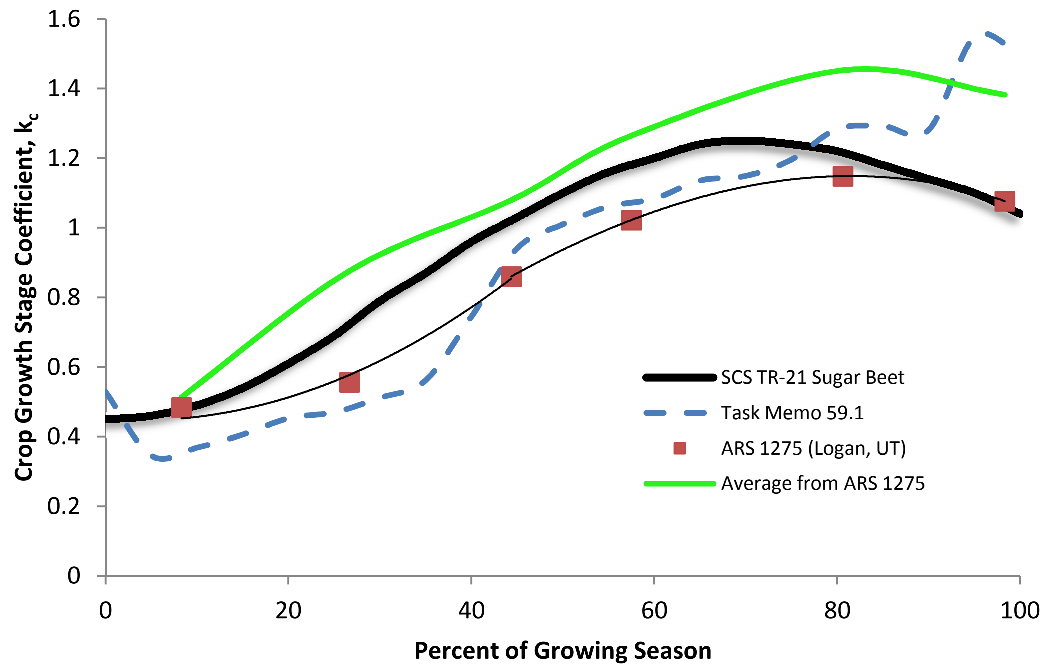

Figure 22 – Comparison of crop curves for sugar beets

Corn. The Task Memo 59.1 crop curve for corn suggests that the ASCE method results in values very similar to the SCS TR-21 method. Findings from our study of ARS 1275 suggest the same. However, the coefficients from Task Memo 59.1 present an unusual shape that is not bell shaped and is suspicious in the later portion of the growing season, which may reflect temperature effects during the fall.

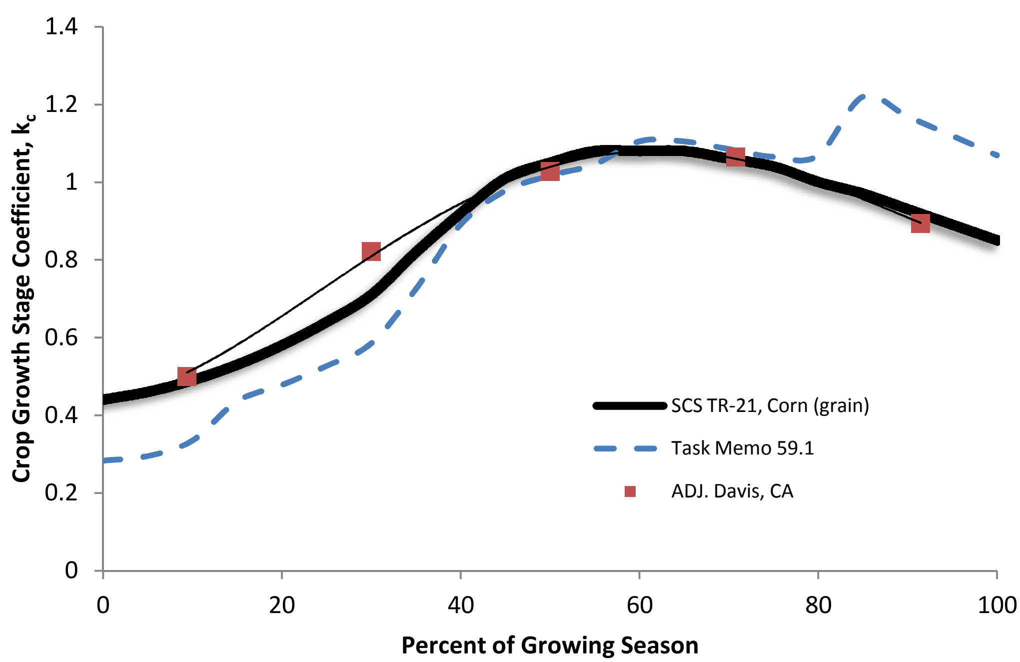

Figure 23 – Comparison of crop curves for corn

Alfalfa. The Task Memo 59.1 crop curve for alfalfa suggests that SCS TR-21 will under-estimate consumptive use. Findings from our study of ARS 1275 do not suggest the same. The coefficients from Task Memo 59.1 present an unusual shape that is not bell shaped and the magnitude is of the peak is suspicious, as is the valley of the curve. Alfalfa values in Pochop, adjusted to 5,000' above sea level, do suggest that the alfalfa may have a slightly higher peak, but it does not confirm the Task Memo curve. The two peaks in Task Memo 59.1 curve may be the result of temperature effects during the shoulder months.

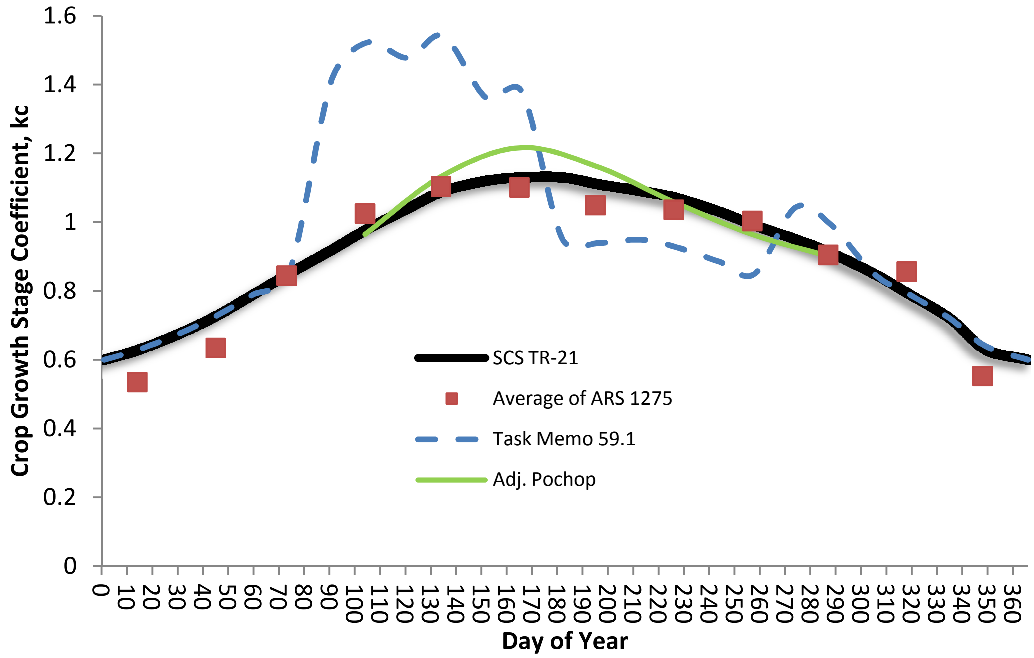

Figure 24 – Comparison of crop curves for alfalfa

Dry Beans. The Task Memo 59.1 crop curve for dry beans suggests that SCS TR-21 will over-estimate consumptive use. Findings from our study of ARS 1275 suggest the same. The coefficients from Task Memo 59.1 present an unusual shape, although one that is somewhat bell shaped.

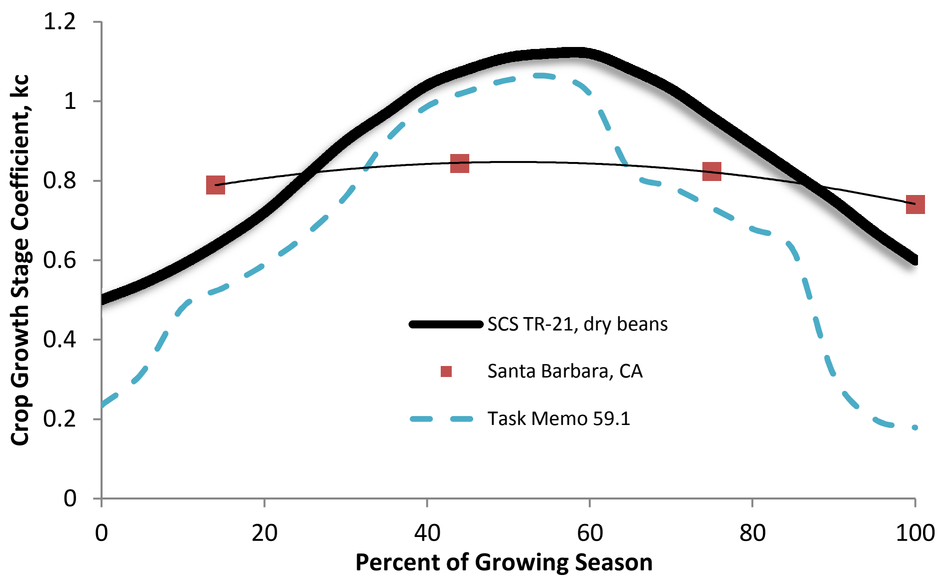

Figure 25 – Comparison of crop curves for dry beans

Small Grain. The Task Memo 59.1 crop curve for small grains suggests that SCS TR-21 will under-estimate consumptive use. Findings from our study of ARS 1275 suggest the same. The coefficients from Task Memo 59.1 present an unusual shape early in the season, although one that is somewhat bell shaped. It is interesting to note that the data from ARS 1275 suggests that the peak of the SCS TR-21 curve should be wider and the top of the k_c curve should be reached earlier in the season. This may explain the peak in the Task Memo 59.1 curve that occurs in May. The difference may have less to do with temperatures during the shoulder months and more with the development of the SCS curve itself.

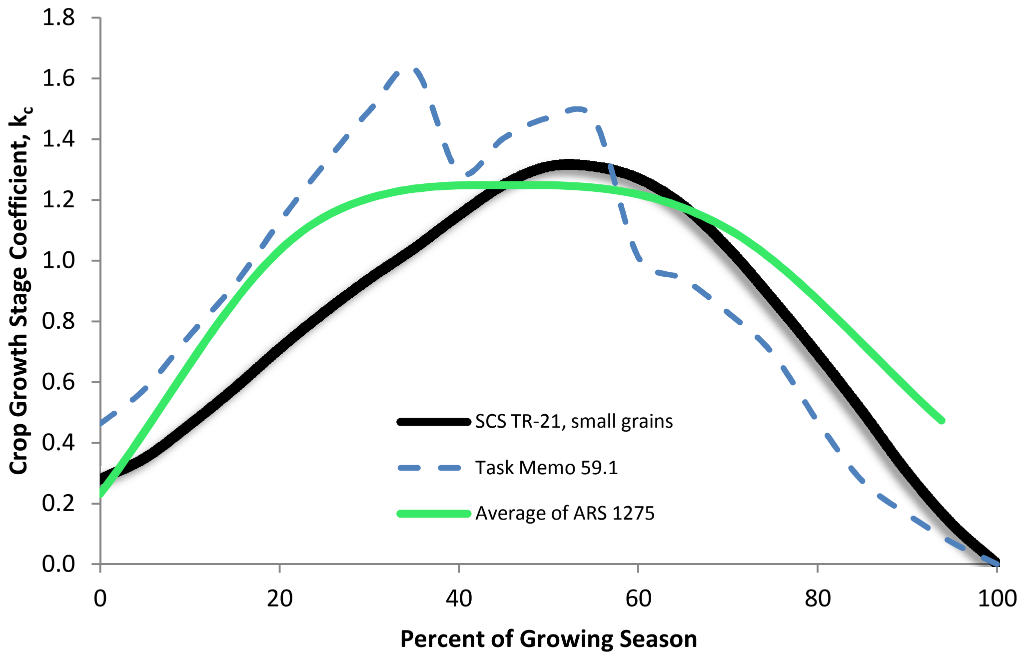

Figure 26 – Comparison of crop curves for small grain

Overall, a trend relative to calibrations during the shoulder months was observed. In our analysis, the growing season for sugar beets & corn was modeled to begin in May while the growing season for beans & sorghum was modeled to being in June. These crops tended to not include the shoulder months and the calibrated curves did not show the high spikes during the growing season.

On the other hand, pasture grasses, alfalfa, and small grains were all modeled to grow during the shoulder months and, coincidentally, the curve is exaggerated curve during the spring and fall. This could support the presumption that high daytime temperatures and low night temperatures during the shoulder months result in the greatest difference of ET when calculated with the Blaney-Criddle and compared to the ASCE equation.

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Appendix A – Table Nos. 2, 3, 4, and 17

Table 2 – Mean Monthly Temperature, in Farenheight

		Month											
City	State	1	2	3	4	5	6	7	8	9	10	11	12
Mesa	AZ	54	58	63	65.9	74	81.6	88.3	86.7	81.7	70.3	61	54
Phoenix	AZ	51	55	61	67	75	85	90	89	83	70	59	52
Davis	CA	47	51	55	59	66	72	76	74	71	64	54	47
Los Angeles	CA	58	59	61	64	66	69	74	74	73	69	63	58
Merced	CA	46	49	53	60	67	74	80	78	72	63	53	46
Murrietta	CA	52	53	57	62	68	73	79	80	77	67	58	52
Pasadena	CA	58	60	61	65	68	72	77	78	76	70	63	57
Sacramento	CA	45	51	55	59	65	71	75	74	71	64	54	47
Salinas	CA	51	53	54	56	58	61	62	64	63	61	56	51
Stockton	CA	53	54	56	58	60	63	66	67	66	63	59	54
Caldwell	ID	47	52	57	61	68	73	77	76	73	65	55	47
Huntley	MT	32	38	47	54.3	58.7	64.8	73.3	70.5	61.5	55	41	32
Mandan	ND	31	34	44	54	64	73	79	78	70	57	43	32
Scottsbluff	NE	29	32	40	49	58	66	73	72	62	50	37	27
Redfield	SD	13	18	29	44	55	65	71	69	58	45	29	17
Logan	UT	26	28	36	47	56	66	73	71	62	50	37	28
St. George	UT	14	19	32	45	58	67	73	71	61	47	31	17
Prosser	WA	40	45	51	60	68	76	79	78	71	61	49	41

Table 3 – k_t values based upon temps. in Table 2 (SCS TR-21, Table 4)

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Mesa	0.62	0.69	0.78	0.81	0.97	1.09	1.21	1.17	1.09	0.9	0.74	0.62
Phoenix	0.55	0.64	0.72	0.85	0.98	1.14	1.24	1.21	1.11	0.9	0.71	0.57
Davis	0.48	0.55	0.62	0.71	0.81	0.91	0.98	0.97	0.9	0.78	0.62	0.5
Los Angeles	0.69	0.71	0.74	0.79	0.83	0.88	0.97	0.97	0.95	0.88	0.78	0.69
Merced	0.46	0.53	0.6	0.71	0.83	0.97	1.07	1.04	0.93	0.78	0.6	0.48
Murrietta	0.59	0.6	0.67	0.76	0.86	0.95	1.05	1.07	1.02	0.85	0.69	0.59
Pasadena	0.69	0.72	0.74	0.81	0.86	0.93	1.02	1.04	1	0.9	0.78	0.67
Sacramento	0.46	0.55	0.62	0.71	0.79	0.9	0.98	0.95	0.91	0.78	0.62	0.48
Salinas	0.57	0.6	0.62	0.66	0.69	0.74	0.76	0.79	0.78	0.74	0.66	0.57
Santa Barbara	0.59	0.62	0.64	0.69	0.72	0.76	0.83	0.85	0.81	0.76	0.69	0.62
Stockton	0.5	0.59	0.67	0.74	0.86	0.95	1.02	1	0.95	0.81	0.64	0.5
Caldwell	0.3	0.34	0.5	0.62	0.69	0.79	0.95	0.9	0.74	0.64	0.4	0.3
Garden City	0.3	0.3	0.43	0.62	0.78	0.95	1.04	1.02	0.88	0.66	0.41	0.3
Huntley	0.3	0.3	0.38	0.53	0.69	0.83	0.95	0.93	0.76	0.55	0.33	0.3
Mandan	0.3	0.3	0.3	0.45	0.64	0.81	0.91	0.88	0.69	0.46	0.3	0.3
Scottsbluff	0.3	0.3	0.31	0.48	0.66	0.83	0.95	0.91	0.74	0.53	0.33	0.3
Redfield	0.3	0.3	0.3	0.46	0.69	0.85	0.95	0.91	0.74	0.5	0.3	0.3
Lubbock	0.38	0.45	0.57	0.71	0.85	0.98	1.04	1.02	0.91	0.74	0.53	0.38
Bushland	0.33	0.38	0.52	0.67	0.85	0.98	1.05	1.02	0.9	0.71	0.5	0.31
Logan	0.3	0.3	0.31	0.5	0.64	0.78	0.93	0.91	0.74	0.55	0.33	0.3
St. George	0.43	0.5	0.64	0.76	0.95	1.11	1.23	1.17	1.04	0.79	0.57	0.41
Prosser	0.3	0.31	0.46	0.59	0.71	0.83	0.93	0.9	0.76	0.59	0.38	0.3

Table 4– Elevation from sea level

	Elevation	
City	(m)	(ft)
Mesa	378	1,243
Phoenix*	340	1,117
Davis	16	52
Los Angeles	71	233
Merced	52	171
Murrietta	334	1,096
Pasadena	263	864
Sacramento	9	30
Salinas	16	52
Santa Barbara	15	49
Stockton	4	13
Caldwell	724	2,375
Garden City	865	2,838
Huntley	921	3,022
Mandan	502	1,647
Scottsbluff	1,186	3,891
Redfield	398	1,305
Lubbock	992	3,256
Bushland**	1,162	3,812
Logan	1,382	4,534
St. George	872	2,860
Prosser	203	666

* Phoenix data were used for Salt River Valley, AZ
** USGS topographical map used for Bushland, TX (www.topoquest.com)

Table 17 – Crop growth stage coefficients for “Pasture Grasses” used in the Kersey Analysis

	Day of Year																								
	1	15	32	46	60	74	91	105	121	135	152	166	182	196	213	227	244	258	274	288	305	319	335	349	365
TR-21	0.48	0.47	0.53	0.58	0.64	0.74	0.82	0.86	0.88	0.90	0.92	0.92	0.93	0.93	0.92	0.91	0.89	0.87	0.84	0.80	0.74	0.67	0.61	0.55	0.48
TM59.1	0.48	0.47	0.53	0.58	1.28	1.48	1.64	1.72	1.28	1.31	1.10	1.11	0.95	0.95	0.91	0.90	1.15	1.12	1.56	1.47	0.74	0.67	0.61	0.55	0.48
DWR	0.48	0.47	0.53	0.58	0.64	0.74	1.35	1.41	1.22	1.24	1.10	1.11	0.94	0.94	0.89	0.88	1.04	1.02	1.22	1.15	0.74	0.67	0.61	0.55	0.48

TR-21: Data taken from IDSCU, source: SCS TR-21, p.80

TM59.1: Calibrated coefficients taken from Task Memo 59.1 for “upper plains”, Table 8, p.17

DWR: DWR calibrated coefficients

Appendix B – Charts 1 thru 15

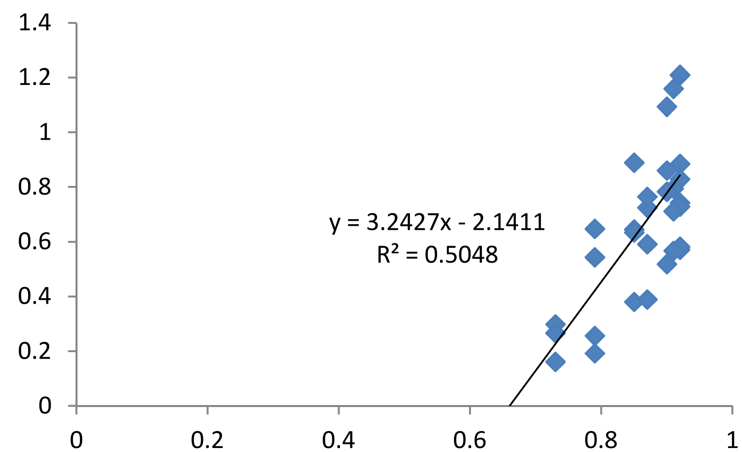

Chart 1 – Pasture Grasses, Coefficients from ARS 1275 vs. SCS TR-21 for “pasture grasses”

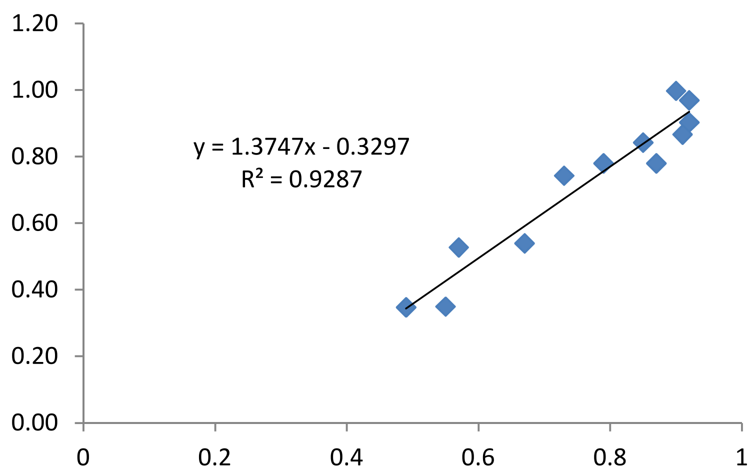

Chart 2 – Lawn Grass, coefficients for “lawn grass” in Pasadena from ARS 1275 vs. SCS TR-21 for “pasture grasses”

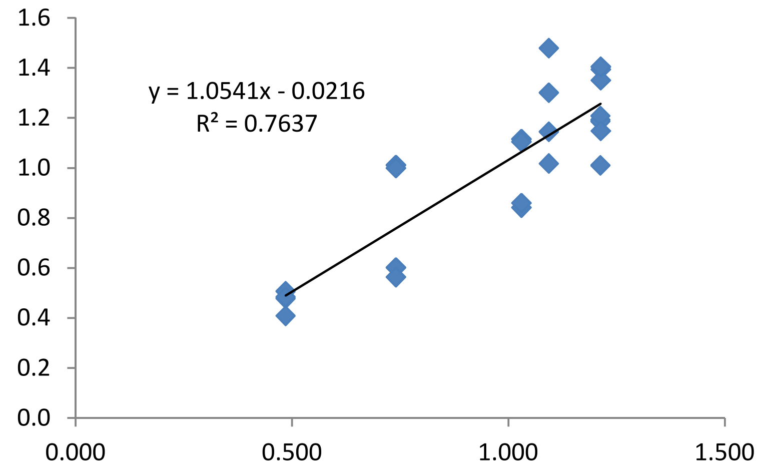

Chart 3 – Sugar Beets, Coefficients from ARS 1275 vs. SCS TR-21 sugar beets

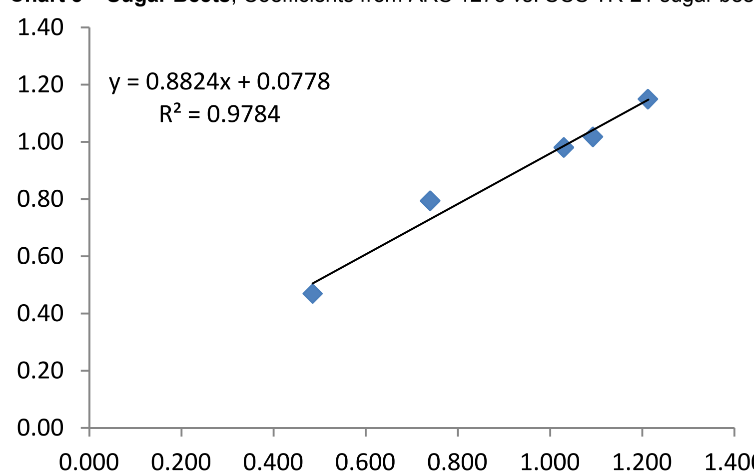

Chart 4 – Sugar Beets, ARS-1275 coefficients (March through August) and Logan, UT (October) vs. SCS TR-21 sugar beets

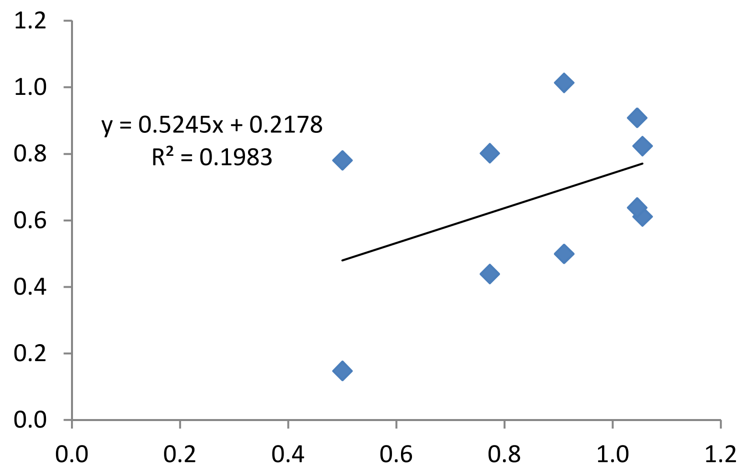

Chart 5 – Corn (grain), Coefficients from ARS-1275 vs. SCS TR-21 coefficients for grain corn

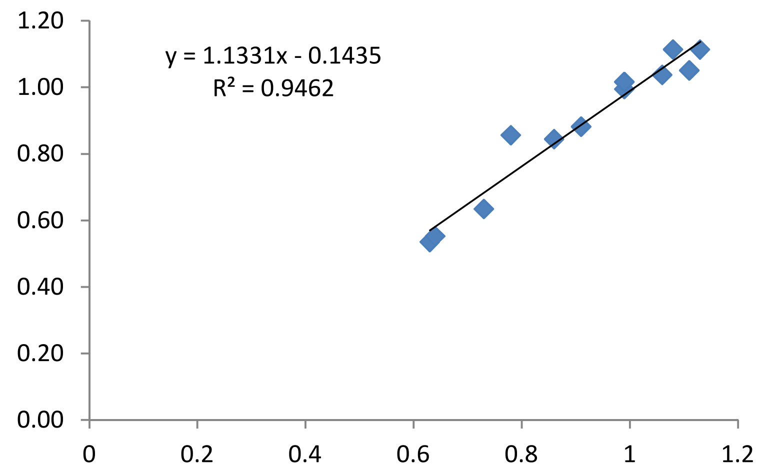

Chart 7 - Alfalfa, Average of ARS-1275 coefficients vs. SCS TR-21 coefficients

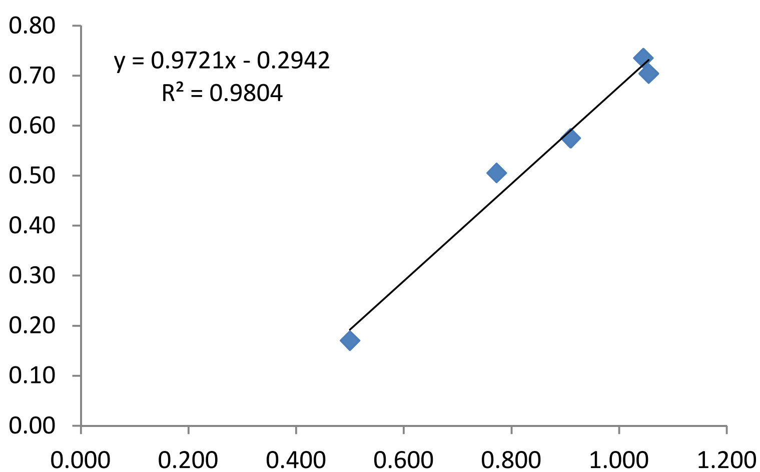

Chart 5 – Corn (grain), Davis, CA corn coefficients from ARS-1275 (adjusted) vs. SCS TR-21 coefficients for grain corn

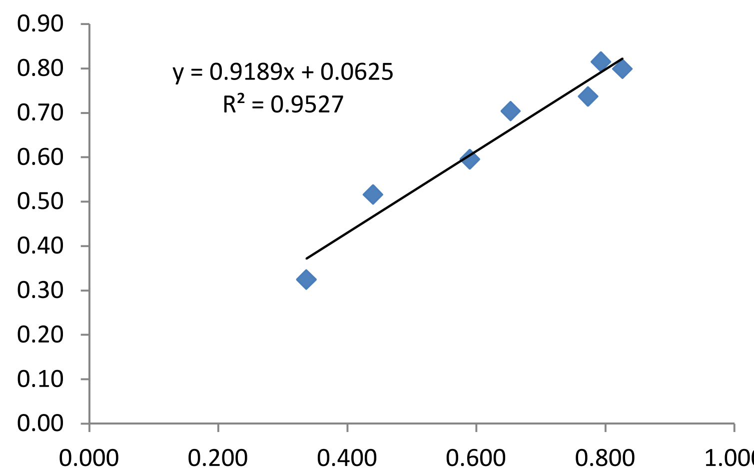

Chart 8 – Small Vegetables, Coefficients from ARS-1275 vs. SCS TR-21 coefficients

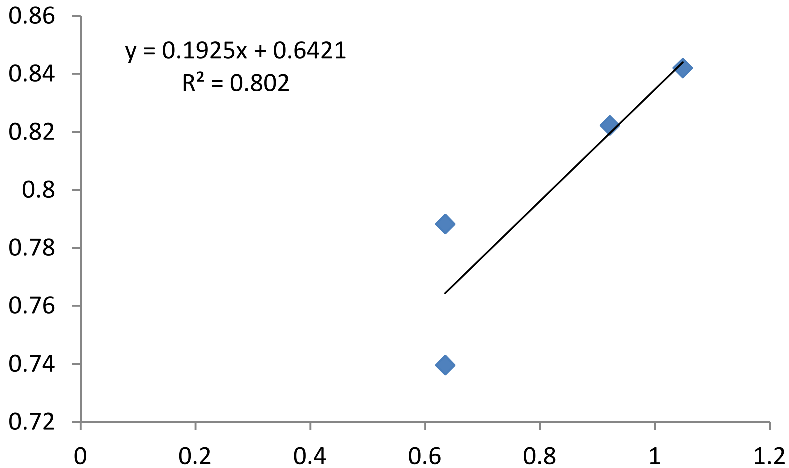

Chart 9 – Dry Beans, ARS-1275 coefficients (Santa Barbara, CA) vs. SCS TR-21 coefficients

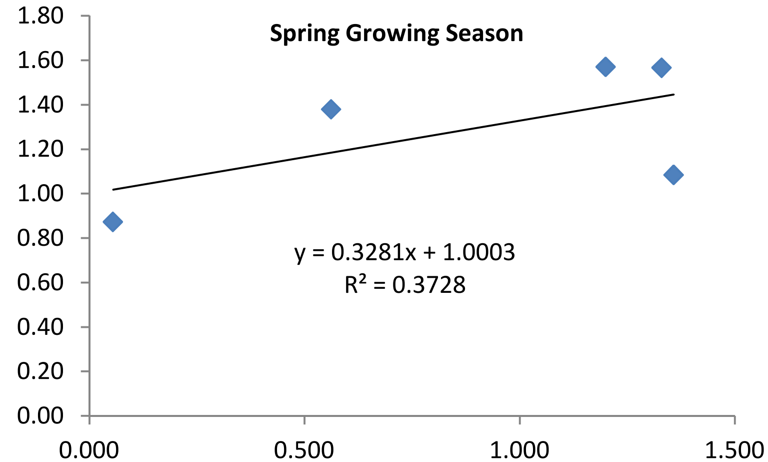

Chart 11 – Winter Wheat, Average of ARS-1275 coefficients vs. SCS TR-21 coefficients

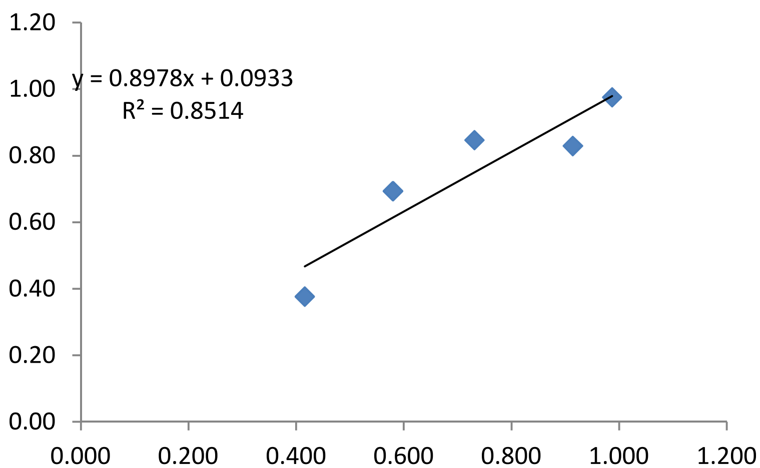

Chart 10 – Sorghum, Average of ARS-1275 coefficients vs. SCS TR-21 coefficients

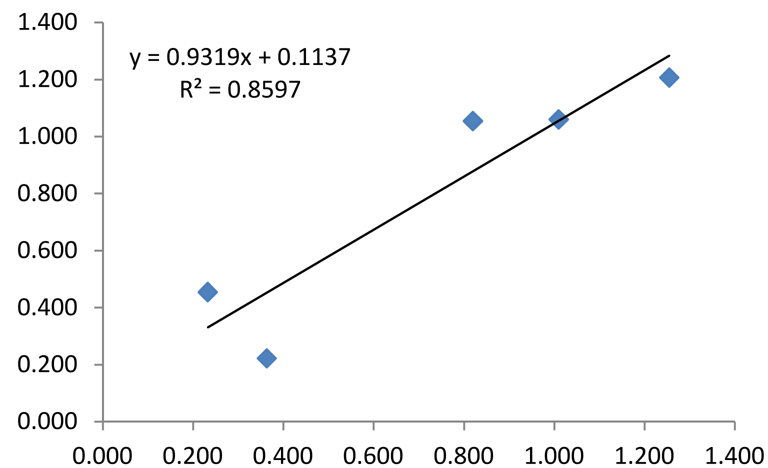

Chart 12 – Barley (Spring Grain), Average of ARS-1275 coefficients vs. SCS TR-21 coefficients

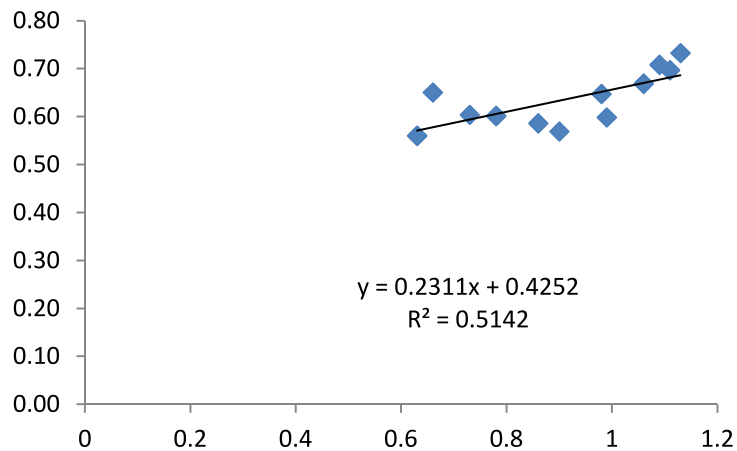

Chart 13 – Orchard with Cover, Average of ARS-1275 coefficients vs. SCS TR-21 coefficients

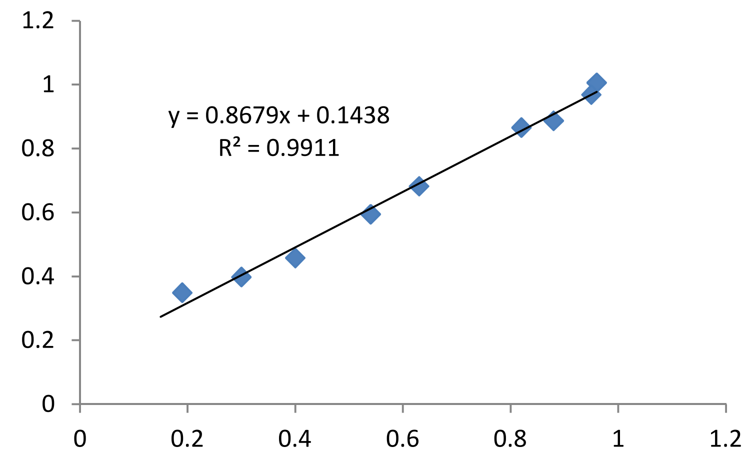

Chart 15 – Orchard without Cover, Average of “deciduous fruit” and walnuts vs. SCS TR-21 coefficients

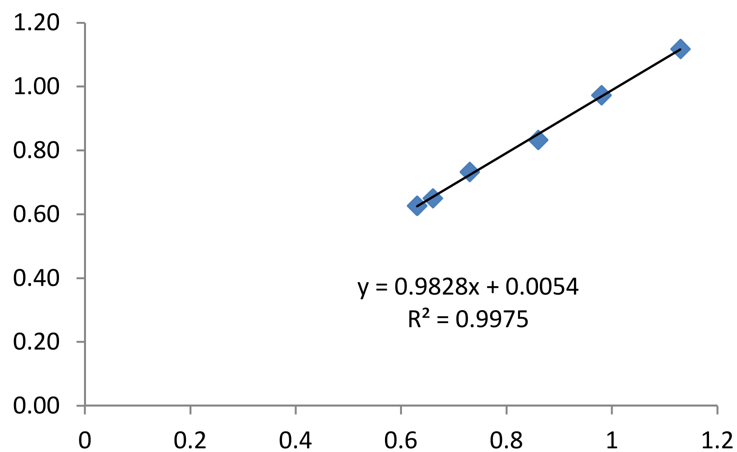

Chart 14 – Orchard with Cover, “hand drawn” line vs. SCS TR-21 coefficients