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Effect of Late Season Water Stress on Corn in Northwest Kansas

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Abstract. *Four separate studies were conducted over the years 1993 through 2008 at the Kansas State University Northwest Research Extension Center at Colby, Kansas to examine the effects of post-anthesis (after silking) water stress on field corn. Prior to anthesis, all treatments in each of the studies were fully irrigated according to their need. The results of these studies suggest that corn yield is nearly linearly related to the amount of crop water use during the post-anthesis period and that total crop water use amounts during the period may average nearly 430 mm. Producers should plan for crop water use during the last 30 and 15 day periods that may average nearly 125 and 50 mm, respectively, to avoid yield reductions. Management allowable depletion during the post-anthesis period should be limited to 45% of the available soil water for a 2.4 m profile on the deep silt loam soils of this climatic region.*

Keywords. *Corn, irrigation, water management, management allowed depletion, production function.*

Introduction

When to terminate the irrigation season is an important irrigation macromanagement decision that can potentially save water and increase net income when made correctly, but can have negative economic consequences when made incorrectly.

Much of the established literature on irrigation management during the late corn growth stages is 40-50 years old and was written at a time when irrigated corn yields were much lower (3 to 6.5 Mg/ha lower) than they are today. It is quite possible that some of the numerous yield-limiting stresses (e.g., water, insects, weeds, nutrient, and soil) that were tolerable at the lower yield level are less tolerable today. On the other side of the issue, there has been much improvement in corn hybrids during the period with incorporation of traits that allow water stress tolerance and/or water stress avoidance.

The post-anthesis grain filling stage in corn is considered to be highly sensitive to water stress with only the flowering (anthesis) and early reproductive period being more sensitive. Plant water stress can cause kernel abortion if it occurs early enough in the post-anthesis period but is more often associated with poor grain filling and thus reduced kernel weight. Grain kernel weight is termed as a very loosely restricted yield component (Yoshida, 1972; Shaw, 1988), meaning that it can be manipulated by a number of factors. The final value is also set quite late, essentially only a few days before physiological maturity. The rate of grain filling is linear for a relatively long period of time from around blister kernel to near physiological maturity. Yield increases of over 0.25 Mg/ha for each day are possible during this period. Providing good management during the period can help to provide a high grain filling rate and, in some cases, may extend the grain filling period a few days thereby increasing yields. Availability of water for crop growth and health is the largest single controllable factor during this period. However, the rate of grain filling remains remarkably linear unless severe crop stress occurs (Rhoads and Bennett, 1990). This is attributed to remobilization of photosynthate from other plant parts when conditions are unfavorable for making new photosynthate. Irrigators in the Central Great Plains sometimes terminate the corn irrigation season on a traditional date such as August 31 or Labor Day (First Monday in September) based on long term experience. However, a more scientific approach might be that season termination may be determined by comparing the anticipated soil water balance at crop maturity to the management allowable depletion (MAD) of the soil water within the root zone. Some publications say the MAD at crop maturity can be as high as 0.8 (Doorenbos and Kassam, 1979). Extension publications from the Central Great Plains often suggest limiting the MAD at season end to 0.6 in the top 1.2 m of the soil profile (Rogers and Sothers, 1996). These values may need to be re-evaluated and perhaps adjusted downward (smaller MAD value). Lamm et al. (1995) found subsurface drip-irrigated corn yields in northwest Kansas began to decrease rapidly when available soil water in the top 2.4 m was lower than 56-60% of field capacity for extended periods in July and August. Lamm et al. (1994) permitted small daily deficits to accumulate on surface-irrigated corn after tasseling, and subsequent analysis of those data showed declining yields when available soil water levels approached 60% of field capacity for a 1.5 m soil profile at physiological maturity.

Procedures

General Procedures

Four studies were conducted at the KSU Northwest Research-Extension Center at Colby, Kansas, USA on a productive, deep, well-drained Keith silt loam soil (Aridic Argiustolls) during the sixteen-year period, 1993-2008. In general, the 1990s were a much wetter period than the

2000s. The summers of 2000 through 2003 would be considered extreme droughts. The climate for the region is semi-arid with a summer pattern of precipitation with an annual average of approximately 480 mm. The average precipitation and calculated corn evapotranspiration during the 120-day corn growing period, May 15 through September 11 is 300 mm and 587 mm, respectively. The corn anthesis period typically occurs between July 15 and 20.

The corn was planted in late April to early May, and standard cultural practices for the region were used.

Irrigation was scheduled as needed by a climate-based water budget except as modified by study protocols that will be discussed in the Specific Procedures section that follows. Calculated crop evapotranspiration (ETc) was determined with a modified Penman equation for calculating reference evapotranspiration (ETr) multiplied by empirical crop coefficients suitable for western Kansas. Precipitation and irrigation were deposits into the crop water budget and calculated ETc was the withdrawal.

Soil water was measured in each plot on a weekly or biweekly basis with a neutron probe to a depth of 2.4 m in 0.3-m increments. These data were used to determine crop water use and to determine critical soil water depletion levels. Water use values were calculated as the sum of the change in available soil water to the specified profile depth, plus the irrigation and precipitation during the specified period. This method of calculating crop water use would also include any deep percolation or rainfall runoff that may have occurred.

Corn yield and yield components of plants/area, ears/plant, and kernel weight were measured by hand harvesting a representative 6 m row sample. The number of kernels/ear was calculated with algebraic closure using the remaining yield components.

Specific Procedures

Four separate studies were conducted over the years 1993 through 2008 to examine the effects of post-anthesis water stress on corn. Prior to anthesis, all treatments in each of the studies were fully irrigated according to their need.

A two-year study (1993 through 1994) consisting of six irrigation treatments with three replications in a complete randomized block design was conducted in small level basins consisting of 6 corn rows each (4.6 m) approximately 27 m long. Surface irrigation was used to provide irrigation amounts for each event that were between 60 to 75 mm to help achieve higher distribution uniformity than smaller applications would have provided. The six irrigation treatments were termination of the irrigation season on either August 5, 10, 15, 20, 25 or 30. The corn hybrid was Pioneer 3183 (a full season hybrid of approximately 118 day maturity). The year 1993 was an extremely poor corn production year characterized by very cool and wet conditions while 1994 was a good year for corn production.

A four-year study (1995 through 1998) consisting of nine irrigation treatments with four replications in a complete randomized block design was conducted in small level basins consisting of 8 corn rows each (6 m) approximately 27 m long. Surface irrigation was used in this study with event irrigation amounts of approximately 60 to 75 mm. The nine irrigation treatments were termination of the irrigation season at either anthesis, anthesis plus 6, 12, 18, 24, 30, 36, 42 or 48 days. The corn hybrid was Pioneer 3183 (a full season hybrid of approximately 118 day maturity). Corn yields in 1995 were somewhat depressed due to a hail storm but were good in 1996 through 1998.

The two studies conducted after 1998 utilized subsurface drip irrigation to more closely control soil water levels and distribution uniformity of irrigation water. Both studies utilized the same field site that had a subsurface drip irrigation (SDI) system installed in 1999 with 1.5-m dripline spacing and an emitter spacing of 0.6 m. The 1.5 m spaced corn rows were planted parallel and centered on the driplines such that each corn row would be 0.38 m from the nearest dripline. The nominal emitter discharge was 1.1 L/h for the 0.6 m emitter spacing.

In a study conducted from 1999 through 2001, seven irrigation treatments were replicated three times in a complete randomized block with plot size of 8 corn rows (6 m) by approximately 85 m. In this study, irrigation during the post-anthesis period was managed for two distinct periods. Four of treatments began at anthesis with one treatment receiving no irrigation after anthesis and the other three treatments only receiving irrigation if the available soil water in the top 1.5m of profile fell below approximately 68, 48 or 27% of field capacity. Three additional treatments were no irrigation after two weeks following anthesis and soil water maintenance level treatments of either 48 or 27% of field capacity beginning also at that time. After anthesis, irrigation amounts were generally not greater than 13 mm for each required event and were conducted daily as needed to return the available soil water to the required treatment level. The year 1999 had above normal precipitation but 2000 and 2001 were extreme drought years. The corn hybrid was Pioneer 3162 (a full season hybrid of approximately 118 day maturity).

The final post-anthesis water stress study (2002 through 2008) was conducted on the same SDI field site as the 1999 through 2001 study but the seven irrigation treatments were the irrigation season being terminated at one week intervals beginning one week after anthesis. This typically meant that the first irrigation treatment ceased about July 20 to 27 and the last irrigation treatment ceased about August 31 to September 7. The crop was fully irrigated until the irrigation termination date occurred and irrigation event amounts were generally not greater than 13 mm. The seven irrigation treatments were replicated three times in a complete randomized block design. The corn hybrid was Pioneer 3162 (a full season hybrid of approximately 118 day maturity). Post anthesis water productivity was calculated as the crop yield in Mg/ha divided by the post-anthesis crop water use in mm.

Results and Discussion

Tabular data analysis for post-anthesis water stress studies

Results from 16 years (1993-2008) of studies indicate that anthesis for corn in Northwest Kansas varies from July 12 to July 24 with an average date of July 19 (Table 1). Physiological maturity ranged from September 14 through October 10 with an average date of September 27. The average length of the post-anthesis period was approximately 70 days. Using the corn grain yield results from the study and the individual treatment irrigation termination dates responsible for those yields, Table 1 was created to indicate the problems with using inflexible dates for determining the irrigation season termination date. Additionally, the corn grain yield results and the treatment irrigation dates were used to estimate the date when a specified percentage of maximum grain yield would occur. Because there was not an unlimited number of irrigation treatment dates there are years when the date required for a specified percentage of maximum grain yield was the same as the date for the next higher percentage. The average estimated termination date to achieve 80, 90 and 100% of maximum corn grain yield was August 2, 13, and 28, respectively, but the earliest dates were July 17, July 17 and August 12, respectively, while the latest dates were September 14, 21, and 21, respectively. Irrigators that use average or fixed dates to terminate the corn irrigation season are not realistically considering the irrigation needs of the corn that may be greater or smaller in a particular year, and thus, often will neither optimize corn production, nor minimize water pumping costs.

Table 1. Anthesis and physiological maturity dates and estimated irrigation season termination dates* to achieve specified percentage of maximum corn grain yield from studies examining post-anthesis corn water stress, KSU Northwest Research-Extension Center, Colby, Kansas, 1993-2008. Note: This table was created to show the fallacy of using a specific date to terminate the irrigation season. Note: Because there was not an unlimited number of irrigation treatment dates, there are years when the date required for a specified percentage of maximum grain yield was the same as the date for the next higher percentage.

Year	Date of Anthesis	Date of Maturity	Irrigation Season Termination Date For		
			80% Max Yield	90% Max Yield	MaxYield
1993	20-Jul	30-Sep	5-Aug	5-Aug	15-Aug
1994	20-Jul	15-Sep	5-Aug	15-Aug	15-Aug
1995	20-Jul	29-Sep	5-Aug	13-Aug	18-Aug
1996	20-Jul	3-Oct	17-Jul	17-Jul	29-Aug
1997	23-Jul	1-Oct	23-Jul	23-Jul	27-Aug
1998	20-Jul	28-Sep	20-Jul	20-Jul	24-Aug
1999	23-Jul	6-Oct	24-Jul	13-Aug	20-Sep
2000	12-Jul	20-Sep	14-Sep	20-Sep	20-Sep
2001	16-Jul	29-Sep	30-Jul	22-Sep	22-Sep
2002	22-Jul	30-Sep	4-Aug	30-Aug	7-Sep
2003	22-Jul	23-Sep	3-Aug	3-Aug	18-Aug
2004	19-Jul	28-Sep	8-Aug	21-Aug	27-Aug
2005	20-Jul	28-Sep	2-Aug	9-Aug	29-Aug
2006	17-Jul	25-Sep	30-Jul	13-Aug	13-Aug
2007	18-Jul	19-Sep	14-Aug	21-Aug	28-Aug
2008	24-Jul	10-Oct	31-Jul	6-Aug	27-Aug
Average	**19-Jul**	**27-Sep**	**2-Aug**	**13-Aug**	**28-Aug**
Standard Dev.	**3 days**	**6 days**	**13 days**	**19 days**	**13 days**
Earliest	**12-Jul**	**14-Sep**	**17-Jul**	**17-Jul**	**12-Aug**
Latest	**24-Jul**	**10-Oct**	**14-Sep**	**21-Sep**	**21-Sep**

* *Estimated dates are based on the individual irrigation treatment dates from each of the different studies when the specified percentage of yield was exceeded.*

Maximum corn yields (MY) during the 16-year period in the various studies averaged 16.2 Mg/ha with a range of 9.7 to 18.7 Mg/ha (Table 2). Extremely poor growing conditions (cold and wet) greatly reduced yields in 1993 and hail suppressed yield in 1995. The post-anthesis water use that occurred for the irrigation treatment that maximized yield (PAWUMY) averaged 430 mm with a range of 378 to 513 mm (Table 2). Assuming that yield formation for the corn crop started at anthesis, the average post-anthesis water productivity (i.e., MY/PAWUMY) was 38 kg/ha-mm and the range of post-anthesis water productivity over the years was 20 to 49 kg/ha-mm (data not shown).

Table 2. Maximum corn yields and post-anthesis water use data from studies examining post-anthesis corn water stress, KSU Northwest Research-Extension Center, Colby, Kansas, 1993-2008.

Year	Maximum Yield (Mg/ha)	$PAWU_{MY}$* (mm)	$PAWU_{MY}$ (mm/d)	$PAWU_{MY}$ during last 30 days (mm/d)	$PAWU_{MY}$ during last 15 days (mm/d)
1993	9.7	488	7.3	7.3	4.5
1994	15.4	394	7.0	5.5	4.5
1995	10.7	463	7.2	5.1	4.4
1996	17.6	391	5.6	4.1	3.5
1997	15.4	410	5.8	4.1	3.8
1998	16.4	420	6.0	3.9	3.5
1999	17.1	470	6.3	3.4	2.1
2000	16.3	514	7.3	7.0	7.7
2001	16.8	494	6.6	4.1	4.1
2002	17.8	422	6.0	3.5	0.4
2003	16.9	384	6.1	2.3	2.7
2004	17.8	413	5.8	4.6	4.2
2005	18.5	414	5.9	2.2	0.9
2006	16.8	419	6.0	2.5	2.6
2007	17.1	413	6.6	2.6	2.7
2008	18.7	377	4.8	2.9	2.3
Average	**16.2**	**430**	**6.3**	**4.1**	**3.4**
Standard Dev.	**2.5**	**42**	**0.7**	**1.5**	**1.7**
Minimum	**9.7**	**377**	**4.8**	**2.2**	**0.4**
Maximum	**18.7**	**514**	**7.3**	**7.3**	**7.7**

* *$PAWU_{MY}$ is the post-anthesis water use occurring for the irrigation treatment that achieved maximum corn grain yield within the specified year.*

PAWUMY averaged 6.3 mm/day during the approximately 70-day period between anthesis and physiological maturity and remained at 65 and 53% of that value (4.1 and 3.4 mm/day) during the last 30 and 15 days of the season, respectively (Table 2). This emphasizes that although crop water use is tapering off during the latter part of the season, due to maturing crop canopies and also due to lower reference evapotranspiration (ETr), it must be considered an important factor in late season crop management. Producers should also be aware that irrigation systems with marginal or insufficient capacity may have allowed considerable soil water depletion (soil water mining) during the pre-anthesis period.

Graphical data analysis for post-anthesis water stress studies

The corn grain yield results within a given year were normalized to the maximum value occurring in that particular year to give the relative yield (RY). The post-anthesis water use within a given year was then normalized with respect to the water use that occurred for the irrigation treatment that maximized corn grain yield in that particular year. This allowed treatments receiving excessive irrigation to have relative post-anthesis water use ($RPAWU_{MY}$) values greater than one.

There was a strong relationship between relative corn yield (RY) and relative post-anthesis water use ($RPAWU_{MY}$) as shown in Figure 1.

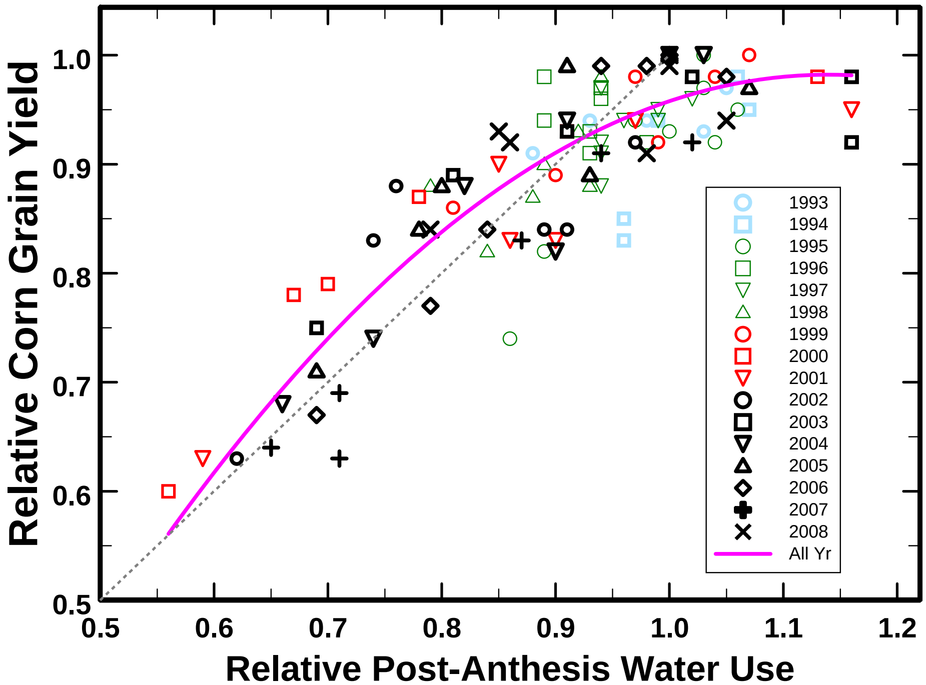

Figure 1. Relative corn grain yield (RY) as affected by relative post-anthesis water use ($RPAWU_{MY}$) for various studies examining the effect of post-anthesis water stress, KSU-NWREC, Colby, Kansas, 1993-2008. The dotted line represents a unity relationship between RY and $RPAWU_{MY}$. Note: $RPAWU_{MY}$ values can exceed one because some treatments received irrigation water in excess of the amount required to maximize corn grain yield (MY). This excessive water may have been lost in deep percolation but would have been included in the calculation procedures of post-anthesis water use.

Although there are a number of curves that can be drawn through the data (e.g., quadratic, logarithmic, etc.), there was a large portion of the data in the efficient range of $RPAWU_{MY}$ (i.e., where $RPAWU_{MY} \leq 1$) that can be adequately characterized by a one-to-one relationship between RY and $RPAWU_{MY}$. The subtle differences between assuming a curvilinear or linear relationship in the efficient range of post-anthesis water use might become important when trying to optimize corn production using water resource and economic constraints.

There was a reasonably good relationship between relative corn grain yield (RY) and the minimum post-anthesis available soil water (MPAASW, a fraction) within the 2.4 m soil profile (Figure 2.) Corn yield tended to decrease for treatments having less than a minimum available soil water of approximately 55% of field capacity for any point-in-time within the post-anthesis period. Thus, the management allowable depletion (MAD) in these studies was approximately 45% as compared to the traditionally larger values often quoted in the literature (e.g., Doorenbos and Kassam, 1979; Rogers and Sothers, 1996). However, the 45% MAD value is consistent with the results of Lamm et al. (1994) and Lamm et al. (1995) from irrigated corn studies on the same soil type.

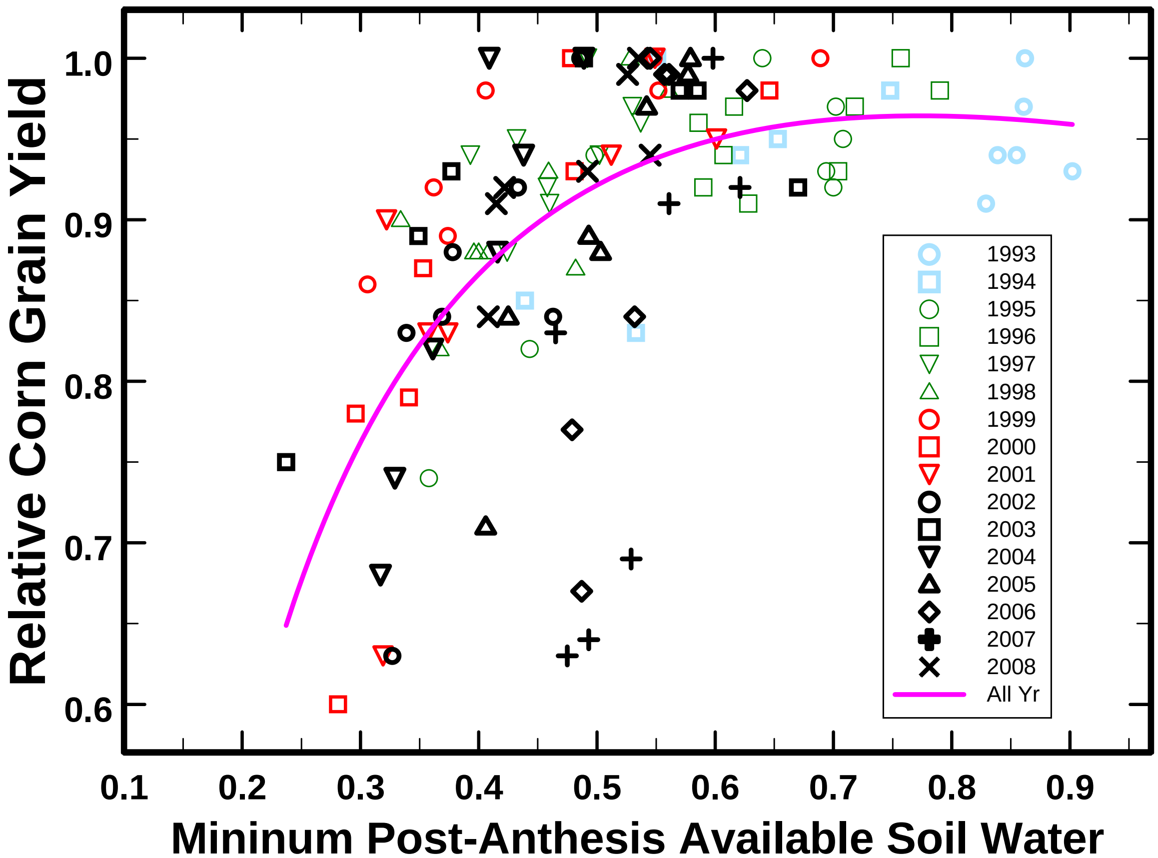

Figure 2. Relative corn grain yield (RY) as affected by the minimum value of available soil water (fraction) within the 8 ft soil profile occurring during the post-anthesis period (MPAASW). Data are from various studies examining the effect of post-anthesis corn water stress, KSU-NWREC, Colby, Kansas, 1993-2008.

There was also a relatively good relationship between $RPAWU_{MY}$ and MPAASW (Figure 3). $RPAWU_{MY}$ tended to decrease for treatments with MPAASW less than 55% of field capacity. This is to be as expected because of the strong relationship between RY and $RPAWU_{MY}$ but does provide additional evidence and rationale for a MAD value of approximately 45% for this soil type in this region as compared to the higher values in the literature.

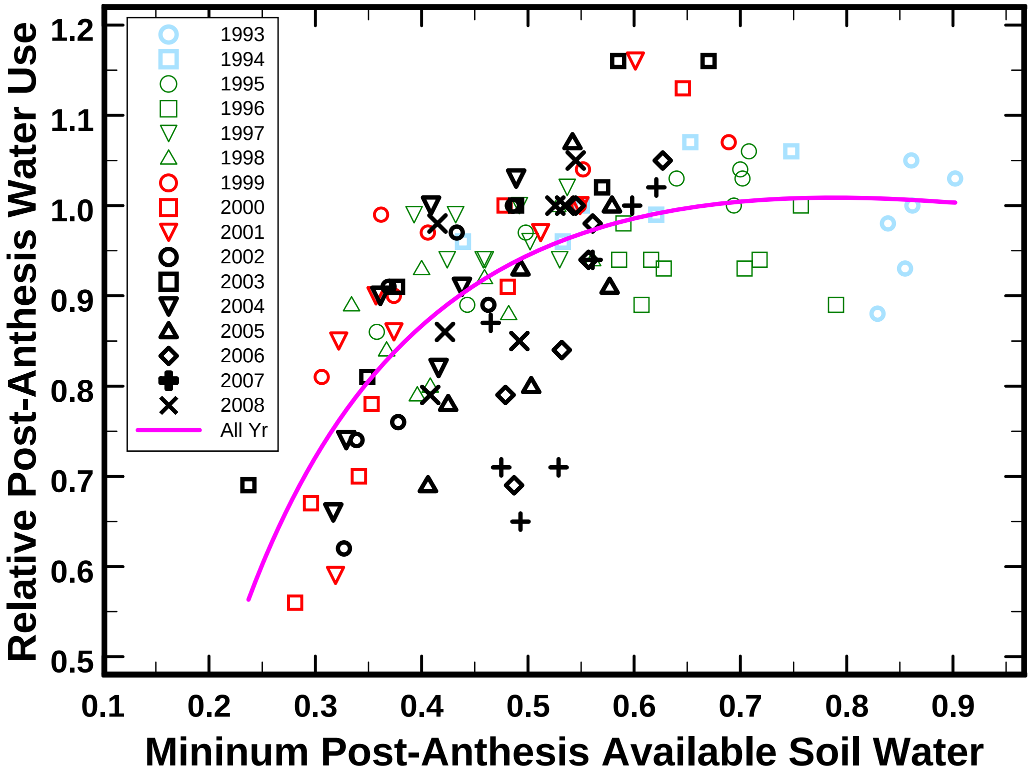

Figure 3. Relative post-anthesis water use ($RPAWU_{MY}$) as affected by the minimum value of available soil water (fraction) within the 2.4 m soil profile occurring during the post-anthesis period (MPAASW). Data are from various studies examining the effect of post-anthesis corn water stress, KSU-NWREC, Colby, Kansas, 1993-2008.

Further data analysis should focus on determining the cause of increased scatter in the graph regions (Figure 2 and 3) where MPAASW is less than 0.55. Additionally, further efforts are justified in comparing the MPAASW values for different soil profile depths to see which depth has the greatest correlation and also to determine the inaccuracy associated with choosing alternative depths.

Recommendations for managing post-anthesis corn water stress

Producers should use a good method of day-to-day irrigation scheduling during the post-anthesis period. The macromanagement decision about when to terminate the irrigation season should not be based on an average or fixed date (e.g., August 31). Producers in the Central Great Plains should plan for post-anthesis water use needs of approximately 432 mm and that water use during the last 30 and 15 days of the season might average nearly 125 and 50 mm, respectively. This water use would need to come from the sum of available soil water reserves, precipitation and irrigation. When irrigation losses are minimized, a percentage decrease in post-anthesis water use will result in nearly a one-to-one percentage decrease in corn grain yield. Producers growing corn on deep silt loam soils in the Central Great Plains should attempt to limit management allowable depletion of available soil water in the top 2.4 m of the soil profile to 45%.

Concluding Statements

Macromanagement decisions at the seasonal boundaries should always be made in the context of having implemented appropriate day-to-day irrigation scheduling. Proper day-to-day scheduling will provide much-needed information about the crop and soil water status and evaporative demand being experienced within the given year.

Corn yield formation was primarily linearly related to the water use during the post-anthesis period for cases when irrigation was limited to the amount required for maximum yield. Limiting available soil water depletion to approximately 45% during the period is important in achieving maximum grain yields.

Acknowledgements

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