EFFECTS OF EARLY-SEASON WATER STRESSES ON CORN PRODUCTION

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ABSTRACT: The corn vegetative stage is often considered the least sensitive stage to water stress and could provide the opportunity to limit irrigation water applications without severe yield reductions. The vegetative stage begins at crop emergence and ends at tasseling when silks begin to emerge. Nine years of research was conducted at the Kansas State University Northwest Research-Extension Center in Colby, Kansas on a productive, deep, silt loam soil where irrigation was delayed in one-week increments, typically ranging from about June 10 to July 20. Delaying irrigation only statistically affected the yield components in three of the nine crop years. Overall, these results suggest that corn grown on this soil type has great ability to handle early-season water stress, provided the water stress can be removed during later stages. In addition to the statistical results, graphical representations indicate that the pertinent yield components are related to measured July crop water use, available soil water, evaporative demand and to the ratio of well-watered evapotranspiration to the sum of irrigation and precipitation.

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KEYWORDS: Corn, irrigation macromanagement, yield components, irrigation scheduling, water stress.

INTRODUCTION

Producers are well aware of the needs of corn for water during the critical reproductive periods, but may want to delay the first irrigation during the vegetative stages. A decision about when to start the corn irrigation season is called a macromanagement decision, which is different than the day-to-day irrigation scheduling decisions during the season. This macromanagement decision can result in significant amounts of water either being used or saved, but does affect corn grain yield. Some yield-limiting stresses that were tolerable at the lower yield level of 30-40 years ago are probably less tolerable today. Additionally, there are irrigation system constraints concerning water application that may confound the understanding of what abilities the corn has to withstand vegetative-period water stress. For example, many irrigation systems cannot apply sufficient amounts of water to replenish depleted soil water reserves during the peak corn water-use periods. A renewed understanding of the biological effects of vegetative-period water stress on corn production appears warranted because there can be solutions to the irrigation system constraints.

The corn vegetative stage is often considered the least sensitive stage to water stress and could provide the opportunity to limit irrigation water applications without severe yield reductions. The vegetative stage begins at crop emergence and ends after tasseling, which immediately precedes the beginning of the reproductive period when the silks begin to emerge. The potential number of ears/plant is established by the fifth leaf stage in corn. The potential number of kernels/ear is established during the period from about the ninth leaf stage until about one week before silking. Stresses during the 10 to 14 days after silking will reduce the potential kernels/ear to the final or actual number of kernels/ear. Therefore, in research studies designed to examine water stresses during the first one-half of the corn crop season, both ears/plant and kernels/ear might be critical factors. Additionally, there could be permanent damaging effects from the vegetative and early-reproductive period water stress that may affect grain filling (kernel weight). The objectives of this study were to examine the effects of delaying the first irrigation during the vegetative and early-reproductive periods on corn production. Pertinent factors were corn yield and yield components as affected by irrigation dates, total water use, evaporative demand, and critical levels of soil water.

PROCEDURES

The study was conducted at the KSU Northwest Research-Extension Center at Colby, Kansas USA on a productive, deep, well-drained Keith silt loam soil (Aridic Argiustolls) with funding from Pioneer HiBred, Inc. during the four-year period 2004-2007 using two corn hybrids [Pioneer 32B33 (full season,118 days to maturity) and Pioneer 33B50 (medium season, 112 days to maturity)]. An additional five years of data (1999-2003) was added to the analysis for the hybrid Pioneer 3162 (full season, 118 days to maturity). The corn was planted in late April to early May, and standard cultural practices for the region were used. Both studies utilized the same field site that had a subsurface drip irrigation (SDI) system installed in 1990 with 5-ft dripline spacing and an emitter spacing of 12 inches. The 2.5-ft spaced corn rows were planted parallel and centered on the driplines such that each corn row would be 15 inches from the nearest dripline. The nominal dripline flowrate was 0.25 gpm/100 ft, which is equivalent to an emitter discharge of 0.15 gal/h for the 12-inch emitter spacing. The 2004-2007 study had six main irrigation treatments and the two corn hybrid split-plot treatments replicated three times in a randomized complete block (RCB) design. The 1999-2003 study used the same experimental design without the split plot.

Irrigation was scheduled as needed by a climate-based water budget except for the specific treatment delays. Calculated water use was determined with a modified Penman equation with empirical crop coefficients suitable for western Kansas. The six irrigation treatments were imposed by delaying the first normal irrigation either 0, 1, 2, 3, 4, or 5 weeks. This would typically result in the first irrigation for Trt 1 being between June 5 and June 15 and the first irrigation for Trt 6 being around July 10 to July 24. The actual dates of treatment initiation are in Tables 1 and 2. The corn silking period typically occurs between July 15 and 20. In some years, excessive rainfall between two adjacent treatment initiation dates would negate the need for irrigation. In that case, the later treatments would be delayed an additional week to provide an extended data set. After the treatment initiation date occurred, SDI was scheduled to provide 0.4 inches/day until such time that the climate-based water budget fully eliminated calculated soil water deficits. It should be noted that this irrigation capacity of 0.4 inches/day is much greater than the typical irrigation capacity in this region. Additionally, the procedure of eliminating the severe irrigation deficits later in the season after the plants had been stunted may lead to excessive deep percolation. The purpose of the study was not to optimize irrigation use within the study but rather to determine what capability the corn crop had to tolerate early season water stress. Thus, the procedures were tailored to alleviate soil water deficits relatively quickly after the treatment initiation date. Soil water was measured in each plot on a weekly or biweekly basis with a neutron probe to a depth of 8 ft. in 1-ft increments. These data were used to determine crop water use and to determine critical soil water depletion levels.

Corn yield components of crop yield, plants/area, ears/plant, and kernel weight were measured by hand harvesting a representative 20 ft-row sample. The number of kernels/ear was calculated with algebraic closure using the remaining yield components.

RESULTS AND DISCUSSION

Delaying irrigation only statistically affected the yield components in three of the nine crop years and then only for the later irrigation dates (Tables 1 and 2). Delaying irrigation until July 10, 2001, July 17, 2003 and July 27, 2005 significantly reduced the number of kernels/ear and the grain yield. These 3 years had an average weather-based calculated July crop ET rate of 0.32 inches/day. This compares with an average July crop ET rate value of 0.26 inches/day for the other six years. It should be noted that the years 2000 through 2003 were extreme drought years in northwest Kansas. Delaying irrigation also significantly reduced ears/plant in 2003 and 2005. In 2003, the reduction in kernels/ear and ears/plant for Trt 6 was partially compensated for by a statistically higher kernel weight. Overall, these results suggest that corn grown on this soil type has great ability to handle vegetative and early-reproductive period water stress provided the water stress can be removed during later stages.

Table 1. Summary of yield component and irrigation data from an early season water stress study for corn hybrid Pioneer 3162, KSU-NWREC, Colby, Kansas, 1999-2003.

Year and Parameter		Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6
1999	First Irrigation Date	22-Jun	29-Jun	6-Jul	13-Jul	20-Jul	27-Jul
	Total Irrigation (in.)	11.2	11.2	11.2	10.0	10.0	7.6
	Yield (bu/a)	253 a	265 a	256 a	255 a	259 a	255 a
	Plant Pop. (p/a)	31073 a	32234 a	31944 a	31653 a	32234 a	32234 a
	Ears/Plant	0.99 a	0.99 a	0.97 a	1.00 a	0.99 a	1.01 a
	Kernels/Ear	575 a	570 a	555 a	572 a	543 a	555 a
	Kernel Wt. (g/100)	36.3 a	36.9 a	37.8 a	35.8 a	38.1 a	35.9 a
2000	First Irrigation Date	5-Jun	12-Jun	19-Jun	26-Jun	3-Jul	10-Jul
	Total Irrigation (in.)	19.7	19.7	19.7	18.9	18.9	18.9
	Yield (bu/a)	225 a	235 a	225 a	227 a	216 a	217 a
	Plant Pop. (p/a)	27878 a	28169 a	26717 a	26717 a	27007 a	27297 a
	Ears/Plant	1.02 a	1.04 a	0.99 a	1.03 a	1.02 a	1.01 a
	Kernels/Ear	544 a	553 a	568 a	544 a	548 a	529 a
	Kernel Wt. (g/100)	36.9 a	36.8 a	38.0 a	38.4 a	36.4 a	37.8 a
2001	First Irrigation Date	12-Jun	19-Jun	26-Jun	3-Jul	10-Jul	17-Jul
	Total Irrigation (in.)	19.2	19.2	19.2	19.2	19.2	19.2
	Yield (bu/a)	254 a	260 a	261 a	250 a	213 b	159 c
	Plant Pop. (p/a)	33977 a	34993 a	35138 a	35284 a	34413 a	33831 a
	Ears/Plant	0.96 a	0.98 a	0.99 a	0.99 a	0.97 a	0.99 a
	Kernels/Ear	581 a	584 a	582 a	541 a	476 b	347 c
	Kernel Wt. (g/100)	33.8 a	33.2 a	32.8 a	33.7 a	34.6 a	34.9 a
2002	First Irrigation Date	12-Jun	19-Jun	26-Jun	3-Jul	10-Jul	17-Jul
	Total Irrigation (in.)	18.5	18.0	18.0	18.0	18.0	18.0
	Yield (bu/a)	233 a	232 a	217 a	219 a	222 a	223 a
	Plant Pop. (p/a)	34558 a	34848 a	34558 a	35719 a	35719 a	34558 a
	Ears/Plant	0.98 a	0.97 a	0.98 a	0.99 a	1.00 a	0.99 a
	Kernels/Ear	454 a	443 a	407 a	435 a	391 a	422 a
	Kernel Wt. (g/100)	38.6 a	39.8 a	40.3 a	36.6 a	40.5 a	39.2 a
2003	First Irrigation Date	12-Jun	21-Jun	26-Jun	3-Jul	10-Jul	17-Jul
	Total Irrigation (in.)	18.8	18.0	18.0	17.2	17.2	17.2
	Yield (bu/a)	177 a	180 a	190 a	186 a	171 a	93 b
	Plant Pop. (p/a)	32815 a	33396 a	34267 a	33106 a	34558 a	32815 a
	Ears/Plant	0.96 a	0.92 b	0.96 a	1.00 a	0.97 a	0.82 c
	Kernels/Ear	588 a	567 a	576 a	569 a	486 b	262 c
	Kernel Wt. (g/100)	24.1 b	26.2 b	25.5 b	25.2 b	26.8 b	33.6 a

Values followed by the same lower case letters are not significantly different at P=0.05.

Table 2. Summary of yield component and irrigation data from an early season water stress study for corn hybrids Pioneer 33B50 and 32B33, KSU-NWREC, Colby, Kansas, 2004-2007.

Year and Parameter		**Trt 1**	**Trt 2**	**Trt 3**	**Trt 4**	**Trt 5**	**Trt 6**
2004 First Irrigation	**Hybrid**	8-Jun	28-Jun	13-Jul	20-Jul	27-Jul	3-Aug
Total Irrig. (in.)		12.8	11.6	10.8	10.8	10.8	10.8
Yield (bu/a)	33B50	220 aA	213 aA	206 aA	233 aA	245 aA	210 aA
	32B33	226 aA	211 aA	209 aA	222 aA	229 aA	206 aA
Plant Pop. (p/a)	33B50	29040 aA	28169 aA	28169 aA	28169 aA	28750 aA	27878 aA
	32B33	28459 aA	29621 aA	29621 aA	28459 aA	29040 aA	28459 aA
Ears/Plant	33B50	0.85 aA	0.91 aA	0.89 aA	0.93 aA	0.88 aA	0.84 aA
	32B33	0.88 aA	0.80 aA	0.79 aA	0.90 aA	0.83 aA	0.83 aA
Kernels/Ear	33B50	595 aB	574 aB	589 aB	595 aA	648 aA	590 aB
	32B33	624 aA	616 aA	634 aA	600 aA	643 aA	612 aA
Kernel Wt. (g/100)	33B50	38.0 aA	36.8 aA	35.7 aA	38.2 aA	38.2 aA	38.6 aA
	32B33	36.8 aB	36.4 aA	36.2 aA	36.8 aB	37.6 aA	36.4 aB
2005 First Irrigation	**Hybrid**	21-Jun	28-Jun	6-Jul	12-Jul	19-Jul	26-Jul
Total Irrig. (in.)		13.2	13.2	13.2	13.2	13.2	13.2
Yield (bu/a)	33B50	254 aA	259 aA	256 aA	238 abA	227 bA	149 cA
	32B33	254 abcA	254 abcA	258 abA	264 aA	235 cA	162 dA
Plant Pop. (p/a)	33B50	28750 aA	28459 aA	28459 aA	28459 aA	29621 aA	28169 aA
	32B33	28459 aA	29040 aA	28459 aA	27848 aA	28750 aA	29621 aA
Ears/Plant	33B50	0.99 abA	1.00 aA	0.99 abA	0.98 abA	0.96 bcA	0.95 cA
	32B33	0.98 bA	0.97 bcA	1.01 aA	1.00 abA	0.96 bcdA	0.94 dA
Kernels/Ear	33B50	641 abA	653 aA	670 aA	604 bA	564 cA	422 dA
	32B33	638 bA	647 abA	644 abA	680 aA	654 abA	421 cA
Kernel Wt. (g/100)	33B50	35.4 aA	35.4 aA	34.5 aA	36.0 aA	35.9 aA	33.6 aA
	32B33	36.2 aA	35.4 aA	35.4 aA	35.5 aA	33.1 aA	35.1 aA
2006 First Irrigation	**Hybrid**	8-Jun	15-Jun	26-Jun	29-Jun	6-Jul	14-Jul
Total Irrig. (in.)		14.0	13.6	12.8	12.8	12.4	12.4
Yield (bu/a)	33B50	225 aA	230 aA	220 aB	220 aA	220 aB	206 aB
	32B33	229 aA	234 aA	246 aA	230 aA	241 aA	244 aA
Plant Pop. (p/a)	33B50	27588 aA	27007 aA	28169 aA	28169 aA	27588 aA	27297 aA
	32B33	28459 aA	27878 aA	28459 aA	27878 aA	28168 aA	28169 aA
Ears/Plant	33B50	0.98 aA	0.98 aA	0.99 aA	0.99 aA	0.99 aA	0.96 aA
	32B33	0.96 aA	0.98 aA	0.98 aA	0.97 aA	0.98 aA	0.97 aA
Kernels/Ear	33B50	561 aB	594 aAB	544 aB	547 aB	550 aB	519 aB
	32B33	597 aA	602 aA	618 aA	583 aA	585 aA	612 aA
Kernel Wt. (g/100)	33B50	37.8 aA	37.2 aA	36.8 aA	36.5 aA	37.4 aA	38.7 aA
	32B33	35.7 aA	36.2 aA	36.3 aA	37.1 aA	38.1 aA	37.2 aA
2007 First Irrigation	**Hybrid**	7-Jun	21-Jun	28-Jun	4-Jul	12-Jul	19-Jul
Total Irrig. (in.)		12.1	11.3	11.3	11.3	11.3	10.9
Yield (bu/a)	33B50	243 aA	252 aA	250 aA	245 aA	234 aA	213 aA
	32B33	259 aA	235 aA	252 aA	239 aA	255 aA	229 aA
Plant Pop. (p/a)	33B50	29040 aA	29621 aA	29331 aA	28459 aA	29040 aA	28169 aA
	32B33	29040 aA	28459 aA	28169 aA	27878 aA	28459 aA	28169 aA
Ears/Plant	33B50	0.98 aA	0.99 aA	1.00 aA	0.99 aA	0.99 aA	1.00 aA
	32B33	0.98 aA	0.95 aA	0.99 aA	0.99 aA	0.99 aA	0.97 aA
Kernels/Ear	33B50	668 aB	672 aB	693 aA	682 aA	645 aB	597 aB
	32B33	728 aA	724 aA	712 aA	712 aA	714 aA	674 aA
Kernel Wt. (g/100)	33B50	32.5 aA	32.5 aA	31.2 aA	32.4 aA	32.0 aA	32.2 aA
	32B33	31.6 aA	30.6 aA	32.3 aA	30.9 aA	32.3 aA	31.7 aA

Irrigation treatment values within the same row followed by the same lower case letters are not significantly different at P=0.05, and hybrid treatment values within the same column followed by the same upper case letters are not significantly different at P=0.05.

The hybrid selection affected yield in only one of four years, 2006 with the longer season Pioneer 32B33 providing significantly greater yields for the later irrigation initiation dates (Table 2). This is probably because of earlier pollination for the Pioneer 33B50 prior to receiving irrigation. Kernels/ear was significantly less for the shorter season Pioneer 33B50 hybrid in three of four years. Hybrid selection did not affect ears/plant in any of the 4 years. In 2004, kernel weight was significantly higher for Pioneer 33B50 for some irrigation treatments, probably because of the smaller number of kernels/ear for this hybrid in that year.

It should be noted that the results do not mean that irrigation can be delayed in the Western Great Plains until mid to late July. These plots generally started the season with reasonably full soil profiles. Most irrigators do not have irrigation systems with adequate capacity (gpm/acre) to quickly alleviate severely depleted soil water reserves. In addition, it is difficult to infiltrate large amounts of water into the soil quickly with sprinkler and surface irrigation systems without causing runoff problems. Rather, look at these study results as describing the corn plant's innate ability to tolerate vegetative-period water stress.

The tabular data do not give a mechanistic explanation of the results. Attempts were made to relate yield component data to a large number of water factors in the broad categories of water use, evaporative demand, and critical profile soil water levels. Final grain yield was largely determined by the number of sinks or kernels/area (Plants/Area population x Ears/Plant x Kernels/Ear) indicating there was little or no effect on the grain-filling stage imposed by the vegetative and early-reproductive period water stress in these two studies (Figure 1). The individual treatment values of corn grain yield and kernels/area were values compared to the irrigation treatment that had no initial delay in irrigation (Trt 1) to give relative values. In a few cases, the Trt 1 values were not the highest value and, thus, relative values could be greater than one. Deviations below the 1 to 1 unity line in Figure 1 would indicate a permanent negative effect on corn grain yield of early-season water stress because of reduced kernels/area. Deviations above the line would indicate some grain yield compensation resulting from better grain filling of the reduced kernels/area.

Relative kernels/area was found to be reasonably well related to relative July water use, the minimum available soil water in the top 4 ft of the soil profile during July and to the July 1 through July 15 water deficit (Ratio of calculated well-watered corn ETc to the sum of irrigation and precipitation). Further analysis is needed to determine an improved overall relationship involving more than a single factor, but the results from each individual factor will be discussed here.

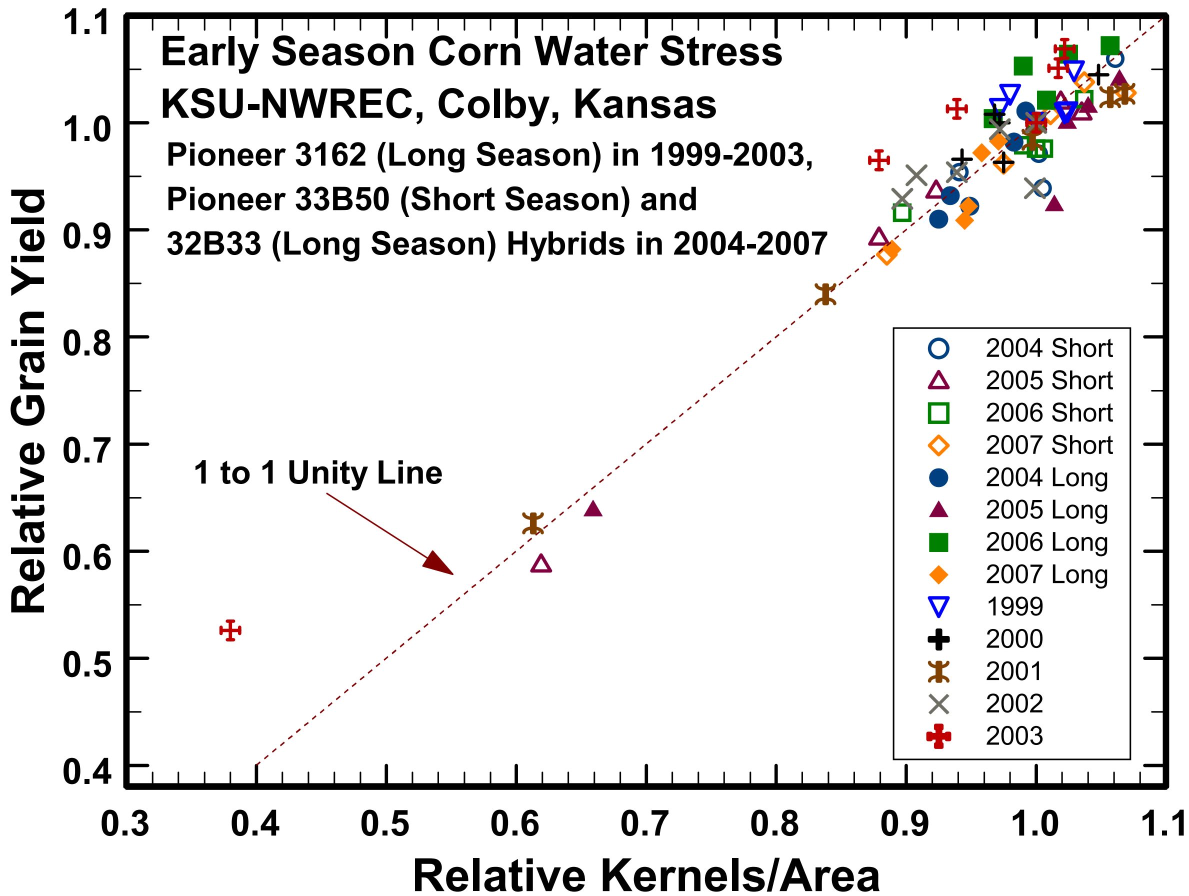

Figure 1. Relative corn grain yield as affected by relative kernels/area in an early-season corn water stress study, KSU-NWREC, Colby, Kansas, 1999-2007.

The 50% critical silking period for corn in this study ranged from approximately July 17 to July 22 during the study period (1999 to 2007). The short-season hybrid in the latter study would typically silk approximately one week earlier. A window of approximately two weeks on both sides around the silking period was used to compare the relative kernels/area to the relative July measured water use (sum of change in available soil water in July plus July irrigation and precipitation). Actual soil water measurements were taken on an approximately weekly basis except for equipment problems or when excessive precipitation delayed measurements, so it was not possible with the data set to always have exactly 31 days of water use. Dates used were those closest to July 1 through 31. There tended to be some reduction in relative kernels/area when relative July water use was less than 80% (Figure 2). Scatter at the lower end of relative July water use may be related to water-use differences occurring within the month or differences in evaporative demand between the years. This relationship may not result in a very good signal for procedures to determine irrigation need because the relative July water use cannot be determined until it is too late to handle the reduction in relative kernels/area.

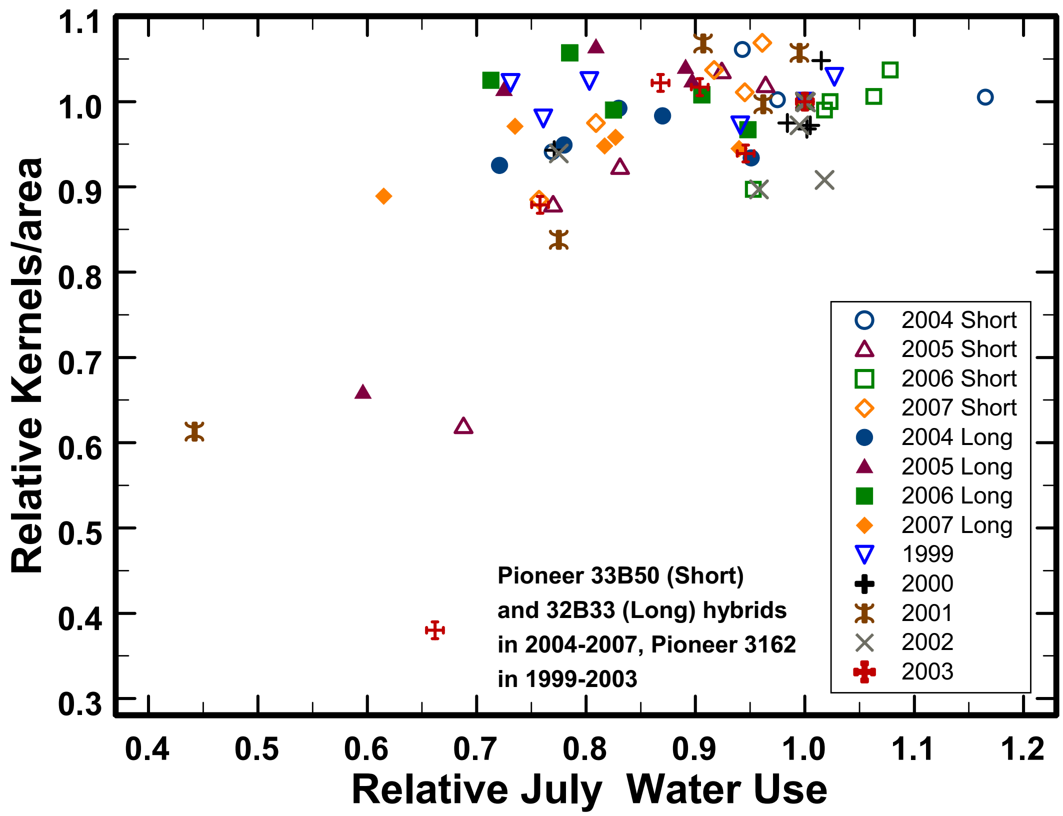

Figure 2. Relative corn grain yield as affected by relative July water use in an early-season corn water stress study, KSU-NWREC, Colby, Kansas, 1999-2007.

The relative kernels/area tended to be reduced when July minimum available soil water in the top 4 ft (JASW) was below 0.6 (fraction) in some years (Figure 3). During years of less evaporative demand, water could be extracted from the soil profile to a further reduced level without much detriment to relative kernels/area, but severe reductions occurred for similar soil water conditions in years with large July evaporative demands. The upper and lower envelope lines of Figure 3 were manually drawn to indicate the effect of evaporative demand of the given year on relative kernels/area. These envelopes would match known theories of water stress and water flow through plants. Water stress is both greater with reduced available soil water and with greater evaporative demand. The kernels/area was most sensitive to the JASW in the top 4 ft of soil as compared to both lesser and greater profile depths. This is reflecting the approximate rooting and soil water extraction depth of corn in July on this soil type. There remains considerable unexplained scatter in this graph that does not appear to be related very well to differences in evaporative demand between the years. For example, there was very little effect on relative kernels/area in 2002, although it had a moderately high evaporative demand. The relationship of relative kernels/area to a critical level of available soil water can have some merit as a signal for determining the need for irrigation because available soil water can both be measured in real time and the value can be projected a few days into the future.

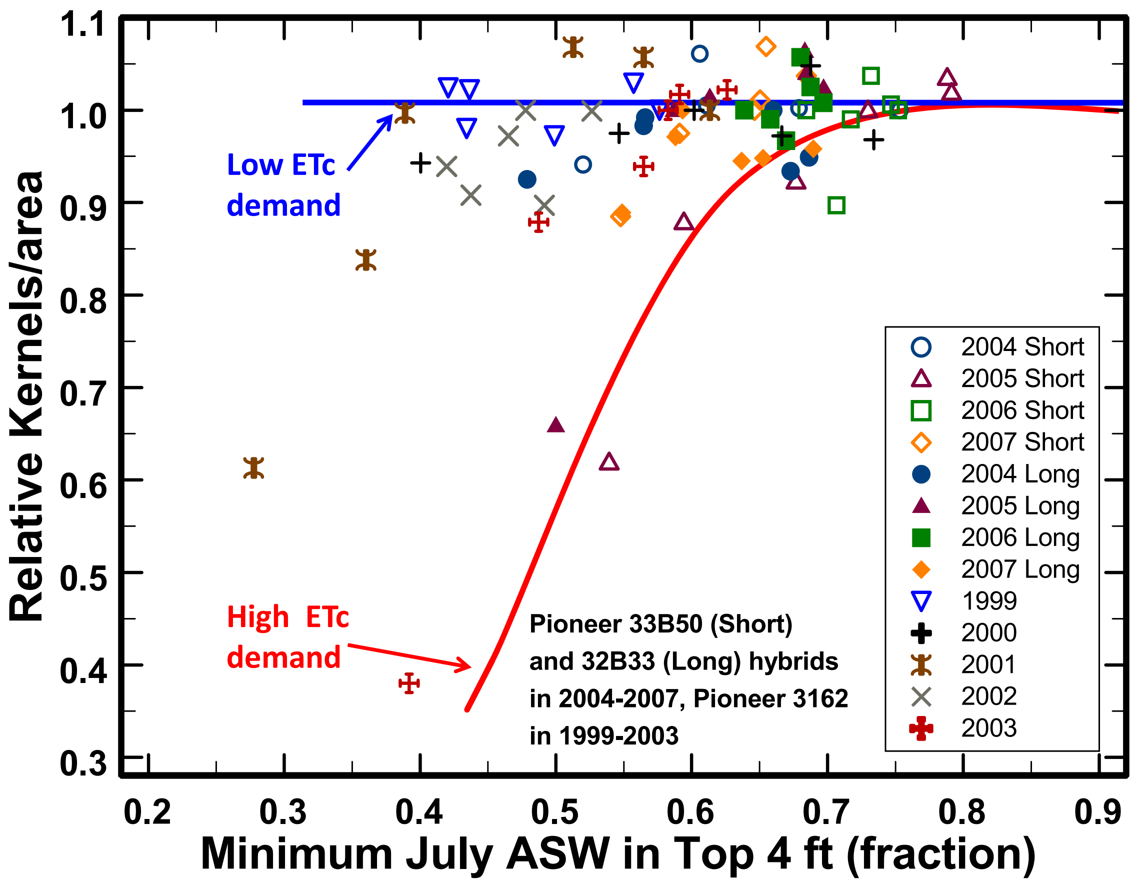

Figure 3. Relative kernels/area as affected by July minimum available soil water in the top 4 ft of soil in an early-season corn water stress study, KSU-NWREC, Colby, Kansas, 1999-2007. The upper (red) and lower (blue) lines are manually drawn to illustrate years with larger and smaller July evaporative demand.

The ratio of calculated well-watered crop ETc to the sum of irrigation and precipitation for July 1 through 15 was also related to the relative kernels/area (Figure 4). Attempts were also made in varying the timeframe of the ratio (both longer and shorter and also shifting within the month of July). It appears that some of the remaining scatter in this graph is related to timing of irrigation and precipitation near the actual point of silking. For example, the isolated point from 2002 near the vertical axis may be related to a significant precipitation event that occurred near silking, but later than July 15. Further analysis should be conducted to allow the window to actually vary around the individual silking dates of each year. This might be done by computing windows based on the number of thermal units (also known as Growing Degree Days) required for silking. This relationship might also be a good signal in determining the need for irrigation because it can be determined in near real time using the accumulated ratio to that point in time.

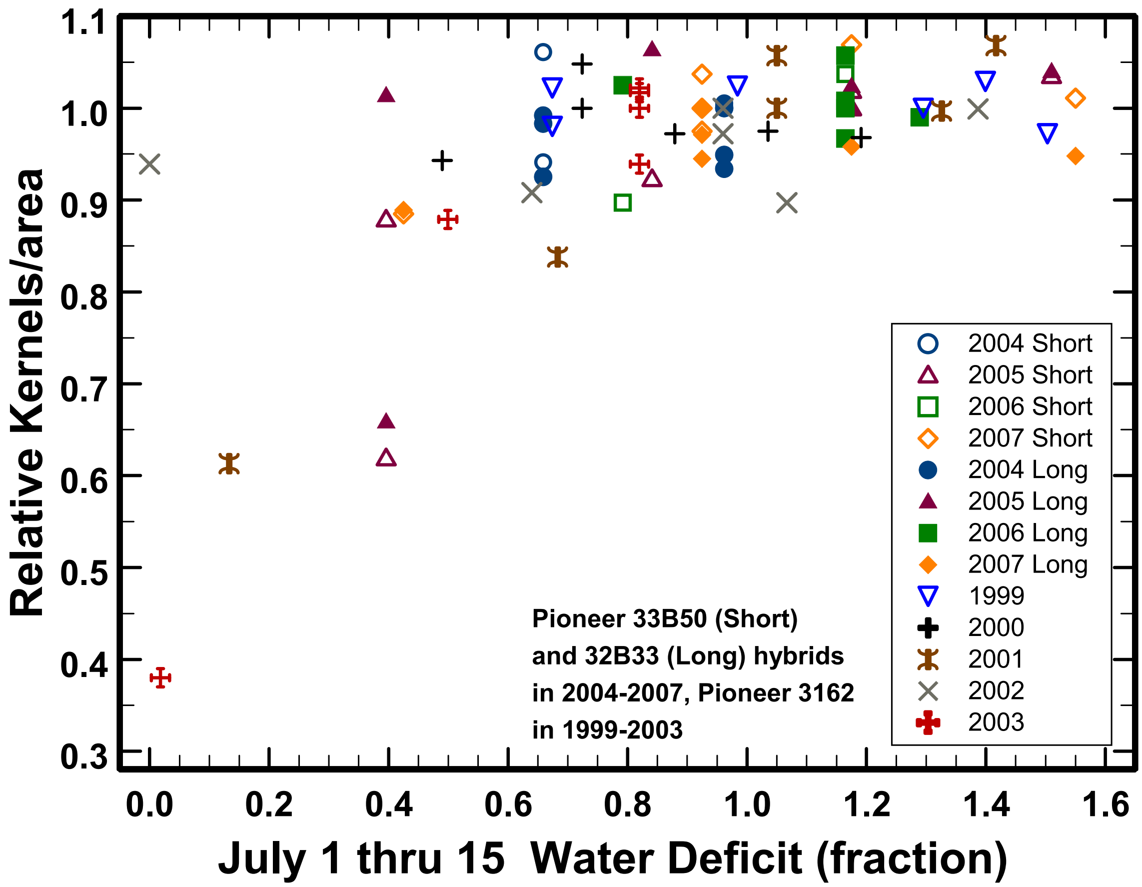

Figure 4. Relative kernels/area as affected by the July 1 through 15 water deficit (ratio of calculated well-watered crop ETc to the sum of irrigation and precipitation) in an early-season corn water stress study, KSU-NWREC, Colby, Kansas, 1999-2007.

CONCLUSIONS

The corn has greater than anticipated ability to withstand vegetative season water stress provided that the water stress can be alleviated during the early-reproductive period. In years of lower evaporative demand, corn grown on this soil type in this region can extract greater amounts of soil water without detriment. Timeliness of irrigation and/or precipitation near silking appears to be important in establishing an adequate number of kernels/area.

Further analysis should center on attempts to combine multiple factors (e. g., measured water use, available soil water, evaporative demand, and/or timing of irrigation and precipitation) with a focus on developing irrigation signals that can be used in near real-time to make early season irrigation decisions.