PROGRESS REPORT
TO SYNGENTA CROP PROTECTION AND THE
CORN GROWER'S ASSOCIATION OF NORTH CAROLINA, INC.

TITLE: Evaluating Maize Hybrid Response to Irrigation Strategies for Water-Efficient Production in Eastern North Carolina

LEADER(S): Gary Payne, Mohamed Youssef, Gail Wilkerson, Ron Heiniger, Jeffrey White, Michael Kudenov

DEPARTMENT(S): Plant Pathology and Entomology, Biological and Agricultural Engineering, Crop and Soil Sciences, Electrical and Computer Engineering

REPORT: Prepared and written by Robert Walters, Technical Specialist

EXECUTIVE SUMMARY

North Carolina has the environmental and soil conditions that make it favorable for identifying the components of yield and stress responses and developing future high yielding maize genotypes. In 2016 research projects developed in collaboration with and funded by Syngenta Crop Protection and the Corn Growers Association of North Carolina (CGANC) continued focusing on the creation of a spectral imaging collection site in North Carolina for testing new sensor technologies to more quickly and reliably identify genotypes with enhanced yield potential. Two irrigation strategies and two maize genotypes were tested in 2016. In 2017 and 2018 the research was modified to test the effects of population and two side-dress fertilizer placement methods on corn growth, yield, and plant nutrient sufficiency indicators. This report summarizes a preliminary analysis of the data collected on the AMPLIFY field site at the Cunningham Research Station in Kinston, N.C.

The objectives of this project were:

1. *Extensively phenotype Syngenta maize hybrids NK78S, NK74R and competitor Pioneer P1870 traits*
2. *Evaluate the response of maize hybrids to two irrigation strategies*
3. *Monitor maize insect and disease trait characteristics*
4. *Evaluate new sensors for plant trait development in a highly monitored field trial*
5. *Evaluate the response of maize hybrids to side-dress fertilizer N application placement*
6. *Evaluate the efficacy of pre-plant micronutrient zinc, copper, and boron application*
7. *Generate a unique dataset combining sensor, crop input, and management information with extensive season-long monitoring of soil moisture, meteorology, and plant growth and nutrient status in soil with well-characterized physical and chemical properties*
8. *Use these data to evaluate existing crop and soil models as potential aids in rapid plant trait development*

Section 1. Key Findings from the 2016-2018 Investigations

- **Stand, Phenology, Vegetation Indices.** With irrigation, we detected phenological differences between 35 days (one day after side-dressing) and 52 days after planting in the growth staging period. No phenological differences were detected prior. Differences in measured leaf collar height, internode length, and canopy height were apparent from 56 to 64 days after planting, under full season and deficit (growth stage VT ±10 days) irrigation compared to rainfed natural precipitation. We found these traits consistently predicted grain yield when measured around VT-R1 irrespective of hybrid when other factors like soil drainage and fertility were controlled for (Figure 1.1).

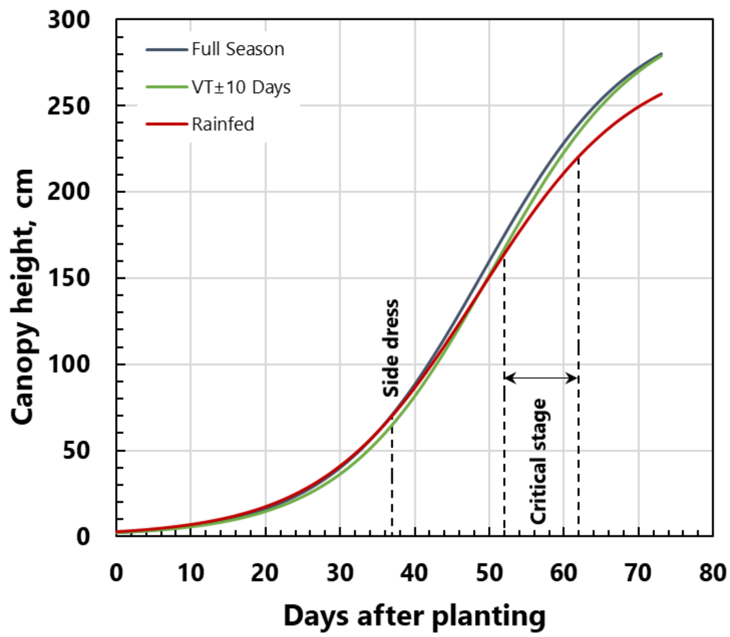

Figure 1.1 Canopy height, measured in the critical growth stage (VT±10 days), was a sensitive and consistent predictor of grain yield in all years. The logistic growth curves in Figure 1 combine hybrids NK78S and NK74R from 2016, as no significant differences between them were detected. Canopy height can also be quantified by near-distance remote sensing applications like hyperspectral imaging and LiDAR scanning, two essential tools for rapid, high-throughput trait evaluation.

Plant population influenced phenological parameters beginning 21 days after planting until silking (R1), generally favoring hybrid NK78S at 30,000 plants/acre, compared with hybrid P1870 at 40,000 plants/acre. Differences were found in total plant biomass and biomass fractions at V6 and silking (R1). Positive differences generally favored full season over deficit irrigation and rainfed natural precipitation, whereas plant biomass and biomass fraction response to plant population varied with development stage. Stand counts at V3 were, on average, 4.9% and 3.7% below the target population for 30,000 and 40,000 plants/acre, respectively. Pollen shed, and silking frequency varied with population whereas hybrid P1870 was more sensitive to irrigation treatment than NK78S.

- **Yield Response.** Full season and deficit irrigation returned, on average, 30 bu/acre more than rainfed, a 23.1% increase. No yield penalty for deficit irrigation was observed in 2018. Side-dress fertilizer nitrogen (N) rate and placement improved yield, favoring the 2x rate with 40,000 plants/acre compared with 1x rate with 30,000 plants/acre. However, the +15-bushel yield gain was small relative to doubling of the side-dress N rate, indicating that fertilizer N rates beyond 200 lb/acre under high (40K plants/acre) maize population would return only fractionally more grain than the standard 1x rate. Differences in test weight were detected for irrigation but not for population. Test weight averaged in the high 54s to low-55s under deficit and full season irrigation, respectively; and low 53s under rainfed natural precipitation. Average 3-year yield gain attributed to full season and deficit irrigation was: 23.2% and 17.4%, respectively, over rainfed. Year-to-year gains were more consistent under full season irrigation compared to deficit irrigation (Table 1).

Table 1. Yield comparisons, 2016-2018

Irrigation	2018*	% Diff	2017**	% Diff	2016***	% Diff	Average§ 3-yr	% Diff
Full Season	160	+23.1	197	+23.9	217	+22.6	191	+23.2
Deficit	160	+23.1	171	+7.5	214	+20.9	182	+17.4
Rainfed	130		159		177		155	

*bu/acre for hybrids NK78S, P1870
**bu/acre for hybrid NK78S
***bu/acre for hybrids NK78S, NK74R
§Arithmetic average across years, non-inferential

- **Yield Components.** Higher plant population increased: ear row number; decreased kernels per row; and did not affect kernel weight. On average, ear row number was generally higher, and kernels per row, and kernel weight, were lower, than in 2017. Irrigation increased kernels per row and kernel weight but not ear row number.

- **Insects and Disease.** Grey leaf spot (*Cercospora zeae-maydis*) and southern leaf blight (*Bipolaris maydis*) were not detected in 2016, 2017, or 2018. Common rust (*Puccinia sorgi*) or Southern rust (*Puccinia polysora*) occurred each year but at low levels. No Rx was applied. Heavy infestations of corn ear worm (CEW) were detected in hybrid NK74R in 2016, and in hybrids NK78S and P1870 in 2018 (Figure 2).

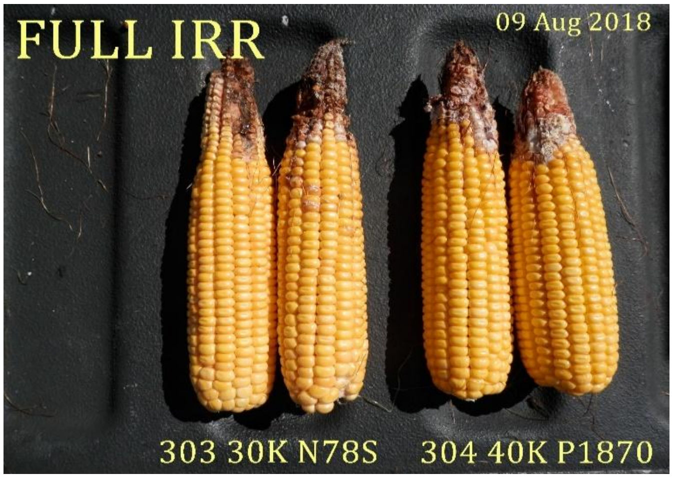

Figure 1.2 Typical corn ear worm (CEW) damage in hybrids N78S and P1870 in 2018. In addition to yield loss up to 10%, feeding by CEW, FAW, and ECB larvae permits entry of fungal pathogens that infect maize kernels, further reducing grain quality and value.

The 2016 infestation can be explained by the fact that hybrid NK74R lacks the Viptera trait package. The 2018 infestation of NK78S may be explained by seed sourced from local supply channels, not from Syngenta, i.e., its trait stack profile was unknown. Pioneer P1870 has no built-in insect resistance. Fall armyworm (FAW) and European corn borer (ECB) were not detected.

- **Plant Tissue Nutrients.** Nitrogen, phosphorus, calcium, magnesium, sulfur, manganese, zinc, and boron leaf tissue concentrations were, on average, borderline sufficient to deficient at growth stage V12, similar to observations in 2017. This suggests that nutrient uptake was unable to keep pace with plant demand during the linear growth phase irrespective of plant population. Leaf tissue nitrogen varied with population at V6, V12, R1, and R3, and with irrigation at V6, R1, and R6. Leaf phosphorus was deficient at V6 through R1. Magnesium levels were low or only marginally sufficient at V6 but sufficient at R1. Pre-plant (PP) application of zinc sulfate had little effect on leaf tissue concentration, whereas PP copper sulfate increased leaf tissue concentration from V6 through R6. Pre-plant boron treatment increased leaf tissue concentration from V6 and thereon but was indifferent to irrigation; non-PP treated plots were sufficient in leaf tissue boron at V6 but exhibited asymptomatic deficiency at V12 and R1 (Figure 1.3).

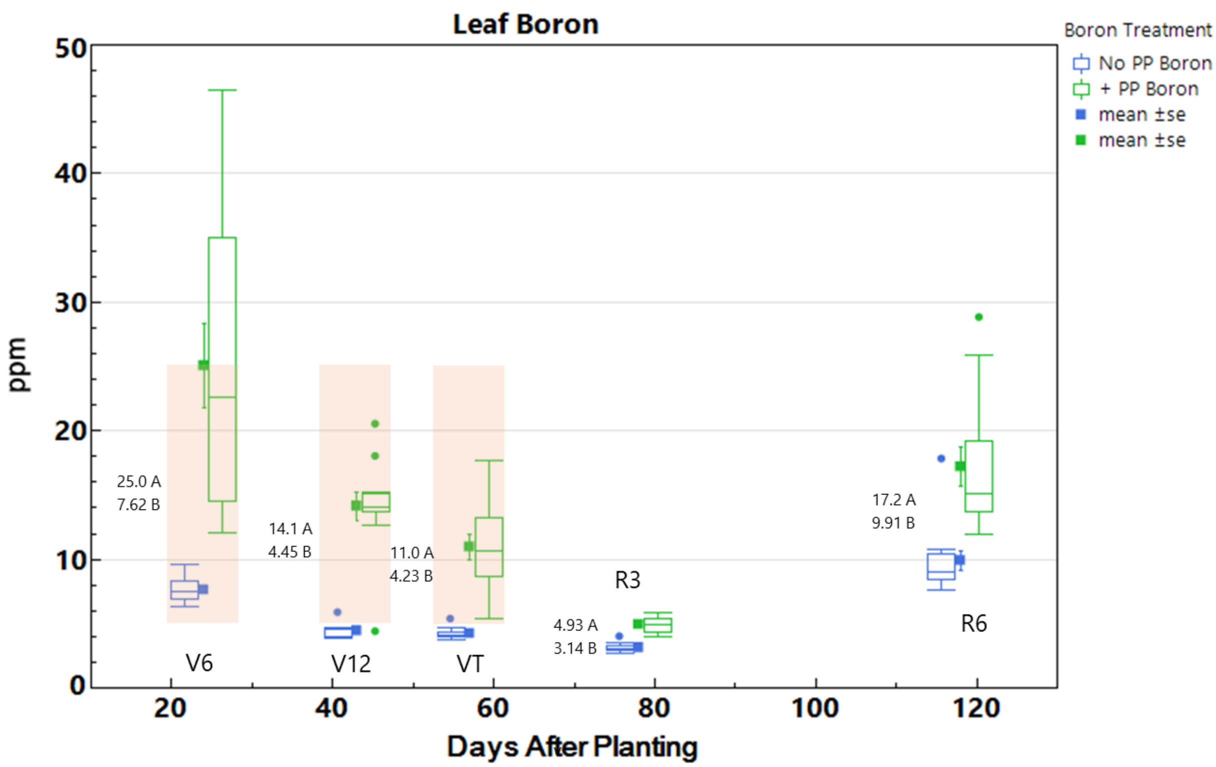

Figure 1.3 Box and whisker plot summary of leaf tissue boron concentration at each of five growth stages: V6, V12, VT, R3, and R6, conditioned on pre-plant (PP) boron treatment. Known sufficiency ranges per SCSB #394 are delineated by the rectangular shaded boxes at growth stages V6, V12, and VT. Boron, zinc, and manganese are the most limiting micronutrients in eastern North Carolina, and globally. Mean ± standard error (±se) is symbolized by solid blue and green squares. Mean value labels appear to the left of the box and whisker. Mean labels followed by the same letter are not different at the 5% probability level. ppm=parts per million.

Section 2. Experimental Approach

The research objectives for year 3 of this three-year project were to evaluate two irrigation regimes: (1) irrigation applied to meet crop evapotranspiration needs throughout the growing season (no deficit water stress); and (2) irrigation applied to meet evapotranspiration needs only during growth stages most sensitive to deficit soil water conditions. The most sensitive, or 'critical' growth stage for maize was defined as R1 ±10 days. The two irrigation treatments were planned to be compared to a baseline rainfed treatment i.e., natural precipitation without supplemental irrigation, replicating the same procedures from years 1 and 2. Irrigation was supplied by a programmable, variable-rate, linear move irrigation system. Irrigation frequency and timing across the experiment area were controlled bi-directionally by actuating overhead sprinkling nozzles "on" and "off" orthogonal, and parallel to, the direction of travel (Figure 2.1).

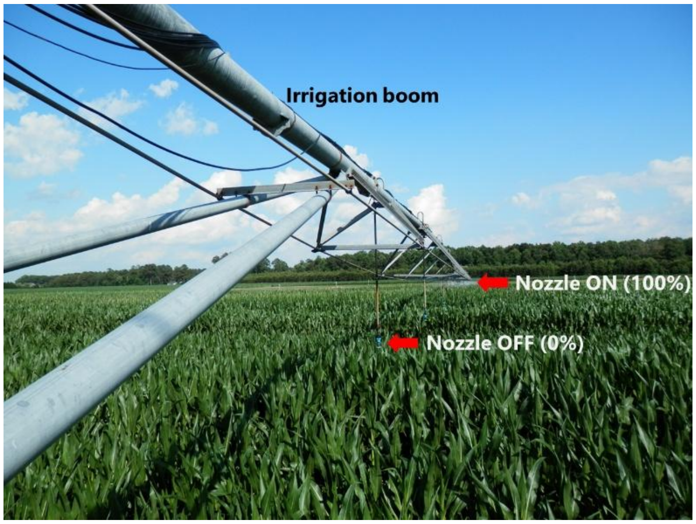

Figure 2.1 Irrigation boom operating with drop nozzles programmed ON/OFF.

In addition, "high" and "low" management treatments were implemented in 2018 to examine the effects of plant population, nutrient supply and placement, and their interactions with irrigation, on maize growth, plant tissue nutrient concentration, phenology, and yield components.

The implementation of the proposed irrigation and management strategies was carried out in field K section of AMPLIFY's research and demonstration site at the Cunningham Research Station in Kinston, N.C. (Figure 2.2). Soils on the site are mapped as Lynchburg sandy loam and Rains sandy loam association. Figure 1 shows the spatial arrangement of the 2018 field plots in K field.

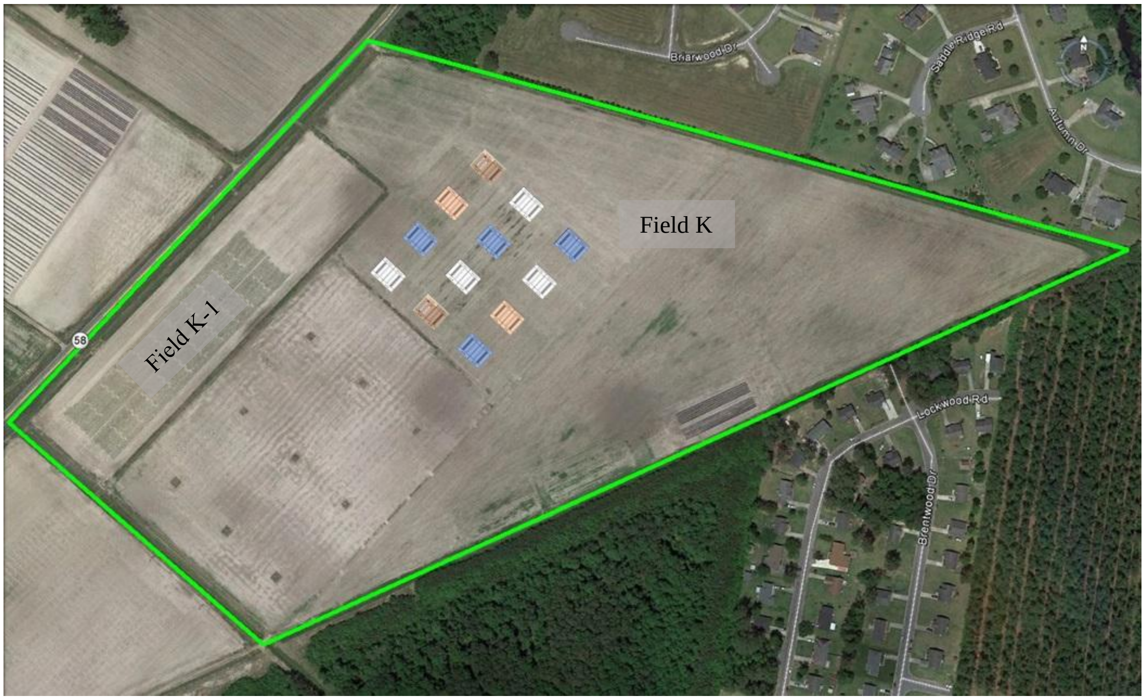

Figure 2.2 A map showing the distribution of irrigation plots in K section of the AMPLIFY research site at Cunningham Research Station, Kinston, N.C.

The maize hybrids were commercially available lines: Syngenta NK78S and NK74R, and Pioneer 1870 (P1870). Syngenta NK78S has the Agrisure Viptera 3111 trait package with resistance to glyphosate and glufosinate herbicides; NK74R the Agrisure 3000GT trait package, with similar herbicide resistance. Pioneer P1870 has no advanced insect or herbicide traits. Table 2 summarizes the treatment levels and design factors from 2016 to 2018.

Year	Treatment	Levels	Factor	Comments
2016	Irrigation	Full, Critical Stage, Rainfed	main	
	Hybrid	N74R, N78S	sub	30K planting density
	Days After Planting	variable	repeated	
2017	Irrigation	Full, Critical Stage, Rainfed	main	
	Planting Density	30K, 40K	sub	Hybrid N78S
	Days After Planting	variable	repeated	
2018	Irrigation	Full, Critical Stage, Rainfed	main	
	Management	“High”, “Low”	sub	Hybrids N78S @30K, P1870 @ 40K
	Days After Planting	variable	repeated	

Table 2. Experimental treatments, levels, and design factors implemented in the joint Syngenta-CGANC plots.

Management treatments were: (1) 30,000 plants/acre (30K) population density, i.e. the current N.C. recommendation, plus fertilization and fertilizer placement replicating that of 2016 and 2017; and, (2) 40,000 plants/acre (40K) population density, plus enhanced fertilization and fertilizer placement, described below. Herein, all reference to population, plant population, planting density, or its variants, denotes the two management systems above, and their respective fertilizer treatments.

Based on North Carolina Department of Agriculture and Consumer Services (NCDA&CS) soil tests supplemented with estimates of nutrient removal in a target grain yield of 300 bu/acre, 375 lb/acre of 16-0-24-9 S, and 120 lb/acre 18-46-0 (diammonium phosphate: DAP) were applied prior to planting. A pre-plant micronutrient tank mix with 2 lb/acre boron + 1 lb/acre copper (Cu^{+2}) + 0.6 lb/acre zinc (Zn^{+2}) was applied to each of twelve 40K sub-plots with a pressurized CO_2 backpack sprayer calibrated to deliver 40 gal/acre at 25 psi. Maize was seeded with a precision planter equipped with GPS auto-guidance to achieve a final population of 30,000 or 40,000 plants/acre (Figure 2.3).

Figure 2.3

Fertilizer 10-27-0 +2.6 S and 0.25 Zn were applied at planting in solution at a rate of 20 gal/acre placed 2 inches below and 2 inches to the side of the seed row. Manganese was applied in the seed furrow at 3 lb/acre in solution at a rate of 5 gal/acre. The herbicide regime consisted of Medal II ATZ broadcast at 2 qt/acre; and SteadfastQ, Banvel, and atrazine tank mixed, all broadcast across the soil surface and below the maize canopy ensuring the herbicide covered the soil surface but did not contact the leaves of the maize plants. Excellent weed control was achieved. On the same day, in 2018, two passes were made to post-direct the liquid N: in one pass, 100 lb/acre liquid N was streamed to one side of the row in the 30K plots; in the second pass, 100 lb/acre liquid N streamed to both sides of the row in the 40K plots such that twice the amount of liquid N was applied to the 40K plots. Hereafter, all reference to 40K or its variants, denote sub-plots that were planted to achieve a target population of 40,000 plants/acre, *plus* receiving additional pre-plant zinc, copper, and boron, and a split-stream side-dress nitrogen placement as described above.

Section 3. Meteorological and Irrigation Information

Weather data, including daily precipitation, air and soil temperatures, relative humidity, solar radiation, photosynthetically active radiation, evapotranspiration, and wind speed and direction, were available for the Cunningham Research Station through the North Carolina Climate Retrieval and Observations Network for the Southeast (CRONOS). Maximum daytime temperatures were generally near, or lower than normal from May through August while nighttime lows were higher than normal (Figure 3.1). Maximum daily temperatures during pollination and silking were near, or below normal while nighttime lows were above normal from May 15 through tasseling, and below normal to the end of the critical stage, and 10-12 days thereafter. Few extended rain-free periods occurred during the season (Figure 3.2).

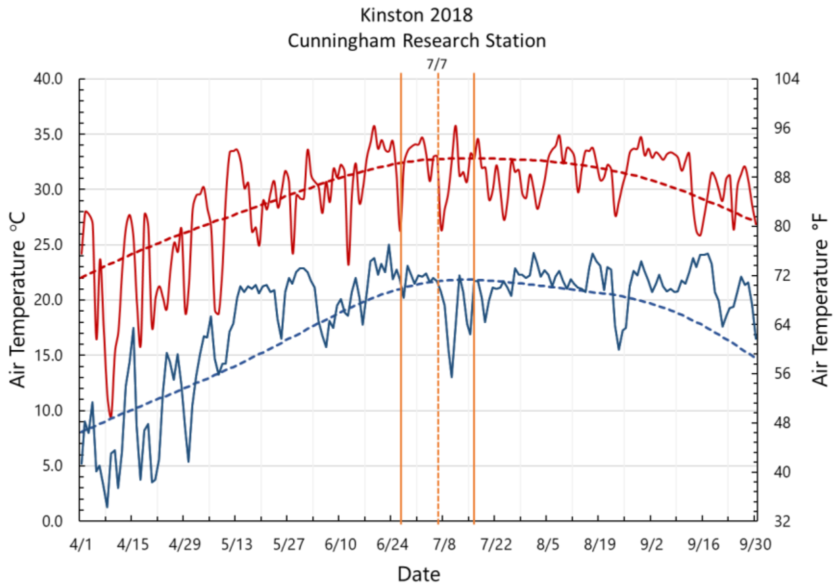

Figure 3.1 Temperature data for the Cunningham Research Station at Kinston, N.C. during the summer of 2018. Solid red and blue lines are daily maximum and minimum temperatures; dashed red and blue lines are 30-year normals for the site; vertical solid orange lines mark the critical stage period for corn irrigation; vertical orange dashed line marks the 50% silking date.

Irrigation was applied on 5 dates from June 21 through July 19 for the no deficit (full season) treatment, and irrigation on 3 dates from July 2 through July 16 for the deficit treatment (see Appendix A for dates and irrigation amounts).

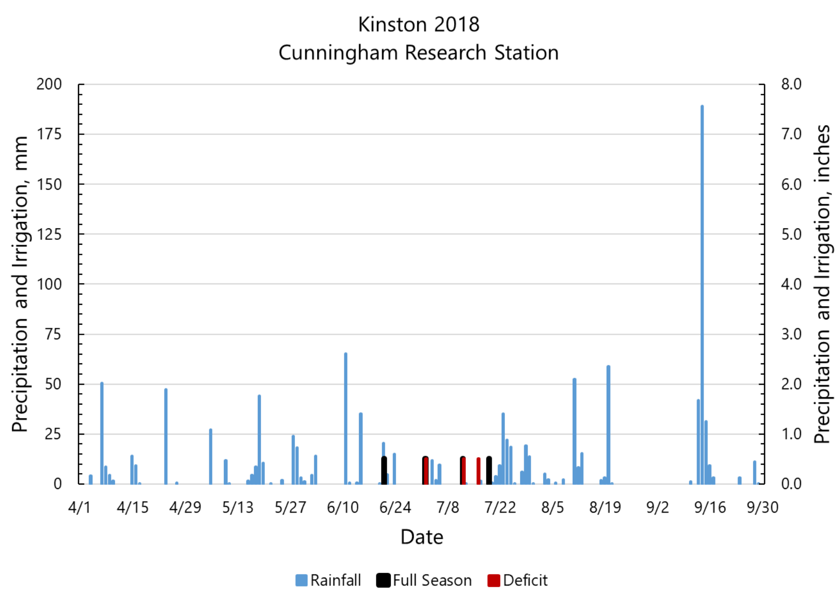

Figure 3.2 Daily rainfall and irrigation amounts for the Cunningham Research site at Kinston, N.C. during the summer of 2018.

Cumulative precipitation generally balanced with, or was above, evapotranspiration (ET) for the season (Figure 3.3). The period July 10 through July 23 was the only time cumulative ET exceeded precipitation. Overall, Cunningham experienced above-normal precipitation during the growing season. Nonetheless, crop stress was apparent during a drier period beginning just prior to VT through mid-July (Figure 3.4).

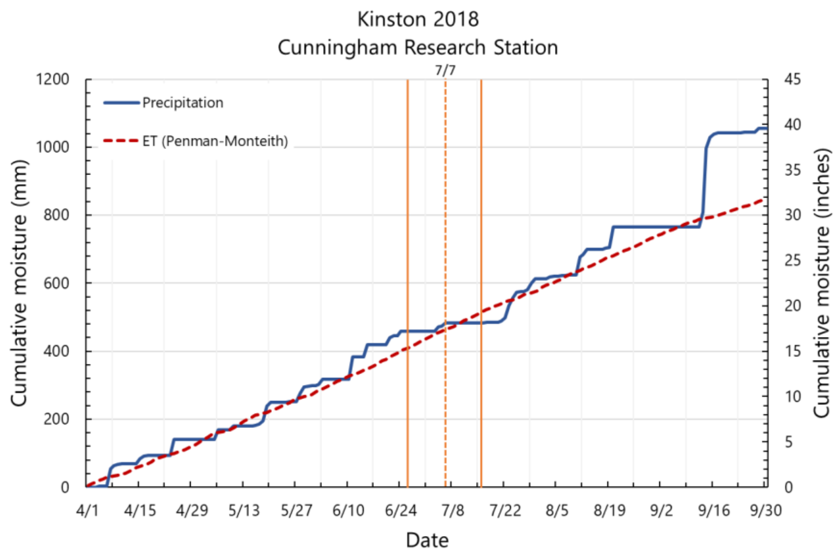

Figure 3.3 Cumulative precipitation and reference evapotranspiration (ET) for the Cunningham Research Station during the summer of 2018. Vertical solid orange lines mark the beginning and end of the critical stage for corn irrigation; orange dashed line marks the 50% silking date.

Figure 3.4 Rainfed plots 403 and 404 exhibiting stress. Even though Cunningham experienced above-normal precipitation through much of the growing season, a drier period beginning VT through mid-July was enough to trigger irrigation.

Appendix A.

Irrigation dates and amounts, 2018 season.		
Treatment	Date	Irrigation, inches
Deficit	July 2	0.5
	July 12	0.5
	July 16	0.5
	Total	**1.5**
Full Season	June 21	0.5
	July 2	0.5
	July 12	0.5
	July 16	0.5
	July 19	0.5
	Total	**2.5**

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