Evaluating the Impact of Superabsorbent Polymer on Processing Tomato Yield and Quality under Different Water Levels (Year 2 Report)

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Abstract

This second-year study evaluated the performance of a biodegradable, fruit-peel–derived superabsorbent polymer (SAP) under varying deficit irrigation regimes in processing tomato production at the UC Davis Research and Experiment Site. A randomized complete block design tested nine treatment combinations: three polymer rates (0, 75, and 150 kg/ha) and three irrigation levels (25%, 50%, and 100% of crop evapotranspiration). Plant growth, soil moisture, yield, and fruit quality were assessed using ground-based measurements, Leaf Area Index (LAI), neutron probe soil moisture, marketable yield, and PTAB laboratory analyses, and supplemented with bi-weekly remote sensing data (NDVI, water stress, CIR imagery) from CeresAI.

Yield outcomes from this second year of evaluation show that irrigation level remains the dominant factor controlling processing tomato productivity. Across treatments, yields were lowest under 25% ET, improved substantially at 50% ET, and did not increase further at 100% ET, suggesting that under the environmental and soil conditions of this site, 50% ET provided sufficient water to achieve maximum yield, while full irrigation may represent unnecessary over-application. Polymer applications did not consistently increase yield, but higher polymer rates tended to reduce within-treatment variability, indicating a stabilizing effect on plant performance under both moderate and severe deficit irrigation. Quality metrics revealed clearer and more consistent treatment effects. Deficit irrigation significantly increased Brix, with all 25% ET treatments producing the sweetest fruit. Within those deficit-irrigated groups, polymer-amended

plots (75 and 150 kg/ha) had higher Brix values compared to non-polymer controls, suggesting that polymers help sustain physiological function under water-limited conditions in ways that enhance soluble solids accumulation. Fruit pH showed limited variation among treatments, while color (a proxy for redness) was generally highest under 100% ET, indicating that full irrigation favors pigment development even when yield does not improve.

Taken together, these results show that polymer application provides modest but meaningful improvements in fruit quality, particularly under deficit irrigation, and contributes to more stable yield responses across irrigation levels. However, the irrigation regime continues to exert the strongest influence on overall productivity. The combined findings suggest that integrating biodegradable polymers with a 50% ET deficit irrigation strategy may offer an optimal balance between yield, quality, and water savings for processing tomato production at this site. Additional reasons are needed to confirm these findings.

Key Takeaways

1 **Irrigation level was the strongest driver of crop performance.**

- 50% ETc produced the highest yields, outperforming both 25% ETc and 100% ETc.
- Full irrigation (100% ETc) used nearly twice as much water as 50% ETc without increasing yield.

2 **Biodegradable SAP provided modest but meaningful benefits.**

- SAP improved soil moisture retention, especially in the upper 0–90 cm under severe deficit irrigation (25% ETc).
- Polymer-treated plots showed more stable yields (reduced variability) across irrigation levels.
- Under 25% ETc, SAP increased Brix, enhancing fruit sweetness.

3 **Tomato canopy growth was resilient to deficit irrigation early in the season.**

- LAI patterns showed similar canopy development under 50% ETc and 100% ETc through mid-season.
- Severe deficit irrigation (25% ETc) did not reduce canopy growth until later in the season when water stress intensified.

4 **4. Fruit quality responded differently to polymer and irrigation.**

- Brix increased sharply under 25% ETc, with SAP further enhancing soluble solids.
- Fruit color was highest under 100% ETc, indicating full irrigation favored pigment development.
- pH differences were small and remained within acceptable processing ranges.

5 **5. Remote sensing highlighted strong field-level variability, not treatment effects.**

- NDVI, water stress, and CIR imagery consistently showed a vigorous zone on the right side of the field, unrelated to treatments.
- This spatial trend was likely caused by shallower drip tape placement, improving irrigation efficiency locally.

6 **Overall Recommendation: 50% ETc offers the best balance of water savings, yield, and quality.**

- A moderate deficit irrigation strategy (50% ETc) maximizes yield, maintains quality, and significantly reduces water use.
- SAP can be considered an additional support tool, particularly under more severe water-limited conditions, but cannot offset the effects of extreme deficit irrigation.

1.0 Background

Global agriculture is increasingly challenged by intensifying drought, rising temperatures, and more variable precipitation patterns, all of which threaten crop production and long-term food security (IPCC, 2021; Lesk et al., 2016). Water scarcity is now one of the primary constraints on agricultural productivity, accelerating soil degradation and placing pressure on freshwater supplies. Although irrigation is essential for mitigating drought stress, heavy reliance on freshwater resources is unsustainable and can amplify water shortages, energy demand, and greenhouse gas emissions associated with pumping and conveyance (FAO, 2022; Grafton et al., 2018). As water availability declines, deficit irrigation strategies are becoming increasingly necessary yet their success depends heavily on the soil's ability to store and supply water to crops during dry periods.

To support crop performance under reduced irrigation, soil amendments that enhance water retention have gained attention. Traditional amendments such as compost and organic matter improve soil structure and infiltration, but their capacity to buffer crops through prolonged or severe drought is limited. Superabsorbent polymers (SAPs) represent a promising alternative because they can absorb large quantities of water, retain it in the root zone, and release it gradually as the soil dries. By stabilizing soil moisture, SAPs may reduce plant stress, improve nutrient retention, and enhance overall water-use efficiency (Yang et al., 2014; Watanabe et al., 2018). However, synthetic SAPs are hindered by slow degradation rates and concerns about microplastic accumulation, prompting increased interest in biodegradable, plant-derived alternatives.

Biodegradable SAPs, such as the fruit-peel–based polymer evaluated in this study, provide water-holding capabilities comparable to synthetic SAPs while reducing environmental risks

(Lertsarawut et al., 2021; Ribeiro et al., 2024). Despite their promise, field-scale evaluations of biodegradable SAPs under realistic irrigation regimes remain limited, particularly for high-value vegetable crops. Processing tomatoes, one of California's most economically important irrigated crops, is highly sensitive to water availability and therefore serves as an ideal system for assessing whether biodegradable polymers can help maintain productivity and fruit quality under deficit irrigation.

This study evaluated the potential of a fruit-peel–derived biodegradable SAP (EF Polymer) to enhance soil moisture availability, support plant growth, and improve processing tomato performance under 25%, 50%, and 100% ET irrigation regimes. By integrating soil moisture monitoring, plant growth measurements, yield assessments, and fruit quality analysis, the study aims to quantify the polymer's effectiveness and determine whether it can help growers reduce water use without sacrificing crop performance.

2.0 Materials and Methods

2.1 Site Description

The experiment was conducted during the 2025 growing season at the UC Davis Research Farm near Davis, CA, on a 1.25-acre field equipped with subsurface drip irrigation. The soil at the site is classified primarily as Yolo silt loam, a well-drained alluvial soil common in the Sacramento Valley and widely used for processing tomato production. Drip lines were installed approximately 20–25 cm below the soil surface with emitters spaced 0.3 m apart.

The climate is Mediterranean, characterized by cool, wet winters and hot, dry summers. Average annual rainfall at the site is approximately 430–460 mm (17–18 inches), with the majority occurring between November and March. Little to no effective rainfall occurs during the tomato growing season, making irrigation essential. The site is representative of commercial tomato production systems throughout the Sacramento Valley.

2.2 Experimental Design

A randomized complete block design (RCBD) was used to evaluate the interactive effects of polymer application rate and irrigation regime on processing tomato performance. Three polymer rates (0, 75, and 150 kg/ha) were crossed with three irrigation levels (25%, 50%, and 100% of crop evapotranspiration, ETc), resulting in nine treatment combinations (Table 1). Each treatment row (≈136 m^2) was replicated across four blocks to account for field heterogeneity, and treatments were randomized within each block.

Table 1. Treatment descriptions.

Treatment #	Polymer Level	Polymer Rate	Irrigation Regime	Treatment Label
1	Low	75 lbs/acre	100%	P75-ET100
2	Low	75 lbs/acre	50%	P75-ET50
3	None	0 lbs/acre	25%	P0-ET25
4	High	150 lbs/acre	100%	P150-ET100
5	Low	75 lbs/acre	25%	P75-ET25
6	High	150 lbs/acre	50%	P150-ET50
7	High	150 lbs/acre	25%	P150-ET25
8	None	0 lbs/acre	50%	P0-ET50
9	None	0 lbs/acre	100%	P0-ET100

2.3 Polymer Application

The biodegradable superabsorbent polymer (SAP) was applied using a tractor-mounted applicator equipped with two hopper boxes, into which the polymer pellets were manually loaded prior to field operations (Figure 1). A single delivery shank positioned at the center of each 5-ft bed was used to place the polymer approximately 10 cm above the subsurface drip tape, ensuring close proximity to the primary wetting zone. The system delivered the SAP at target rates of 0, 75, and 150 kg/ha, with application rates calibrated prior to field installation by adjusting tractor speed and measuring the mass of polymer dispensed over a known distance. This setup allowed for precise, uniform placement of the biodegradable SAP within the crop root zone across all treatment beds.o

Figure. 1. Tractor-mounted applicator used to apply biodegradable superabsorbent polymer (SAP). Polymer pellets were loaded into the two hopper boxes and delivered through a single center shank that placed the material approximately 10 cm above the subsurface drip tape within 5-ft beds.

2.4 Planting and Irrigation

Polymer was applied on April 24, 2025, at the designated rates (0, 75, or 150 lb/acre), immediately followed by transplanting of processing tomato seedlings on 5-ft (1.52 m) wide beds, consistent with regional commercial production practices. Irrigation began the same day, with all plots initially irrigated at 100% ETc to support early crop establishment.

Separate irrigation manifolds were installed on May 5, 2025, to supply independent flow to each of the three irrigation regimes. The subsurface drip system delivered water at a flow rate of approximately 0.45–0.60 gph (1.7–2.3 L/hr) per emitter, typical for processing tomato production in the Sacramento Valley. Deficit irrigation treatments (50% and 25% ETc) commenced on May 14, approximately three weeks after transplanting. Flowmeters were installed on June 6 to quantify cumulative water application for each irrigation line.

Throughout the growing season, subsurface drip irrigation was applied six days per week (Monday–Saturday), typically between 08:00 and 18:00. Differences among irrigation treatments were imposed by varying irrigation duration while maintaining a constant emitter flow rate across all treatments.

2.5 Sensor Installation/Monitoring

Three Agurotech soil moisture sensor units were installed, one within each irrigation regime, to provide continuous monitoring of soil and environmental conditions.

To obtain detailed soil moisture profiles throughout the rooting zone, neutron probe access tubes were installed in the first three replications of each treatment. Installation involved manually augering holes to a depth of 6 ft using a hand-operated soil auger, after which aluminum access tubes were inserted vertically to ensure direct contact with the surrounding soil. Tubes were installed to allow measurement depths ranging from 1 ft to 6 ft, effectively capturing moisture dynamics across the active root zone of processing tomatoes.

Soil moisture measurements were collected using a CPN 503 Hydroprobe® neutron probe, which detects hydrogen content as a proxy for volumetric water content. Neutron count ratios were converted to volumetric water content using a site-specific calibration equation developed for the soil conditions at the UC Davis field site.

2.6 Fertilization and Pest Management

Fertilization practices followed standard recommendations for processing tomato production in California. At transplanting on April 24, 2025, 25 lb/acre of 8-24-6 starter fertilizer was applied to support early root establishment. Supplemental nitrogen was delivered via fertigation on May 23, June 5, June 22, and July 10, supplying 28, 37, 50, and 40 lb N/acre, respectively, through UAN-32. Over the course of the season, a total of 180 lb N/acre was applied.

Weed, insect, and disease management were performed according to University of California Integrated Pest Management (UC IPM) guidelines and typical commercial production practices for processing tomatoes.

2.7 Agronomic and Remote Sensing Data Collection

Leaf Area Index (LAI) measurements were collected approximately every two weeks using an LP-80 ceptometer positioned between crop rows to quantify canopy light interception throughout the season. Processing tomatoes were mechanically harvested on September 9 using a commercial Johnson tomato harvester (Figure 2), which cuts the vines, elevates the plants onto a conveyor system, separates fruit from foliage, and transfers marketable tomatoes into a trailing bulk collection trailer pulled by a tractor. The total weight of marketable fruit from each treatment row was recorded at harvest. A representative subsample from each plot was delivered to the Processing Tomato Advisory Board (PTAB) laboratory for standardized assessment of fruit quality, including pH, color, and Brix (soluble solids content).

In addition to ground-based measurements, remote sensing data were collected bi-weekly using a fixed-wing aircraft operated by CeresAI equipped with thermal and multispectral sensors. These data provided field-scale NDVI, crop water stress indices, and color infrared (CIR) imagery, which were used to document spatial patterns in canopy vigor and crop stress across treatments over the growing season.

Figure. 2. Commercial mechanical harvest of processing tomatoes using a Johnson tomato harvester. The machine cuts the vines and conveys fruit onto an onboard sorting and cleaning system before transferring marketable tomatoes into a tractor-pulled collection trailer.

2.8 Statistical Analysis

The effects of SAP polymer application rate and irrigation regime on yield were analyzed independently for each response variable. Group normality was evaluated using the Shapiro–Wilk test, and homogeneity of variance was assessed using Levene's test. Based on the outcomes of these assumption checks and the number of groups with valid observations, comparisons were conducted using one of the following approaches: (1) one-way ANOVA with Tukey's HSD post-hoc tests for three or more normally distributed groups with equal variances, or (2) Welch's or Student's t-tests for two-group comparisons with equal or unequal variances. All statistical analyses were performed in Python using standard scientific and statistical libraries.

3.0 Results and Discussion – Year 2

Applied irrigation water

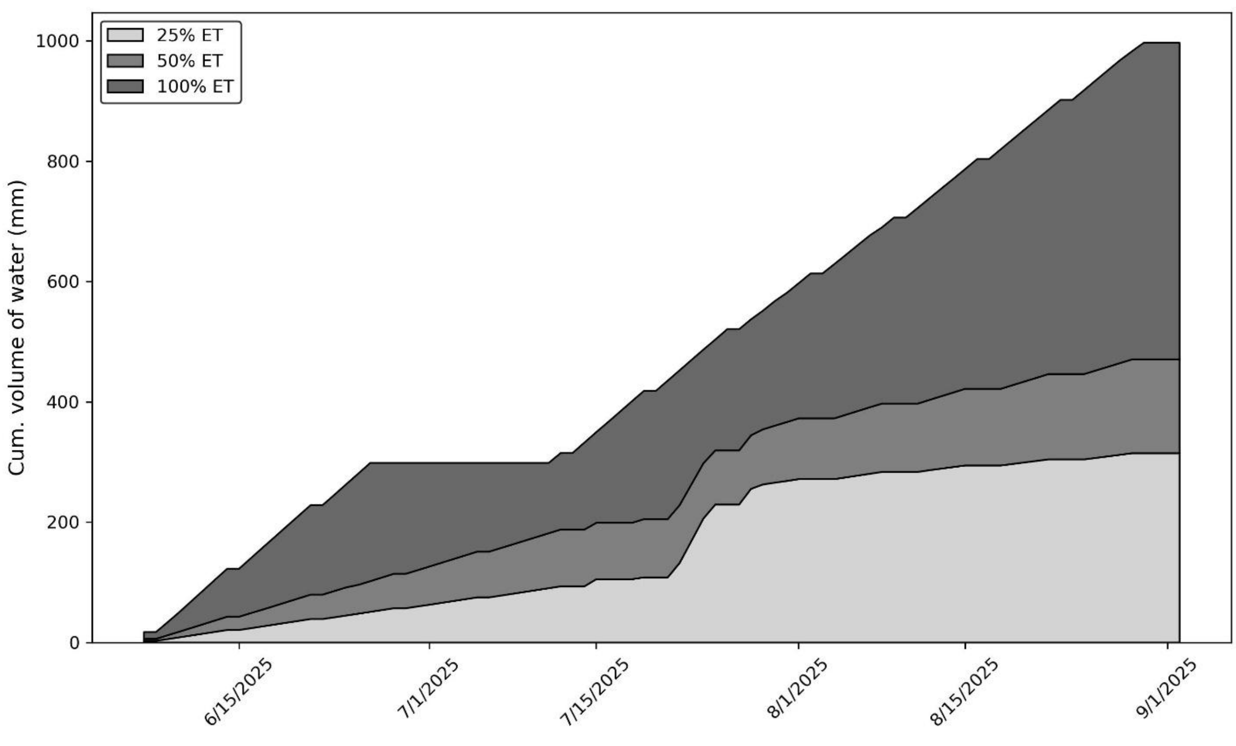

Figure 3: Cumulative irrigation applied under the 25%, 50%, and 100% ETc irrigation regimes

during the 2025 growing season. Total water applied reached 315 mm, 471 mm, and 997 mm for the 25%, 50%, and 100% ETc treatments, respectively.

The cumulative irrigation at 100% ETc (darkest shaded area) consistently exceeded the amounts applied in the 50% and 25% ETc regimes (lighter shaded areas) throughout the season (Figure 1). Differences among treatments were achieved by varying irrigation duration, not application rate: the 100% ETc treatment typically received irrigation for approximately 8 hours per day, while the 50% and 25% ETc treatments received proportionally shorter durations of about 4 hours and 2 hours per day, respectively. By the end of the season, total irrigation applied was 997 mm, 471 mm, and 315 mm for the 100%, 50%, and 25% ETc treatments, respectively. This corresponds to the 50% ETc treatment receiving 47.2% of the full irrigation amount, and the 25% ETc treatment receiving 31.6% of the water applied under 100% ETc.

Leaf Area Index

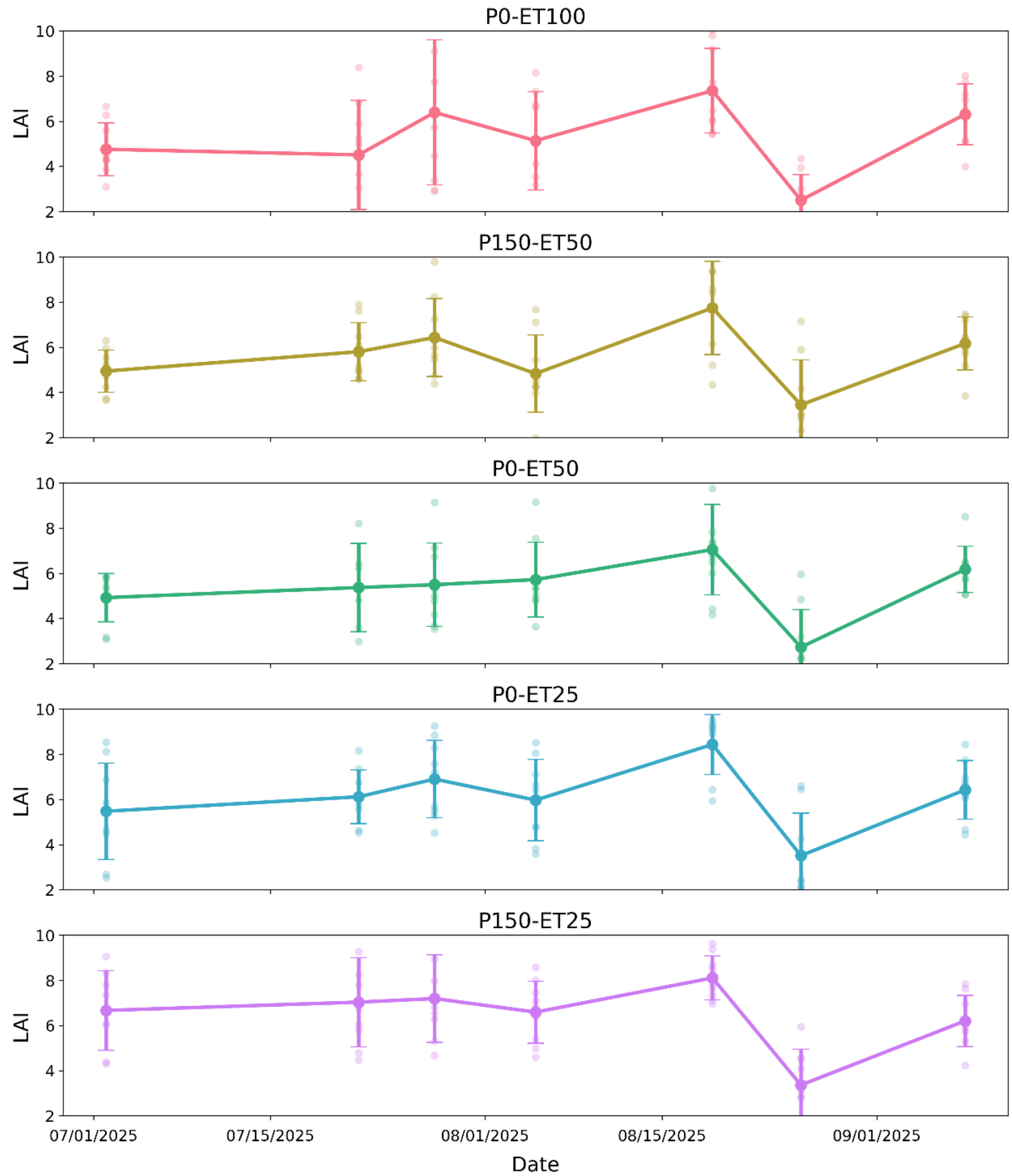

Figure 4: Leaf Area Index (LAI) dynamics for selected combinations of polymer rate (P0 or P150 kg/ha) and irrigation level (25%, 50%, or 100% ETc) during the 2025 growing season. Each subplot displays mean LAI (solid line) with standard deviation error bars and individual plant-level measurements (faint points). Mean LAI for each sampling date is shown with solid

lines and standard deviation error bars, while transparent points represent individual plant measurements.

Leaf Area Index (LAI) followed a similar seasonal trajectory across all treatments, increasing steadily from early July, reaching peak values from late July through mid-August, and then declining as harvest approached (Figure 2). During the early- and mid-season sampling dates, LAI under deficit irrigation (50% and 25% ETc) remained comparable to that observed under full irrigation, indicating that canopy growth was largely maintained despite reduced water inputs. Treatments receiving 150 kg/ha of SAP polymer frequently matched or slightly exceeded the LAI of non-polymer plots, suggesting a modest benefit to canopy development, particularly under the 25% ETc regime. Overall, these results indicate that tomato canopy growth was relatively resilient to both moderate and severe deficit irrigation early in the season. However, the apparent advantages of polymer application diminished later in the season, when intensifying water stress led to more pronounced reductions in LAI.

Remote Sensing Data

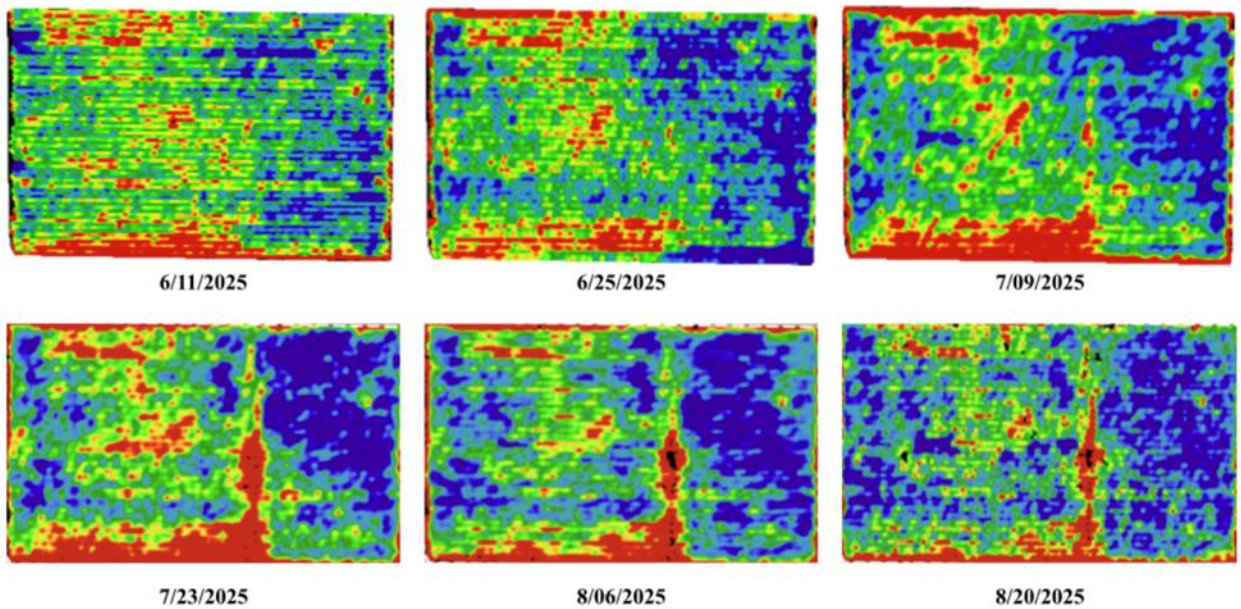

Figure 5. Spatial distribution of crop water stress across the field from CeresAI thermal imagery on six dates during the 2025 season. Red areas indicate higher water stress, while blue areas indicate lower stress.

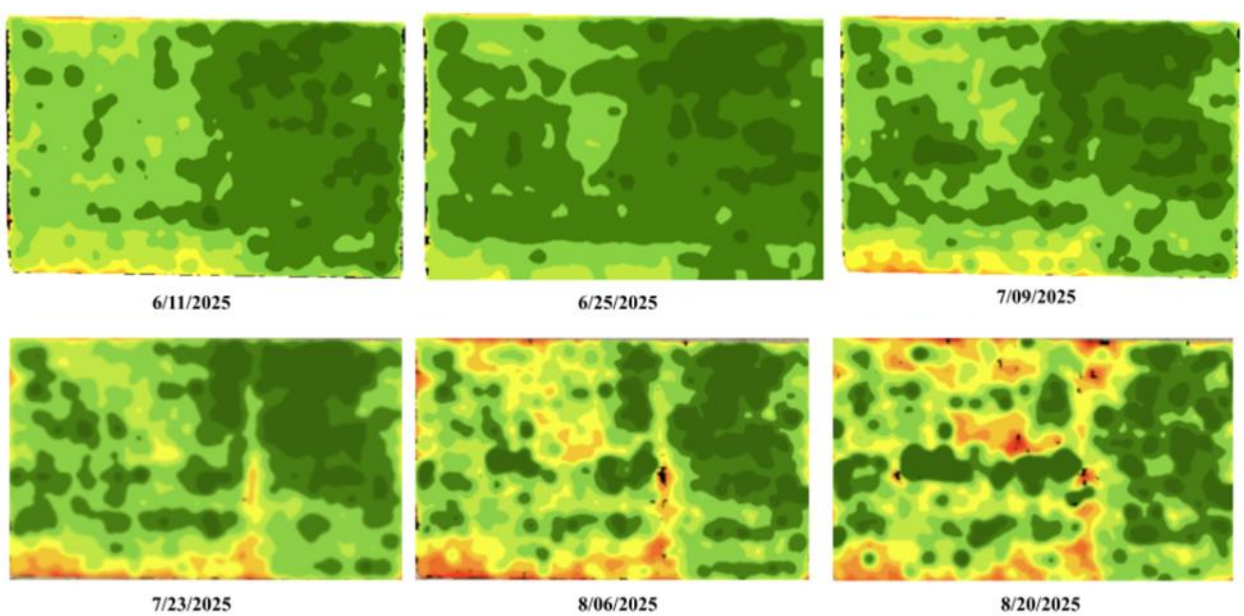

Figure 6. Bi-weekly Normalized Difference Vegetation Index (NDVI) maps from CeresAI during the 2025 growing season. Higher canopy vigor is shown in green, and lower vigor in red.

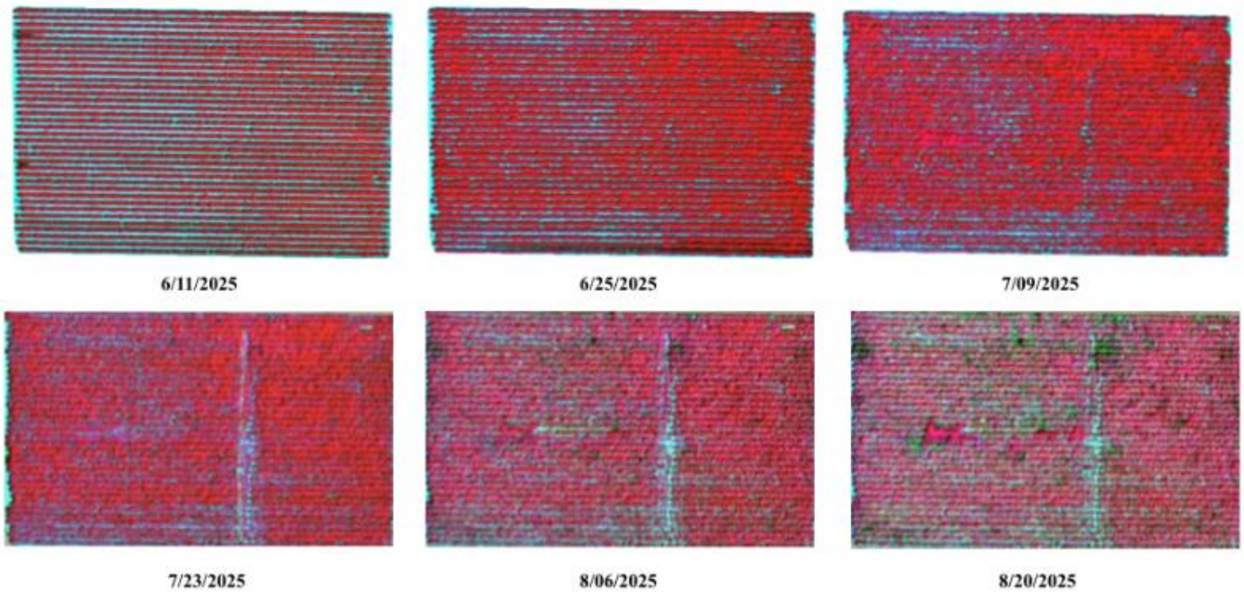

Figure 7. Bi-weekly Color Infrared (CIR) imagery from CeresAI during the 2025 growing season. Healthy vegetation appears in bright red tones, while areas with reduced vigor or increased stress appear in darker, duller red hues.

Across all dates, the water stress (Fig. 5), NDVI (Fig. 6), and color-infrared (CIR) (Fig. 7) imagery revealed strong spatial variability in canopy vigor across the field rather than clear differences among individual treatment rows. The imagery consistently showed a band of higher vigor characterized by higher NDVI values (dark green), lower thermal-based water stress (blue), and stronger CIR reflectance (bright red) on the right side of the field. In contrast, the left and central areas displayed more mixed or weaker signatures, including lower NDVI, higher water stress, and duller CIR tones, particularly as the season progressed. These patterns indicate that field-level heterogeneity, rather than treatment effects, dominated the remote sensing signal. The consistent spatial gradient suggests an underlying structural cause, most likely the subsurface drip tape being closer to the soil surface or functioning more effectively on the right side of the field—resulting in more efficient wetting of the root zone and consequently higher canopy vigor, independent of irrigation level or polymer application.

Soil Moisture

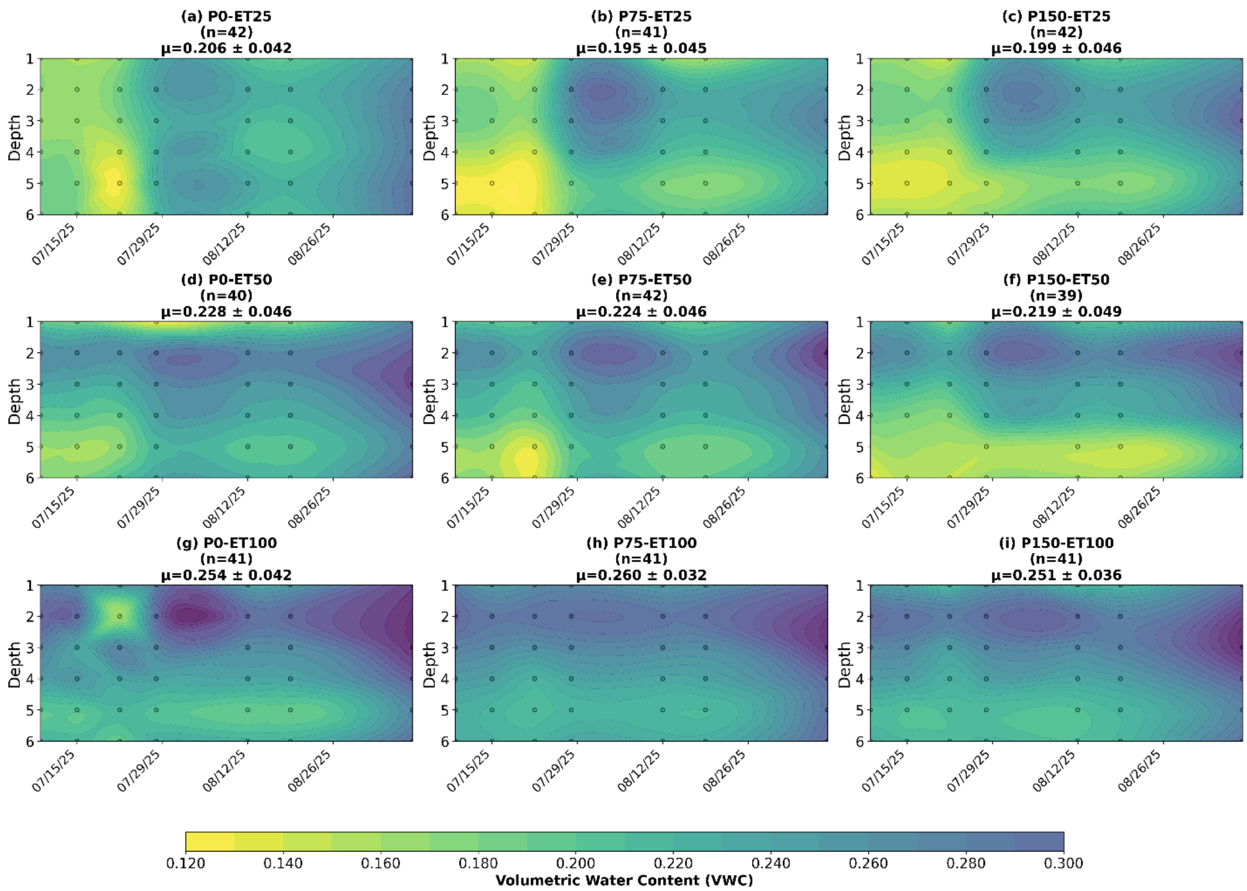

Figure 8: Volumetric Water Content (VWC) profiles showing soil moisture dynamics at different depths from July 2025 to September 2025 for each treatment. **(a)** P0-ET25, **(b)** P75-ET25, **(c)** P150-ET25, **(d)** P0-ET50, **(e)** P75-ET50, **(f)** P150-ET50, **(g)** P0-ET100, **(h)** P75-ET100, and **(i)** P150-ET100. The mean VWC (μ) and standard deviation (σ) derived from neutron probe measurements were converted to volumetric water content using the calibration equation VWC = MC × 2.76×10^{-5} - 0.0919.

Treatments receiving higher irrigation levels (ET100) consistently maintained greater volumetric water content throughout the 1–6 ft soil profile, with the more uniform moisture observed in the P75–ET100 and P150–ET100 treatments (h, i). In contrast, the treatments with deficit irrigation

(ET25) produced visibly lower soil moisture across the monitored soil profile (a-c). However, the treatments with polymer applications under 25%ET displayed higher soil water content within the upper 3 ft of soil (b, c). <u>These patterns indicate that polymers can potentially help enhance soil moisture retention under water-limited conditions</u>.

Yield

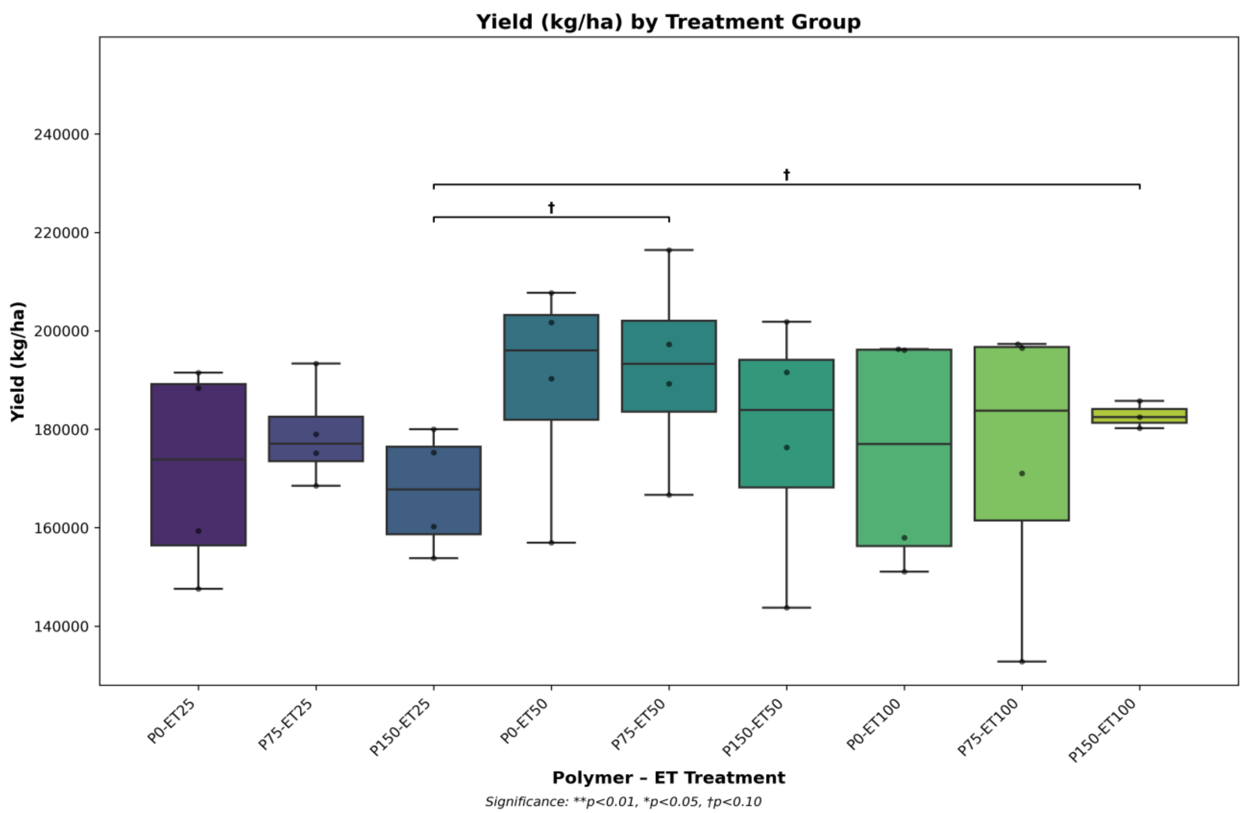

Figure 9: Processing tomato yield (kg/ha) for each polymer–irrigation (ET) treatment combination after IQR-based outlier filtering. Treatments are ordered by irrigation level (ET25, ET75, ET100) and polymer rate (P0, P75, P150). Boxplots display the median and interquartile range, with individual observations shown as black points. Significance symbols displayed above treatment groups were generated using pairwise Welch's t-tests applied to all treatment

combinations. For each pair, comparisons with $p < 0.10$ were annotated on the figure using the following thresholds: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, and +$p < 0.10$.*

Yield responses showed a clear dependence on irrigation level, with the highest yields consistently occurring under the 50% ETc treatments. Across polymer rates, the 50% ETc treatments produced yields in the range of approximately 185,000–205,000 kg/ha, outperforming both the 25% ETc and 100% ETc treatments. In contrast, the 25% ETc treatments yielded the lowest productivity (roughly 160,000–185,000 kg/ha), reflecting the impact of severe deficit irrigation on fruit production. Yields under 100% ETc were generally comparable to or slightly lower than those under 50% ETc, suggesting that full irrigation did not confer an advantage and may have resulted in unnecessary water application. Polymer effects were modest: while no consistent yield increase was observed with higher polymer rates, polymer-amended treatments tended to exhibit reduced yield variability, indicating a stabilizing effect under both deficit and full irrigation. Statistical comparisons (Fig. 9) further showed only marginal differences among polymer treatments within the same irrigation regime, reinforcing that irrigation level, not polymer rate, was the primary driver of yield outcomes in this study.

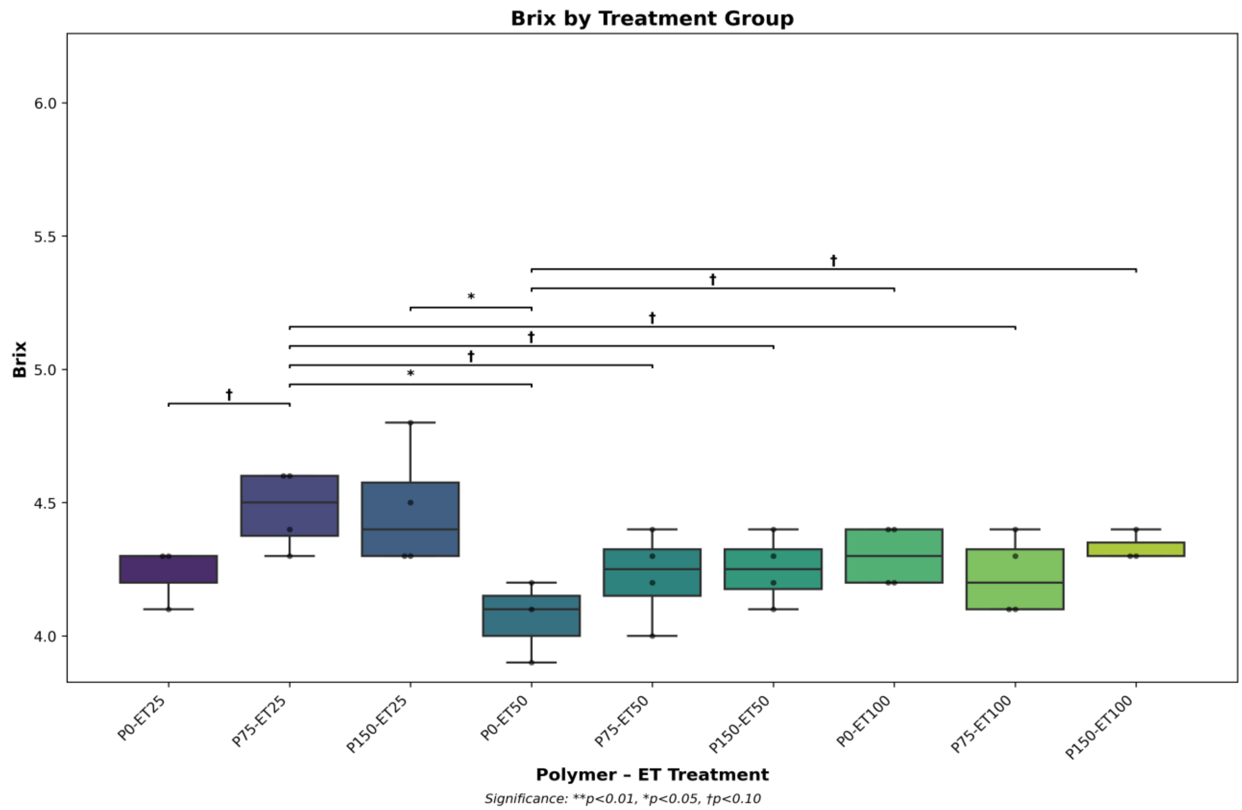

Figure 10. Processing tomato Brix values for each polymer–irrigation (ET) treatment combinations after IQR-based outlier filtering. Horizontal brackets denote statistically significant differences among groups at significance levels of $p < 0.01$, $p < 0.05$, and $+p < 0.10$.

Brix values showed a strong and consistent response to irrigation level, with the highest soluble solids concentrations occurring under the 25% ETc deficit irrigation treatments. Across polymer rates, the 25% ETc treatments produced Brix values ranging from approximately 4.3 to 4.9, significantly higher than both the 50% and 100% ETc treatments. The 50% ETc treatments showed intermediate Brix values (roughly 4.0–4.4), while the 100% ETc treatments consistently produced the lowest Brix values (around 4.2–4.35), indicating that increased irrigation diluted fruit sugars—a well-documented effect in processing tomatoes. Polymer application further enhanced Brix within deficit irrigation regimes: both the 75 and 150 kg/ha polymer treatments under 25% ETc showed significantly higher Brix than the non-polymer control, suggesting that SAP may help maintain physiological function and concentrate soluble solids when water is limited. Statistical comparisons (Fig. 10) support these trends, with several significant differences detected between polymer-treated and untreated plots within the low irrigation treatments. Overall, these results demonstrate that deficit irrigation strongly improves fruit sweetness and that SAP application can amplify this benefit under the most water-limited conditions.

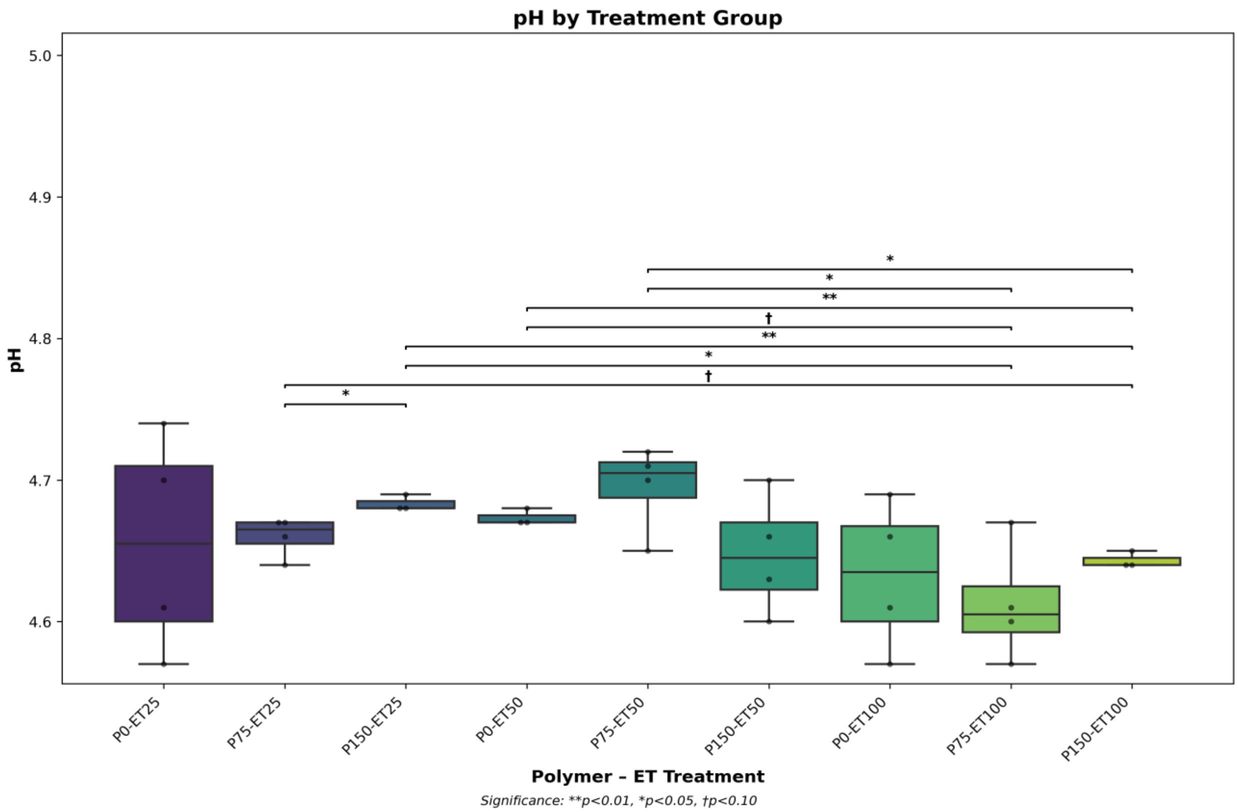

Figure 11. Processing tomato pH values for each polymer–irrigation (ET) treatment combinations after IQR-based outlier filtering. Horizontal brackets denote statistically significant differences among groups at significance levels of $p < 0.01$, $p < 0.05$, and $+p < 0.10$.

Fruit pH showed relatively small but statistically detectable differences among irrigation and polymer treatments. Overall, pH values ranged from approximately 4.60 to 4.72, a narrow interval typical of processing tomatoes. The 25% ETc treatments tended to have slightly lower pH—indicating marginally higher acidity—relative to the 50% and 100% ETc treatments. Meanwhile, the 50% ETc treatments, particularly those receiving polymer, showed the highest pH values (around 4.70–4.72). Differences among polymer rates were subtle; however, several significant pairwise comparisons (Fig. 11) showed that polymer-amended treatments, especially at 50% ETc, produced marginally higher pH than their non-polymer counterparts. Despite these statistical differences, the overall variation in pH across treatments was small and remained well within the acceptable industry range, indicating that neither deficit irrigation nor SAP application had a major practical impact on fruit acidity

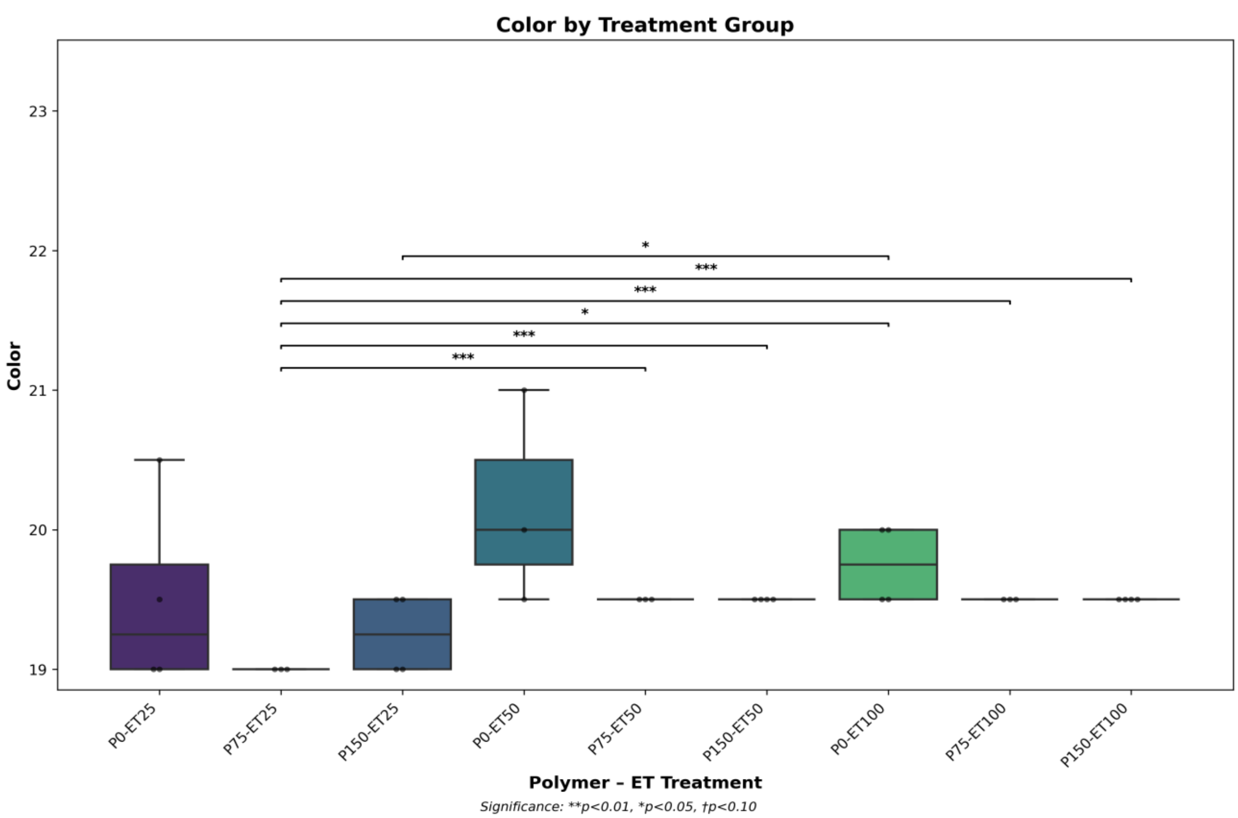

Figure 12. Processing tomato color analysis result for each polymer–irrigation (ET) treatment combinations after IQR-based outlier filtering. Horizontal brackets denote statistically significant differences among groups at significance levels of $p < 0.01$, $p < 0.05$, and $+p < 0.10$.

Fruit color, an important quality attribute for processing tomatoes, showed clearer treatment differences than pH but a more complex pattern than Brix. Overall, higher irrigation levels were associated with improved color, with the 100% ETc treatments producing the highest color values (≈20.0–20.2). The 50% ETc treatments also produced relatively strong color (≈19.5–21.0), whereas the 25% ETc treatments showed the lowest color scores (≈19.0–19.8), indicating that severe deficit irrigation reduced pigment intensity. Polymer effects on fruit color were minimal and inconsistent: while polymer-amended plots under 50% ETc tended to produce slightly higher color values than the non-polymer control, no clear pattern emerged across irrigation levels, and differences among polymer rates were minor relative to irrigation effects. Several statistically significant pairwise differences (Fig. 12) confirm that irrigation level—not polymer rate—was the dominant factor shaping fruit color, with full irrigation providing the most favorable conditions for pigment development. Despite these differences, color values for all treatments remained within the acceptable commercial range for processing tomatoes..

4.0 Conclusion

This second-year evaluation of biodegradable superabsorbent polymer (SAP) under multiple deficit irrigation regimes provides new insights into the potential of polymer–irrigation strategies to enhance processing tomato production under water-limited conditions. Across all measurements, irrigation level was the strongest determinant of plant performance, with 50% ETc delivering the most favorable balance of productivity and quality. Despite receiving only half of the full irrigation amount, the 50% ETc treatments consistently produced the highest yields, indicating that full irrigation (100% ETc) offered no agronomic advantage and resulted in substantial additional water use.

Canopy growth patterns, as measured by LAI and supported by remote sensing, showed that tomato plants were surprisingly resilient to moderate deficit irrigation, maintaining comparable canopy development under 50% and even 25% ETc early in the season. Soil moisture profiles confirmed that SAP application improved water retention—particularly within the upper 0–90 cm of soil—under severe deficit irrigation, although this effect diminished as seasonal water stress intensified.

Remote sensing imagery (NDVI, water stress, and CIR) revealed strong field-level spatial gradients that were unrelated to treatment assignments, likely driven by variability in subsurface drip tape placement depth. These patterns highlight the importance of accounting for field heterogeneity when interpreting canopy or stress responses.

Yield responses demonstrated that SAP had modest direct impact on total fruit production, though polymer-treated plots often showed reduced yield variability, suggesting a stabilizing effect under fluctuating moisture conditions. In contrast, fruit quality traits were more sensitive to both irrigation and polymer treatments. Brix increased sharply under 25% ETc, and SAP application further enhanced soluble solids under the most water-limited conditions. Fruit pH showed only minor variation across treatments, while color scores were highest under full irrigation, reflecting more favorable conditions for pigment development when water availability was non-limiting.

Together, these results demonstrate that deficit irrigation at 50% ETc is a viable and water-efficient strategy for processing tomato production in the Sacramento Valley. Biodegradable SAP polymers provide subtle but meaningful benefits most notably in improving soil moisture retention, reducing yield variability, and enhancing fruit sweetness under severe deficit conditions yet irrigation regime remains the dominant driver of crop performance. Continued multi-year monitoring will be essential to further understand polymer behavior in different soil and climate contexts, optimize placement and rate recommendations, and refine combined irrigation–polymer strategies that maximize yield, fruit quality, and water-use efficiency under increasing agricultural water scarcity.

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