**Assessment of Super Absorbent Polymer in Soybean Cultivation under Variable Irrigation Conditions in Nebraska**

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**Abstract**
Water limitation is a primary constraint to soybean productivity in both irrigated and rainfed systems. Soil-applied superabsorbent polymers (SAPs) have been proposed as a strategy to buffer crops against episodic drought stress; however, their physiological and agronomic performance under varying irrigation regimes remains insufficiently quantified. Here, we evaluate three biodegradable polymer formulations: broader granules (BB), original granules (OG), and powder (PWR) applied at low (17.7 lb/ac) and high (120 lb/ac) rates under full (100% ET), reduced (50% ET), and no irrigation conditions in western Nebraska. Polymer application had negligible effects under full irrigation, with yields comparable to untreated controls. Under reduced irrigation, high-rate applications substantially improved yield, with OG 120 and BB 120 increasing yields by up to 21 bu/ac relative to control. Under rainfed conditions, yield divergence was most pronounced: BB 120 (55.1 bu/ac) and OG 17.7 (52.4 bu/ac), representing more than a twofold increase of yields relative to untreated plots. Soil moisture measurements confirmed modest but consistent increases in volumetric water content across polymer treatments, particularly in surface and mid-root zones. These gains were accompanied by substantial improvements in water use efficiency. Water productivity increased from 0.042 to 0.094 bu/ac/mm under rainfed conditions and by 40-50% under reduced irrigation. Similarly, irrigation efficiency more than doubled under deficit irrigation, exceeding 0.30 bu/ac/mm in high-rate polymer treatments compared to 0.146 bu/ac/mm in the control. These results demonstrate that superabsorbent polymers function primarily as drought-buffering agents rather than yield-enhancing inputs under optimal conditions. The magnitude of benefit increases with water limitation, suggesting that SAPs may offer a viable strategy for stabilizing soybean production in water-constrained agroecosystems.

**Introduction and overview**

Water limitation is a primary constraint to soybean productivity in both irrigated and rainfed systems. Soil-applied superabsorbent polymers (SAPs) have been proposed as a strategy to buffer crops against drought stress; however, their physiological and agronomic performance under varying irrigation regimes remains insufficiently quantified.

Here, we assess the performance of three different formulations of a biodegradable SAP. The SAPs evaluated in this study were commercially available formulations provided by EF Polymer Pvt. Ltd. including Broader Granules (BB), Powder (PWR), and Original Granules (OG), applied at varying rates in soybean production systems. Experimental trials were conducted at the University of Nebraska research farm under both full and deficit irrigation regimes. Data collected included soil moisture across multiple depths, canopy health indicators via NDVI (Normalized Difference Vegetation Index) and NDRE (Normalized Difference Red Edge), and soybean growth parameters (pod numbers) and yields.

Through this study, we aim to:

***1.*** Quantify yield response to polymer formulation and rate under varying irrigation regimes.
***2.*** Evaluate canopy reflectance (NDVI) and chlorophyll stability (NDRE) as indicators of physiological drought buffering.
***3.*** Determine whether rate or formulation exerts the dominant influence under water limitation.
***4.*** Assess the potential role of polymer application as a drought-risk mitigation strategy in soybean production.

## 2. Materials and Methods

### *2.1 Experimental Site*

The experiment was conducted at the Henry J. Stumpf International Wheat Center, Grant, Nebraska (40.84° N, 101.73° W), on fine sandy loam soils. Mean daily temperature during the trial period (July–September 2025) ranged from 28–33 °C, with total in-season rainfall of 588 mm.

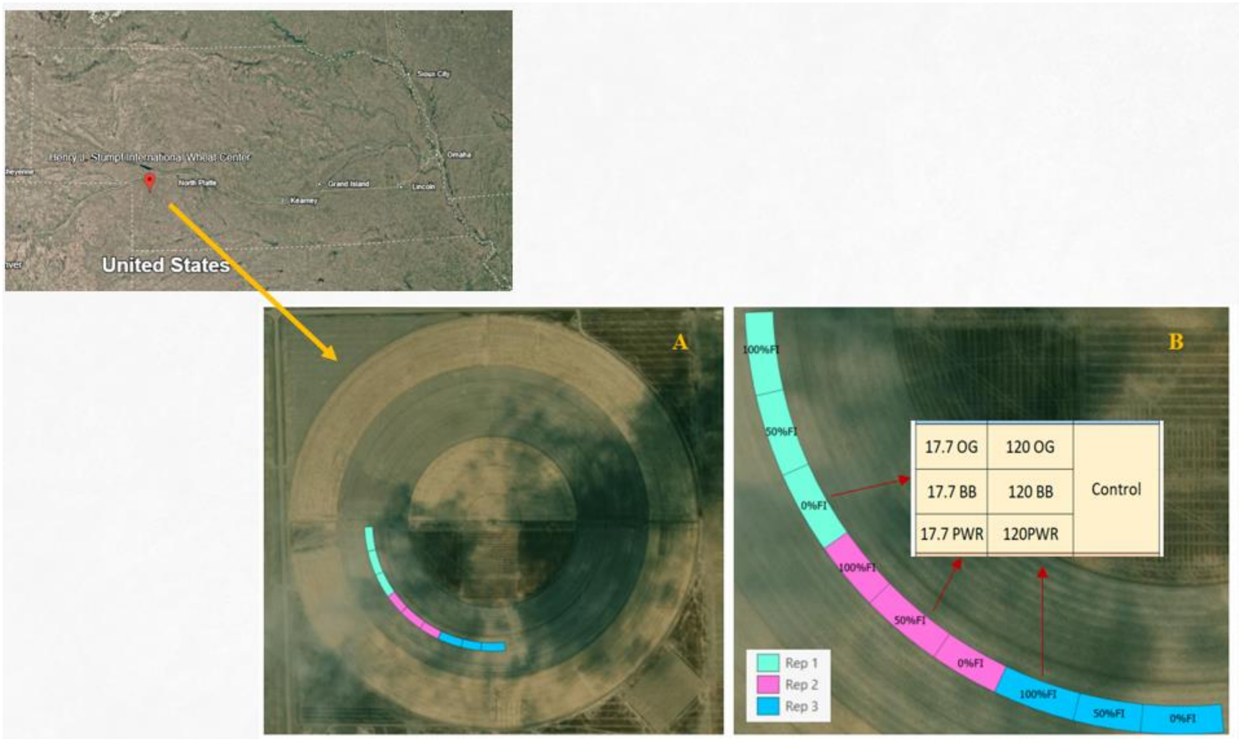



**Figure 1.** ***Designed Experimental plots at the University of Nebraska farm in Grant. A) Irrigation treatments (rainfed, 50% ET, 100% ET) each with 3 replications, and B) Polymer plots in each of the irrigation treatment replications.***

### *2.2 Experimental Design*

A randomized complete block design (RCBD) was used with five treatments:

1. Control (no polymer)
2. BB (Broader Granule, 120 lb/ac)
3. PWR (Powder, 120 lb/ac)
4. OG (Original Granule, 120 lb/ac)
5. OG (17.7 lb/ac)

Each treatment was replicated across three irrigation regimes:

- Full irrigation: 100% evapotranspiration (ET) replacement
- Reduced irrigation: 50% ET
- No irrigation or Control

Polymers were incorporated manually into 4 in (10 cm) depth via broadcast and a rotary tiller before planting. Treatment effects were evaluated descriptively across irrigation regimes.

### **2.3 Soybean Management**

Soybean (Variety P30A75E) was planted on June 03, 2025 using 8-row precision planter at a depth of 2-3 inches along Span 6 in circle under 8-span Sprinkler Valley center pivot. Irrigation was triggered using soil moisture sensors installed in fully irrigated plots. A standard herbicide and weed management program was implemented. At maturity, soybean yields were harvested on October 15. We collected the yield manually by cutting 2 rows in the middle for each of the 4-row plots across all treatments. Ideally, a John Deere Combine on site is used for yield collection; however, given the small plots and limited application of the EF polymer, this was not used in this experiment.

### 2.4 Application of EF Polymer Products in Soybeans

As shown in Figure 2, first, an 8-row planter was used to open crop rows at about 2 to 3-inch depth and thereafter, each polymer product was incorporated manually along the middle 2 rows via broadcast as well as a rotary tiller before planting. However, the rotary tiller failed to work, and we opted for manual broadcasting. Once the application was completed, the open rows with the product were covered using the row covers on the planter and then soybean was planted along the rows at an offset of about 2 inches next to the row with the product.

### 2.5 Irrigation Management

Irrigation was applied using a center pivot system and scheduled based on crop evapotranspiration (ET) demand and soil moisture conditions. Three irrigation regimes were implemented: full irrigation (100% ET), reduced irrigation (50% ET), and rainfed (0% irrigation). Total irrigation applied under the full irrigation treatment was 246 mm over the growing season, with monthly distribution of 37 mm (May), 85 mm (July), 86 mm (August), and 38 mm (September). Reduced irrigation treatments received approximately 50% of these amounts. Irrigation scheduling was guided by soil moisture sensor readings in fully irrigated plots.

**Figure 2.** ***Planting stage showing soybean planting and polymer incorporation into the soil.***

**3.0 Data Collection**

***3.1 Weather Data***

Weather information including rainfall, air temperature and solar radiation was collected from a nearby Weather Station belonging to Nebraska Mesonet. Daily precipitation was recorded at the experimental site during the growing season (May-September). The total rainfall recorded was 23 inches (588 mm). Daily maximum and minimum air temperatures were also recorded at the experimental site during the 2025 growing season. Maximum temperatures frequently exceeded 25 °C during the reproductive stages. Rainfall events were collected and accessed from the same weather station.

***3.2 Soil Moisture***

Soil moisture was monitored using a Neutron Gauge with aluminum access tubes. Each tube was installed between the two rows with the product and 7.5 inches from one row. Weekly readings were collected on days without irrigation and rainfall from 0-36 inches at an increment of 12 inches: 0-12", 12-24", and 24-36". A well-calibrated Neutron Gauge against Gravimetric Methods was used to ensure accuracy in soil moisture readings.

***3.3. In-season Drone Imagery***

Drone flying campaigns were done during the growing season on August 8 (V7) and September 3 (R2) using DJI Inspire 2 drone (DJI, Shenzhen, China) mounted with a 6X multispectral camera (Sentera, Minneapolis, MN, USA). The collected images were stitched and processed using a Pix4Dfields software (Version 2.10.1) (Pix4D S.A., Prilly, Switzerland). Vegetation indices including Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge (NDRE) were extracted from the stitched images for each treatment (irrigation regimes × polymer product × rate).

***3.4 Pods and Yields***

Before cutting soybean plants for yield analysis, pods were manually counted from all the plants accounting for middle 2 rows of each treatment plot. To determine the yields, the same plants were cut, threshed to collect seeds from the pods, and finally seeds were weighed at 15% moisture content.

***3.5 Data Analysis***

- Weather data: Daily rainfall as well as maximum and minimum temperature were collected and analyzed to generate plots for daily rainfall events and amounts and temperature events over the growing season, calculated daily Cumulative Growing Degree Days (CGDDs) and were plotted as cumulative seasonal CGDDs, and lastly, computed drought stress periods in the season using rainfall data and a plot was also created.
- Vegetation Indices: NDVI was considered and calculated across treatments for the two sensing campaigns – August 08 and September 3, 2025. Also, mean differences were computed between formulations (OG, BB, PWR) and irrigation regimes (full, deficit, and rainfed). Plots were generated to compare NDVI across polymer formulations and rates and irrigation regimes**.**
- Soil Moisture Data: Percentage changes in soil moisture across treatments were calculated compared to the control (without irrigation or rainfed treatment). Data was tabulated but also graphed.
- Crop-water relationship: A water-yield curve was plotted to understand the yield response to total water applied. To evaluate the efficiency of water use across treatments, two complementary metrics were calculated: Crop water productivity (CWP) and irrigation efficiency (IE). Water productivity was defined as the ratio of grain yield to total water input, where total water input represents the sum of seasonal rainfall and irrigation applied:

$$CWP = \frac{(Ra\inf all + Irrigation)}{Yield} \qquad (1)$$

Irrigation efficiency was calculated as the incremental yield gain relative to the rainfed control or no irrigation condition, normalized by the amount of irrigation applied:

$$IE = \frac{Yield\ treatment - Yield\ ra\inf ed}{Irrigation\ applied} \qquad (2)$$

Rainfed control yield was used as a baseline to isolate the contribution of irrigation and polymer treatments to yield improvement. Irrigation efficiency was computed only for irrigated treatments (50% ET and 100% ET), as the metric is undefined under zero irrigation input. These metrics were used to assess both the effectiveness of water use and the extent to which polymer application improved the productivity of limited irrigation resources.

- Pod Counts: Number of pods were compared across a) irrigation treatments and b) polymer formulation and rates. Data was presented in tabular form,and graphs were also generated.
- Yields: Average yields across irrigation rates and different polymer formulation and rates were calculated and summarized in a bar graph. Also, the yield advantage of polymer formulation was analyzed based on the control (no irrigation) as a baseline.
- Preliminary Economic Analysis: Net Return ($/ac) was calculated using Equation 3, Return on Investment using Equation 4, and finally, break-even yield using Equation 5. In simple terms, break-even yield explains how much extra yield the farmer/customer needs just to cover the cost.

$$\text{Net Return}\left(\frac{\$}{\text{ac}}\right) = (\text{Yield Increase} \times \text{Crop Price}) - \text{Product Cost} \tag{3}$$

Where: Yield increase = treatment yield − control yield; Crop price = $9/bu (assumed market price); Product cost = EF Polymer cost per acre

$$\text{ROI (Return on Investment)} = {}^{\text{Net Return}}/_{\text{Product Cost}} \tag{4}$$

$$\text{Break} - \text{even yield} = {}^{\text{Cost of Soybean}}/_{\text{Cost of the formulation}} \tag{5}$$

## *4.* Results and Discussion

### 4.1 *Weather data*

Most of the rainfall was received in the peak growing season around flowering stage and was more pronounced in June as shown in Figure 3A-B. Likewise, the highest temperatures (Figure 3A) were observed in the same period where the observed average was above $30^{o}$ C on most days between June-August. As shown in Figure 3C, the total cumulative Growing Degree Days (CGDDs) was about 1500, indicating enough thermal units for better growth of soybeans and ability to reach the yield potential of the planted soybean variety. In Figure 3D, extended days before substantial rainfall were analyzed and there was a delay at some periods in the growing season shown by the high peaks in early May, late July and early August, and after August. In such a period, there could be greater soil water deficits which can lead to water stress in case irrigation is not triggered and applied.

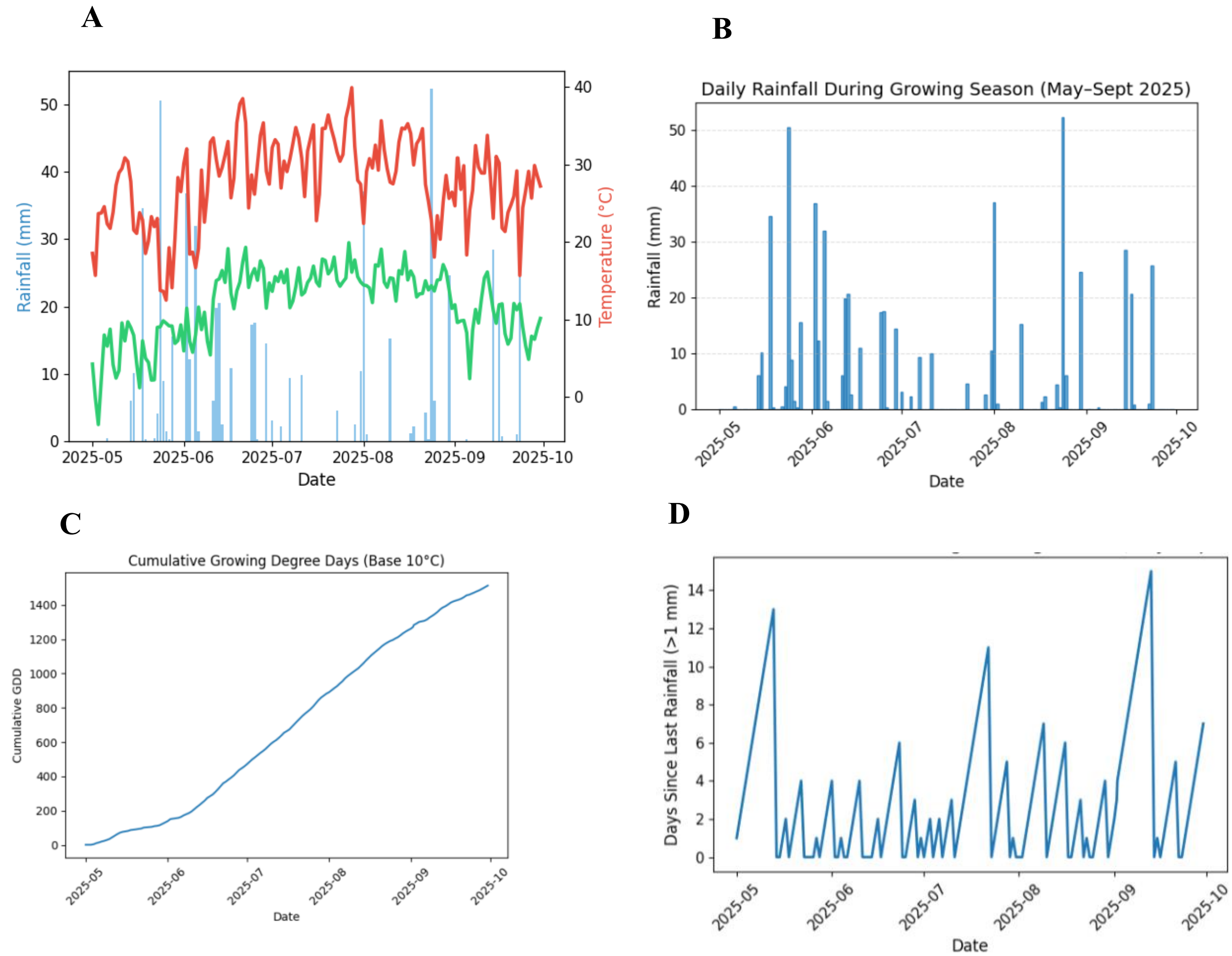



**Figure 3.** ***Weather data, Cumulative Growing Degree Days, and Drought Periods. A) Daily rainfall and air temperature during the 2025 soybean growing season. Daily precipitation (bars) and maximum and minimum air temperatures (lines) recorded at the experimental site from May-Sept 2025. Periods of limited precipitation coinciding with elevated temperatures likely increased crop water demand and contributed to transient soil moisture deficits during reproductive stages. B) Daily rainfall during the 2025 soybean growing season Daily precipitation recorded at the experimental site during the 2025 growing season (May–September). C) Accumulated growing degree days during the soybean growing season Cumulative growing degree days (GDD; base temperature 10 °C) are calculated from daily maximum and minimum temperatures during the 2025 growing season. Accumulated thermal units reached approx. 1500 GDD by late September, indicating normal crop developmental progression during the trial. D) Soil water deficit periods during the growing season of 2025. Days since the last rainfall event (>1 mm) calculated from daily precipitation records between May and September 2025. Extended intervals between rainfall events indicate potential soil moisture deficit periods during which crops may experience water stress.***

### 4.2 NDVI results trends and interpretation

As shown in Table 1, there was significant difference in NDVI between control and irrigation regimes across all treatments on August 8, ranging from 0.75-0.85 and 0.82-0.86, respectively. However, the values were higher on September 03 with minimal differences across all the treatments and ranging between 0.884-0.900, indicating that low-rate polymer had limited canopy stabilization under stress at this early date (Aug 08). For all polymer formulation, decent NDVI values were observed at a higher rate of 120 Ib/ac (0.81-0.89 for full, 0.86-0.90 for deficit, and 0.88-0.90 for control) where canopy reflectance was maintained even under drought stress. Furthermore, at the vegetative stage (Aug 08), NDVI values among OG, BB, and PWR formulations at 120 lb/ac were tightly clustered, suggesting minimal formulation-driven differentiation. Polymer concentration, rather than product type, was the primary determinant of canopy reflectance early in the season.

**Table 1. Comparison of NDVI values between irrigation regimes and polymer formulation and rates.**

| Irrigation | Treatment | Aug 08 (17.7 lb/ac) | Aug 08 (120 lb/ac) | Sept 03 (17.7 lb/ac) | Sept 03 (120 lb/ac) |
|---|---|---|---|---|---|
| **100% ET** | OG | 0.85 | 0.89 | 0.89 | 0.90 |
| | BB | 0.85 | 0.89 | 0.88 | 0.89 |
| | PWR | 0.86 | 0.90 | 0.88 | 0.89 |
| **50% ET** | OG | 0.84 | 0.89 | 0.89 | 0.91 |
| | BB | 0.83 | 0.90 | 0.88 | 0.90 |
| | PWR | 0.84 | 0.89 | 0.88 | 0.90 |
| **No Irrigation** | OG | 0.81 | 0.88 | 0.88 | 0.90 |
| | BB | 0.80 | 0.89 | 0.87 | 0.89 |
| | PWR | 0.80 | 0.89 | 0.87 | 0.89 |

In Figure 4, the formulation-specific effects on NDVI were minimal during vegetative growth at August 08, where polymer rate exerted the dominant influence. However, by September 03, differentiation among products became more evident under severe irrigation deficit. Treatments maintaining NDVI values above 0.90 under 0FI corresponded with greater yield preservation, suggesting formulation-dependent differences in late-season moisture buffering. These findings indicate that while concentration influences early canopy response, product-specific swelling and water-release characteristics may influence canopy response during reproductive-stage drought period (Sept).

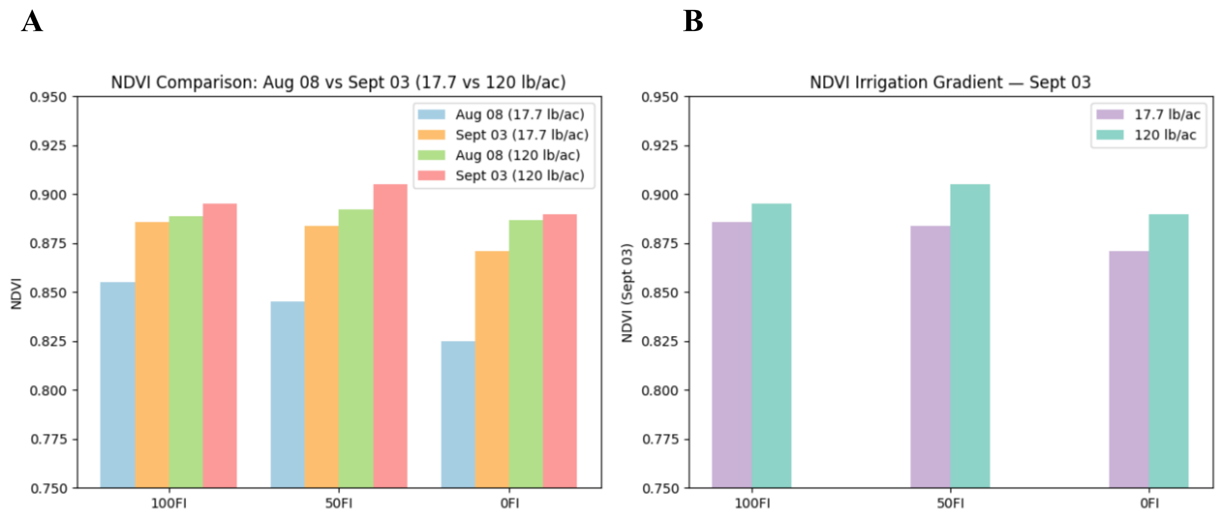



**Figure 4.** ***Normalized Difference Vegetation Index (NDVI) results. A) Normalized Difference Vegetation Index (NDVI) measured on August 08 and September 03 under full (100%ET), reduced (50% ET), and no irrigation regimes for polymer application rates of 17.7 and 120 lb/ac. Across irrigation treatments, NDVI increased from August to September, reflecting canopy maturation. The 120 lb/ac rate consistently maintained higher NDVI values compared to 17.7 lb/ac, particularly under deficit irrigation (50% ET and no irrigation), indicating improved canopy stability and reduced sensitivity to water stress at higher polymer concentration. B) Normalized Difference Vegetation Index (NDVI) measured on September 03 across full (100% ET), reduced (50% ET), and no irrigation regimes for polymer application rates of 17.7 and 120 lb/ac. Across all irrigation levels, the 120 lb/ac rate maintained consistently higher NDVI compared to 17.7 lb/ac. The divergence between rates was most pronounced under reduced (50% ET) and no irrigation, indicating enhanced canopy stability and improved drought resilience at the higher polymer concentration during the reproductive stage.***

### 4.3 Soil Moisture Distribution

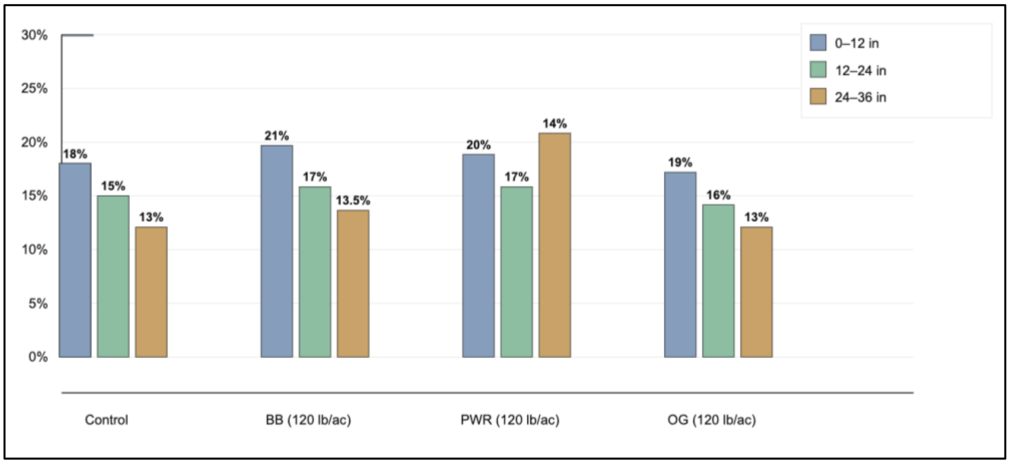
Table 2 shows the changes in soil moisture storage or retention of polymer and irrigation treatments compared to control irrigation. At a higher rate (120 lb/ac), BB had the highest soil water retention than its counterparts at both surface and mid-root zone in contrast to powder which performed better at the same rate at deeper root-zone. Regardless of the polymer formulation and the rates, soil moisture retention slightly increased with addition of the polymer to the soil.

**Table 2. Soil Moisture Retention (% Volumetric Water Content) as Mid-Season Average**

| Treatment | Surface (0–12") | Mid-Root (12–24") | Deep (24–36") |
|---|---|---|---|
| Control | 18% | 15% | 13% |
| BB (120 lb/ac) | **21% (+17%)** | **17% (+13%)** | 13% (+0%) |
| PWR (120 lb/ac) | 19% (+6%) | 17% (+13%) | **14.5% (+11%)** |
| OG (17.7 lb/ac) | 18.5% (+3%) | 15.5% (+3%) | 13% (+0%) |
| OG (120 lb/ac) | 20% (+11%) | 16% (+7%) | 13.5% (+4%) |

In Figure 5, EF Polymer treatments improved soil moisture storage across all measured depths. The BB formulation showed the highest increase in surface (0-12 in) VWC, averaging 21%, compared to 18% in control. Under full irrigation, BB and PWR increased mean soil moisture by 2.8% and 2.1%, respectively. In addition, under reduced irrigation, moisture advantage persisted, with polymer-treated plots maintaining 13–15% VWC versus 11% in control. However, OG at low application rates (17.7 lb/ac) showed minimal benefit, confirming a rate-dependent response.

**A**

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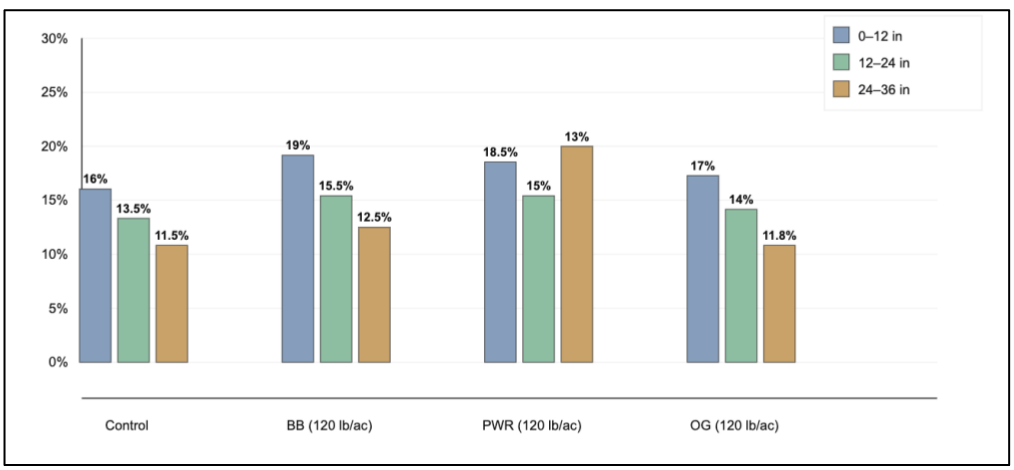



**Figure 5.** ***Soil moisture measurements. The two graphs compare volumetric water content (VWC%) across soil depths (0-12", 12-24", 24-36") for each treatment: Control, BB (120 lb/ac), PWR (120 lb/ac), and OG (120 lb/ac) under full irrigation conditions and reduced irrigation. In graph A) Polymer-treated plots retained 2-3% higher VWC than the control. In B) BB and PWR maintained 2-3% higher VWC, even with 25% less water applied.***

**4.4 Water-yield relationship, Crop water productivity and irrigation efficiency**

Total water applied appears highly correlated to the crop yield (Figure 6). BB at 120 lb/ac outperformed at low water application. In no irrigation condition, BB at 120 lb/ac yields 55.1 bu/ac versus just 24.7 for the Control i.e., more than double. This gap narrows as irrigation increases, with yields essentially converging at full irrigation (~834 mm).

Crop water productivity and irrigation efficiency varied strongly across irrigation regimes, indicating that polymer effectiveness was closely tied to water availability. Under rainfed conditions, polymer treatments substantially improved CWP, with BB at 120 lb/ac achieving 0.094 bu/ac/mm compared to 0.042 bu/ac/mm in the control more than a twofold increase. This suggests that polymer-mediated water retention enhances the effective use of limited rainfall.

Under reduced irrigation (50% ET), high-rate polymer treatments further increased CWP to ~0.089-0.090 bu/ac/mm, representing a 40-50% improvement over the control. Irrigation efficiency showed a similar pattern: values increased from 0.146 bu/ac/mm in the control to over 0.30 bu/ac/mm in BB and OG at 120 lb/ac, indicating that polymer application substantially improves yield gains per unit of irrigation water.

In contrast, under full irrigation (100% ET), differences among treatments were minimal, reflecting a saturation effect where water is no longer limiting.

Together, these results indicate that polymers operate through two primary mechanisms: preserving yield under rainfed conditions and improving water use efficiency under deficit irrigation. Their benefits diminish under full irrigation, reinforcing their role as drought-buffering inputs rather than yield-enhancing technologies under optimal conditions.

**Table 3. Crop water productivity and irrigation efficiency across polymer treatments and irrigation regimes**

| Irrigation Regime | Treatment | Irrigation (mm) | Total Water (mm) | Yield (bu/ac) | Crop Water Productivity (bu/ac/mm) | Irrigation Efficiency (bu/ac/mm) |
|---|---|---|---|---|---|---|
| **No irrigation** | Control | 0 | 588 | 24.7 | 0.042 | — |
| | BB (120 lb/ac) | 0 | 588 | 55.1 | 0.094 | — |
| | OG (17.7 lb/ac) | 0 | 588 | 52.4 | 0.089 | — |
| | OG (120 lb/ac) | 0 | 588 | 33.6 | 0.057 | — |
| | PWR (120 lb/ac) | 0 | 588 | 23.2 | 0.039 | — |
| **50% ET** | Control | 123 | 711 | 42.7 | 0.060 | 0.146 |
| | BB (120 lb/ac) | 123 | 711 | 63.0 | 0.089 | 0.311 |
| | OG (17.7 lb/ac) | 123 | 711 | 38.5 | 0.054 | 0.112 |
| | OG (120 lb/ac) | 123 | 711 | 64.0 | 0.090 | 0.320 |
| | PWR (120 lb/ac) | 123 | 711 | 58.3 | 0.082 | 0.273 |
| **100% ET (Full)** | Control | 246 | 834 | 60.7 | 0.073 | 0.146* |
| | BB (120 lb/ac) | 246 | 834 | 61.7 | 0.074 | 0.150 |
| | OG (120 lb/ac) | 246 | 834 | 54.0 | 0.065 | 0.119 |

| | | | | | |
|---|---|---|---|---|---|
| | PWR (120 lb/ac) | 246 | 834 | 60.1 | 0.072 | 0.144 |

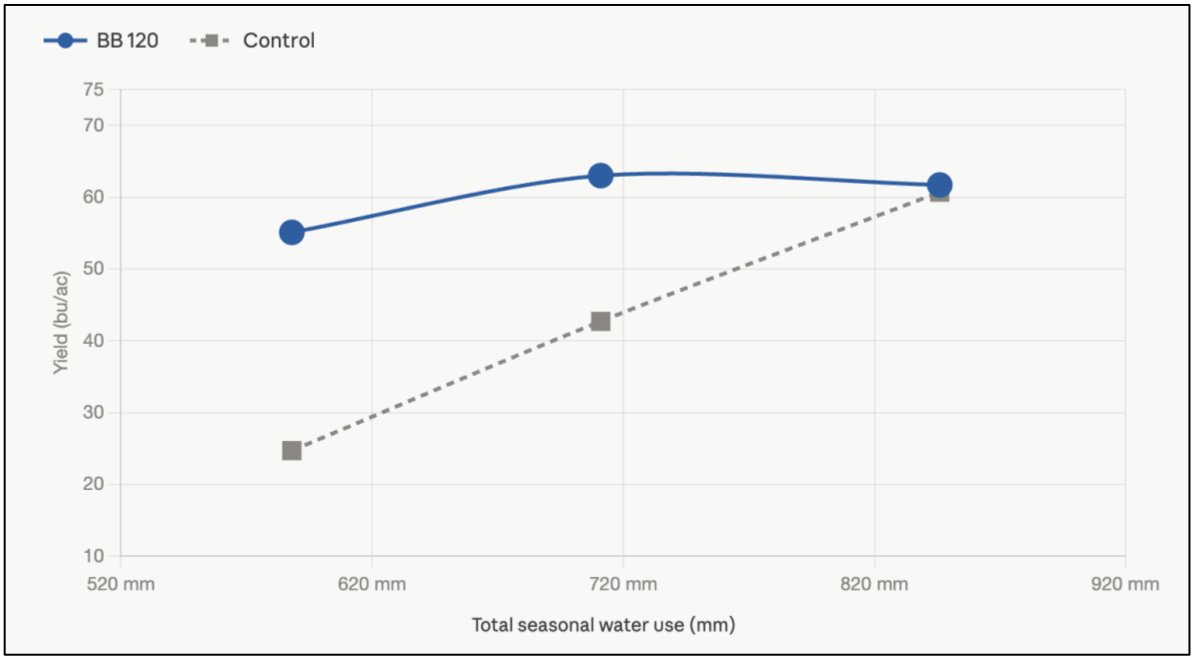



**Figure 6.** ***Water-yield curve for Control and BB 120 treatments across three irrigation levels (0, 50%, and 100%). Total seasonal water use (mm) includes both rainfall and applied irrigation. BB 120 lb/ac maintained substantially higher yields under deficit and rainfed conditions, with the yield advantage narrowing as irrigation increased.***

### 4.5 Number of Pods

**a. Pods per Plant by Polymer formulation and Rate**

Control plots averaged 31.8 pods per plant, lower than polymer-treated plots, which ranged from 38-45 pods per plant depending on formulation and rate. This corresponds to a 20-40% increase in pod formation relative to the untreated control. Pod numbers declined with irrigation reduction, averaging 50 pods per plant under full irrigation and 33 pods per plant under no irrigation. Despite slightly higher pod counts at the 17.7 lb/ac rate, yield preservation was strongest at the 120 lb/ac rate under water limitation, indicating that polymer-mediated yield benefits were primarily associated with improved seed filling rather than increased pod initiation.

Table 4. Pods per plant by Polymer formulation and Rate

| **Product** | **Rate** | **Pods/Plant** |
|---|---|---|
| BB | 17.7 | **44.85** |
| PWR | 17.7 | **43.98** |
| OG | 17.7 | **42.67** |
| BB | 120 | **41.36** |
| OG | 120 | **38.75** |
| PWR | 120 | **38.31** |
| Control | - | **31.8** |

## b. Pods per Plant by Irrigation and Rate

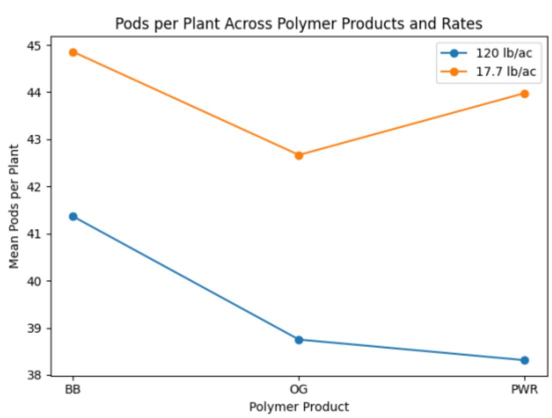
Pods per plant were higher at the 17.7 rate across all formulations. Higher rate polymers may improve seed fill, seed weight, or moisture retention during grain fill rather than increasing pod number. On average, 100% irrigation had approximately 50 pods/plant compared to ~43 pods/plant for 50% irrigation and ~33 pods/plant. At no irrigation**,** we observed that pod formation was highly water sensitive**.**

Table 5. Pods per Plant by Irrigation and Rate

| Irrigation | Rate | Pods/Plant |
|---|---|---|
| T1 (Full) | 17.7 | **50.72** |
| T1 (Full) | 120 | **42.19** |
| T2 (50%) | 17.7 | **43.72** |
| T2 (50%) | 120 | **41.19** |
| T3 (No Irrigation) | 17.7 | **33.67** |
| T3 (No Irrigation) | 120 | **33.63** |

Figure 7A explains an increase in pod numbers with a lower polymer rate, and the same was true with irrigation regimes. However, both for high and lower rates, BB product had more pod than other polymer formulation (Figure 7B). In general, soybeans planted in polymer treated soils had more pods with a difference approximated at 10 pods per plant (Figure 7C).

**A**

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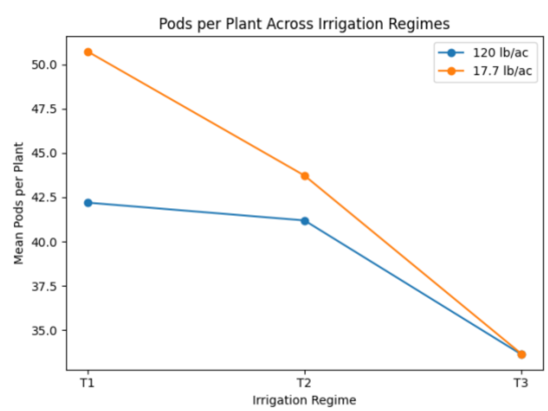


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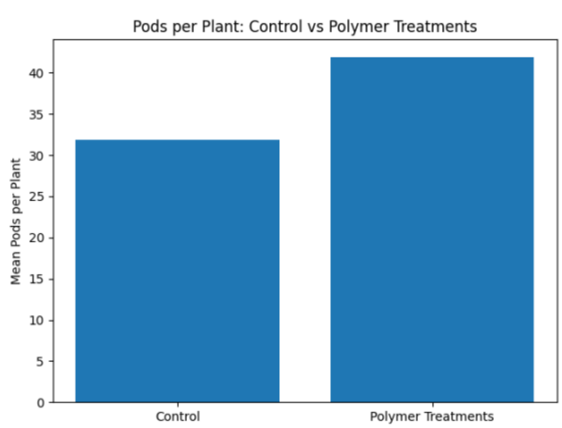

**Figure 7.** ***Counted pods per plant. A) Pods per Plant Across Polymer Products and Application Rates. Mean soybean pods per plant across polymer formulations (OG, BB, PWR) at two application rates (17.7 and 120 lb/ac). B) Number of Pods across irrigation regimes and EF polymer treatments. A) Pods per Plant Across Irrigation Regimes. The data presented are Mean soybean pods per plant across irrigation regimes (T1, T2, T3) for polymer application rates of 17.7 and 120 lb/ac. C) Pods per Plant: Control vs Polymer Treatments. The data presented is a comparison of mean pods per plant between untreated control plots and polymer-treated plots. Control plots averaged 31.8 pods per plant, whereas polymer-treated plots averaged approx. 40-45 pods per plant depending on formulation and application rate.***

### 4.6 Crop Yields

Figure 8 summarizes the seasonal soybean yields that were collected from all the treatments. However, yield differences were minimal across polymer formulation under full irrigation (100% ET) and BB 120 had yields that marginally exceeded the control (Figure 8A). Furthermore, OG and BB at 120 Ib/ac under reduced irrigation (50% ET) significantly outperformed both the control and 17.7 Ib/ac treatments, thus explaining high performance of the polymer product at a high-rate application. Polymer treatment rate (particularly BB 120 and OG 17.7) without irrigation had comparable yield to irrigated soybeans which suggested improved drought resilience but associated with specific formulation-rate combinations. While in Figure 8B, the percentage yield increase was calculated with untreated control as a benchmark, and most treatments exhibited minimal yield advantage relative to the control. Notably, 120 Ib/ac treatments at 50% ET had substantial yield gains (~ 35-50%), showing the importance of high rates under moderate stress conditions. Under no irrigation, BB 120 and OG 17.7 showed a greater yield advantage over control without polymer application, which supports the importance of polymer addition to the soil to ensure drought resilience.

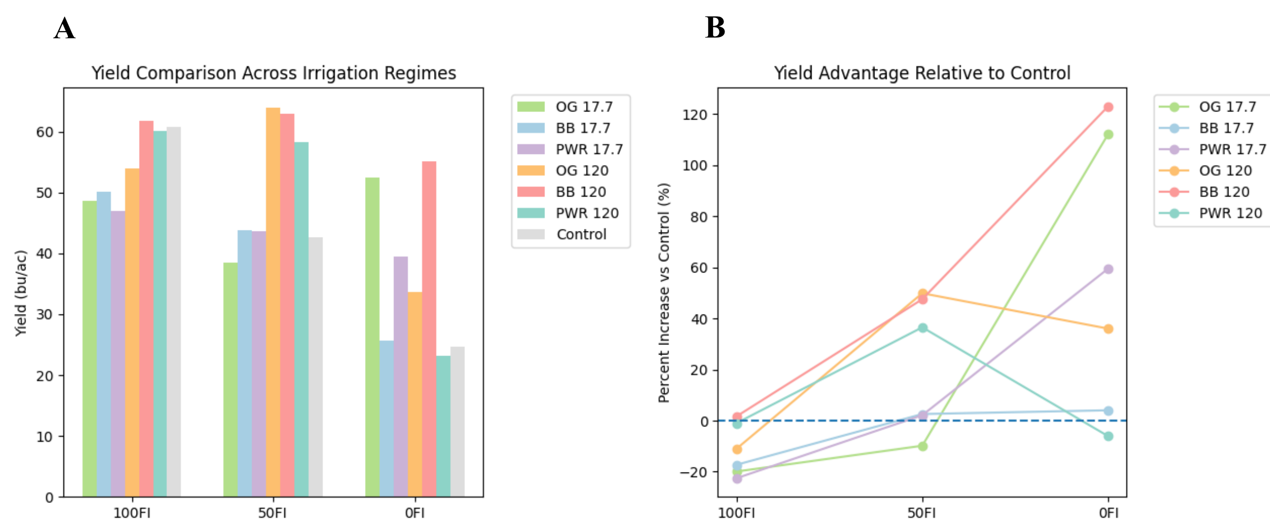


**Figure 8.** ***Final Soybean yields. A) Soybean yield (bu/ac) across full (100% ET), reduced (50% ET), and no irrigation regimes for polymer formulations (OG, BB, PWR) applied at 17.7 and 120 lb/ac, compared with an untreated control. Under full irrigation (100% ET), yield differences among treatments were minimal, with BB 120 marginally exceeding the control.***

***Under reduced irrigation (50% ET), 120 lb/ac treatments, particularly OG 120 and BB 120, substantially outperformed both the control and 17.7 lb/ac treatments, demonstrating a strong rate-dependent response. Under no irrigation, yield divergence was most pronounced; BB 120 and OG 17.7 showed marked yield preservation relative to control, indicating enhanced drought resilience associated with specific formulation–rate combinations. B) Percent yield increase relative to untreated control across full, reduced, and no irrigation regimes for polymer formulations (OG, BB, PWR) applied at 17.7 and 120 lb/ac. Under full irrigation, most treatments exhibited minimal or negative yield advantage relative to control. Under reduced irrigation, 120 lb/ac treatments demonstrated substantial yield gains (≈35-50%), indicating strong rate-dependent performance under moderate water stress. Under no irrigation, BB 120 and OG 17.7 exhibited the greatest relative yield advantage (>100% increase over control), highlighting pronounced drought resilience. The dashed horizontal line represents zero percent change relative to control.***

### 4.7 Preliminary Economic Analysis

This analysis was conducted based on yields to determine the Return on Investment (ROI). The average yield required to breakeven based on the polymer cost was determined and summarized in table 6. Powder formulation might require less yield per acre in soybean production to realize the economic benefits as compared to others like Granular and BBs.

**Table 6. Yield-based ROI**

| Product | Cost ($/ac) | Break-even Yield Gain |
|---|---|---|
| Powder | $56-70 | 6.2 – 7.8 bu/ac |
| Granular | $64-80 | 7.1 – 8.9 bu/ac |
| BBs | $100 | 11.1 bu/ac |

Different case scenarios were considered to evaluate economic feasibility with different polymer formulations. Case 1 was focused on full irrigation against control without formulation (table 7) and it is only in BB 120 where yield gain of 1 bu/ac was observed, making an extra revenue of about $9/ac. Given the cost of BB at $100/ac, there is a negative net profit of about $91, making the business less viable. For Case II under reduced irrigation (table 8), there was yield gain of 20.3 bu/ac for BB 120 with generated revenue of $183/ac and positive net profit of about $83/ac, and this could possibly be a good business for soybean growers. Lastly, Case III under no irrigation (table 9), possible formulations were still BB 120 and PWR 17.7, making revenue of $274/ac and $132/ac, respectively and net positive profit approximated at $143/ac and $62-76/ac in the same order. Thus, these two polymers one at high rate and another at lower rate could be considered for better soil water retention to buffer drought impacts and to maximize the yield potential and close yield gaps in soybeans.

**Table 7. Case I: 100FI (Full Irrigation)**

| Treatment | Yield (bu/ac) | Δ vs Control (60.7) |
| --- | --- | --- |
| OG (17.7) | 48.6 | -12.1 |
| BB (17.7) | 50.2 | -10.5 |
| PWR (17.7) | 47.0 | -13.7 |
| OG (120) | 54.0 | -6.7 |
| BB (120) | **61.7** | **+1.0** |
| PWR (120) | 60.1 | -0.6 |

**Table 8. Case II: 50% Irrigation**

| Treatment | Yield (bu/ac) | Δ vs Control (42.7) |
| --- | --- | --- |
| OG (17.7) | 38.5 | -4.2 |
| BB (17.7) | 43.8 | **+1.1** |
| PWR (17.7) | 43.6 | **+0.9** |
| OG (120) | **64.0** | **+21.3** |
| BB (120) | 63.0 | +20.3 |
| PWR (120) | 58.3 | +15.6 |

**Table 9. Case III: 0% Irrigation**

| Treatment | Yield (bu/ac) | Δ vs Control (24.7) |
| --- | --- | --- |
| OG (17.7) | 52.4 | +27.7 |
| BB (17.7) | 25.7 | +1.0 |
| PWR (17.7) | **39.4** | **+14.7** |
| OG (120) | 33.6 | +8.9 |
| BB (120) | **55.1** | **+30.4** |
| PWR (120) | 23.2 | -1.5 |

## *5.* Conclusion

Superabsorbent polymer application enhanced soybean production primarily under water-limited conditions, with minimal benefits under full irrigation. Across treatments, yield responses were closely aligned with water availability, confirming that polymers function as drought-buffering inputs rather than yield-enhancing technologies under optimal conditions. Polymer-treated plots exhibited substantial gains in crop water productivity, particularly under rainfed and deficit irrigation conditions, where yield per unit water input increased by up to twofold relative to the control. Similarly, irrigation efficiency represents more than a twofold increase under reduced irrigation, indicating that polymers significantly improve the effectiveness of limited water inputs. These findings demonstrate that polymer application operates through two complementary pathways: preserving yield under rainfall variability and enhancing the marginal productivity of irrigation water under deficit conditions. Our preliminary economic analysis indicates that polymer application is not viable under full irrigation but may become profitable under water-limited conditions, generating net returns of up to ~$140/ac under rainfed systems and ~$80/ac under reduced irrigation, highlighting its value as a drought-risk mitigation strategy. Overall, this study positions biodegradable SAPs as a targeted strategy for improving yield stability and water-use efficiency in water-constrained agroecosystems. Their adoption may be particularly valuable in regions facing increasing water scarcity, where improving the productivity of each unit of water is critical for sustaining agricultural production.

## *6.* Acknowledgements

The authors acknowledge EF Polymer Pvt. Ltd. for the support and providing the materials used in this study. We thank the staff at the University of Nebraska-Lincoln research farm at the Henry J. Stumpf International Wheat Center for their support in field operations and data collection.