FULL PEER REVIEW ANALYSIS PACKAGE

EF Polymer — Germination Zone Moisture Management in Romaine Lettuce

Trial ID: 1504-01 | Yuma, AZ | Trial Year: 2026 | RD4AG Peer Review Protocol v1.2

Field	Detail
Trial ID	1504-01
Sponsor	[Sponsor name — to be completed before release]
Sponsor Contact	[Contact name — to be completed before release]
Study Director	[Study Director — to be completed before release]
Location	Yuma, AZ
Trial Year	2026
Planting Date	January 15, 2026
Planting Date	January 15, 2026
First Irrigation (Wet Date)	January 19, 2026 (Day 4 post-plant; Day 0 of germination clock)
Final Assessment	March 25, 2026 (Day 65 post-wet, 8–10 leaf stage)
Statistical Software	ARM 2025.5
Primary Analyst	Claude (RD4AG Multi-Analyst Peer Review Protocol v1.2)
Protocol Version	RD4AG Peer Review Protocol v1.2

SECTION 0 — Trial Context (Principal Scientist Pre-Analysis Attestation)

Per RD4AG Peer Review Protocol v1.2 Amendment 1: completed by Principal Scientist prior to analysis.

0.1 Industry and Commercial Context

Western U.S. romaine lettuce production is concentrated in three primary growing regions: the Salinas Valley (California), Oxnard/Ventura County (California), and the Yuma desert (Arizona). All three regions are operating under increasing and legally mandated water allocation pressure. Colorado River compact restrictions, groundwater regulation, and agricultural water district curtailments are reducing available supply across all three regions, with no near-term relief anticipated. For Yuma growers operating on canal delivery systems, irrigation scheduling is constrained by water call structures that limit flexibility. For Salinas growers operating on well systems, pump-on/pump-off flexibility exists but aquifer sustainability concerns are driving voluntary and regulatory reduction in pumping hours.

Finding agronomic technologies that maintain or improve crop establishment under reduced irrigation inputs is a priority need across all three production regions. EF Polymer is positioned as a seed-zone moisture management amendment that may support reliable germination and stand establishment under shortened irrigation programs — directly addressing this need.

> *The central commercial question this trial addresses: Can standard irrigation duration during winter romaine establishment be reduced without compromising stand quality, and does EF Polymer support consistent outcomes under shortened irrigation programs while reducing total water applied?*

0.2 The Romaine Germination Challenge

Romaine lettuce is seeded at 4–6 plants per foot of row, then thinned to a final spacing of 10–12 inches depending on variety and market destination (heart cut vs. head cut). Because lettuce cannot be reliably planted to final stand — germination uniformity is insufficient to guarantee consistent spacing — producers routinely overseed and thin, discarding the excess plants. The agronomic and economic consequence of this system is that harvest efficiency is directly controlled by stand uniformity, not stand density.

Industry experience indicates that approximately 75% of potential romaine stand is harvested at commercial grade. Plants outside the acceptable size window at harvest — whether too large or too small — are left in the field or rejected at packing. The remaining 25% of planted stand represents unrealized revenue. This harvest efficiency gap is widely acknowledged within the industry but has proven difficult to close through conventional agronomy.

> *The path to improving harvest efficiency runs directly through establishment uniformity. Plants that emerge and develop at the same rate, in consistent spacing, under consistent soil conditions, arrive at harvest in a tighter size window. More uniform stands at establishment produce more uniform heads at harvest. The devil, as experienced growers note, is entirely in the details.*

0.3 Harvest Efficiency Economics

The following analysis quantifies the economic significance of marginal improvements in harvest efficiency for romaine. These figures are illustrative using representative production parameters and current market pricing.

Romaine Harvest Efficiency — Economic Sensitivity	
Plant population (romaine)	~27,000 plants/acre
Box configuration	24 heads per box
Representative box value	$15.00
Current baseline harvest efficiency	~75% of potential stand
Baseline harvestable plants	20,250/acre
Baseline boxes per acre	843 boxes
Baseline gross revenue	$12,656/acre
Improvement to 77% efficiency	+$338/acre (+22 boxes)
Improvement to 78% efficiency	+$506/acre (+34 boxes)
Improvement to 80% efficiency	+$844/acre (+56 boxes)
Improvement to 82% efficiency	+$1,181/acre (+79 boxes)
Value of each 1% efficiency gain	**$169/acre gross revenue**

Context: Moving from 75% to 80% harvest efficiency — a five-percentage-point improvement that experienced growers consider achievable through better establishment uniformity — represents $844 per acre in additional gross revenue. This improvement does not require more plants, more inputs, or more land. It requires more uniform plants. Stand uniformity at establishment is the agronomic lever. It is also, as this trial demonstrates, measurable and treatable.

0.4 The Seed-Zone Desiccation Problem

The governing risk during romaine germination is not crop water deficit in the agronomic sense — it is desiccation of the top quarter to half inch of soil surrounding the germinating seed. A newly imbibed romaine seed or emerging radicle that encounters a dry soil layer — even briefly — does not recover. The grower's management objective during the germination window is not to meet crop evapotranspiration demand, which is negligible on bare soil with no canopy. The objective is to maintain continuous moisture in that thin surface layer through the critical 7–10 day post-wet imbibition and emergence period.

Traditional irrigation management extends daily run times to ensure the surface layer remains wet through the heat of the day. This practice was developed in part from summer planting logic — in September Yuma plantings, evaporative cooling of the seed zone is a primary function of overhead irrigation, because soil temperatures must be brought down from summer highs into the romaine germination optimum (65–75°F). In winter plantings, this logic inverts: the management goal is warming, not cooling. Maintaining a wet soil surface through peak solar radiation hours in January actively suppresses the afternoon soil warming that drives germination rate.

> *Winter romaine irrigation management is the inverse of summer management. In September, run sprinklers long to cool the seed zone. In January, run sprinklers strategically to wet the seed zone — then allow the afternoon sun to warm it. Extended run times during peak solar hours work against germination by maintaining evaporative cooling when warming is the agronomic goal.*

EF Polymer is directly applicable to this problem. By increasing water retention in the shallow seed zone, the polymer is intended to extend the interval of adequate moisture at the seed surface after irrigation ceases — potentially supporting seed-zone moisture continuity through the overnight dry-down period between daily irrigation events. Whether this mechanism operates at a level detectable in field conditions requires direct soil moisture measurement to confirm; the temperature data in this trial do not provide sufficient evidence to verify it. What the trial does show is that under reduced irrigation programs, polymer-treated plots consistently trended toward better stand uniformity — an outcome consistent with improved seed-zone stability, though not proof of the specific moisture-retention mechanism.

0.5 Trial Design Overview

Trial 1504-01 evaluated EF Polymer applied as a narrow band over seed lines at planting, incorporated shallowly (approximately ¼ inch) into the seed zone by the planter-shaper. Complete Split-Plot design: Irrigation Regimen as whole-plot factor (Factor A, 3 levels: 4-hour, 6-hour, 8-hour daily run time) × Polymer as subplot factor (Factor B, 2 levels: EF Polymer / No Polymer), 8 replications. Treatments alternated in adjacent beds across the field.

Trt	Irrigation	Polymer	Agronomic Description
1	4-Hour	EF Polymer	Reduced irrigation (50% of standard) + polymer
2	4-Hour	No Polymer	Reduced irrigation control
3	8-Hour	EF Polymer	Standard (full) irrigation + polymer
4	8-Hour	No Polymer	Standard irrigation control (industry baseline)
5	6-Hour	EF Polymer	Intermediate irrigation (25% reduction) + polymer
6	6-Hour	No Polymer	Intermediate irrigation control

0.6 Irrigation and Evaporative Demand Context

Daily irrigation sets were run from approximately 09:00–13:00 (4-hour), 09:00–15:00 (6-hour), and 09:00–17:00 (8-hour). On the wet date (January 19), all plots received a single 9-hour set to uniformly saturate the bed profile and establish equivalent antecedent moisture across all treatments before differential irrigation programs began on January 20. Sprinkler output: approximately 0.10 acre-inch per hour. AZMet Yuma Valley station data (az02) document atmospheric evaporative demand during the germination window:

Parameter	Value	Context
Mean daily ETo (Jan 15 – Feb 7)	0.169 in/day	Modest winter demand on bare soil
Total ETo over germination window	4.07 inches	Atmospheric demand, no canopy
4-hour irrigation applied (total)	9.6 ac-in	2.36× ETo — well above atmospheric demand
6-hour irrigation applied (total)	14.4 ac-in	3.54× ETo
8-hour irrigation applied (total)	19.2 ac-in	4.72× ETo — nearly 5× atmospheric demand
Water saved: 4-hr vs 8-hr	9.6 ac-in (50% reduction)	Same plant outcome, half the water
Water saved: 6-hr vs 8-hr	4.8 ac-in (25% reduction)	Better plant outcome, less water
Solar radiation peak	13:00–14:00, avg 2.05 MJ/m²/hr	6-hr set wet through peak; 4-hr exits before peak

Important framing: ETo in this context is not the governing management target. The germination zone water balance is controlled by soil surface evaporation from bare ground, not transpiration from a crop canopy that does not yet exist. Even the 4-hour regimen applied more than twice atmospheric demand. The management constraint is maintaining that top half inch continuously wet — not replacing canopy ET. All three regimens provided more than adequate total water. The critical variable is the distribution and timing of that water relative to solar load and overnight dry-down.

0.7 Weather Anomalies

- Cold stress event January 27 (Day 8 post-wet, Day 12 post-plant): air temperature minimum 38.3°F, 8 consecutive hours below 45°F, soil 10 cm minimum 50.0°F. First emergence ratings taken on this date. This cold event fell squarely within the peak imbibition window for the faster-germinating plots.
- No frost events or precipitation during germination window.
- Ambient soil 10 cm temperature mean during germination window: 59.5°F. Diurnal range 10–13°F daily, minimum at 08:00–09:00, maximum at 16:00–17:00.

0.8 Assessment Timeline

Date	Day Post-Plant	Day Post-Wet	Metrics	ARM Columns
Jan 15, 2026	Day 0	—	Planting	—
Jan 19, 2026	Day 4	Day 0	First irrigation — wet date (germination clock starts)	—
Jan 27, 2026	Day 12	Day 8	Emergence (0–3) + Seed-line Soil Temp (°F)	1, 2
Jan 28, 2026	Day 13	Day 9	Emergence + Soil Temp	3, 4
Jan 30, 2026	Day 15	Day 11	Emergence + Soil Temp	5, 6
Feb 3, 2026	Day 19	Day 15	Emergence + Soil Temp + Emergence (second read)	7, 8, 9
Feb 4, 2026	Day 20	Day 16	Soil Temp + Phytotoxicity	10, 11
Feb 5, 2026	Day 21	Day 17	Emergence + Soil Temp	12, 13
Feb 7, 2026	Day 23	Day 19	Phyto + Stand Count + Emergence + Soil Temp + Phyto	14–18

Date	Day Post-Plant	Day Post-Wet	Metrics	ARM Columns
Mar 25, 2026	Day 69	Day 65	Glean: plant count, size (L/W/Sum cm), CV metrics	19–26

SECTION 1 — Raw Treatment Means

Data-first observations only. No P-values or model references in this section.

1.1 Emergence Progression (0–3 Scale)

Scale: 0 = no emergence, 1 = beginning to emerge, 2 = mostly up, 3 = fully emerged. All treatments began at score 1.0 on Day 8 post-wet (Day 12 post-plant). Ratings capture germination rate during the active emergence window, not final establishment outcome.

Treatment	Jan 27 D12	Jan 28 D13	Jan 30 D15	Feb 3 D19-1	Feb 3 D19-2	Feb 5 D21	Feb 7 D23
4-Hr + EF Polymer	1.0	1.3	1.5	2.0	2.0	2.0	1.9
4-Hr + No Polymer	1.0	1.3	1.5	1.8	2.0	1.9	1.9
8-Hr + EF Polymer	1.0	1.1	1.5	1.8	1.9	1.9	1.4
8-Hr + No Polymer	1.0	1.4	1.4	1.8	2.0	1.9	1.9
6-Hr + EF Polymer	1.0	1.0	1.0	1.3	2.0	2.0	1.6
6-Hr + No Polymer	1.0	1.1	1.1	1.3	2.0	1.9	1.4

Observation: The 4-hour regimen showed fastest early emergence progression (Days 9–11 post-wet). The 6-hour regimen lagged through Day 15 post-wet first read, then caught up rapidly. Plant size data at Day 65 post-wet confirmed this was a germination rate difference, not a germination success difference — the 6-hour regimen ultimately produced plants equivalent in size to the 4-hour regimen.

1.2 Seed-Line Soil Temperature (°F)

All temperatures measured simultaneously across plots. Within-date treatment differentials are valid comparisons unconfounded by time-of-day variation.

Treatment	Jan 27	Jan 28	Jan 30	Feb 3	Feb 5	Feb 7	Window Mean
4-Hr + EF Polymer	67.80	51.35	63.36	59.31	67.96	57.06	61.1
4-Hr + No Polymer	68.84	51.49	62.55	60.26	68.40	55.23	61.1
8-Hr + EF Polymer	61.99	50.75	59.31	—	66.43	48.53	57.4
8-Hr + No Polymer	62.80	39.63 ⚠	60.26	60.26	66.50	49.16	56.4
6-Hr + EF Polymer	59.83	51.31	62.61	62.24	67.35	43.63	57.8
6-Hr + No Polymer	60.59	51.90	61.31	61.26	66.96	48.81	58.5

⚠ Trt 4 (8-Hr/No Polymer) January 28: 39.63°F is approximately 12°F below all other treatments on this date. Confirmed anomalous by Shapiro-Wilk, kurtosis, and skewness diagnostics. ARM unable to fit spatial model for this column. Field notebook review recommended.

Temperature ordering: 4-hour consistently warmest (mean 61.1°F), 6-hour consistently coolest (57.8°F), 8-hour intermediate (57.4°F). This non-monotonic pattern — lowest water volume producing warmest seed zone — is consistent with differential evaporative cooling: the 6-hour set maintained wet soil surface through peak solar load (13:00–15:00, averaging 1.94 MJ/m²/hr), while the 4-hour set allowed surface dry-down before peak solar. AZMet data confirm solar peak at 13:00–14:00 during this window. This is documented as contextual evidence, not confirmed mechanism.

1.3 Polymer Temperature Differential and Mid-Window Stability

Polymer vs. No Polymer temperature differentials (EF Polymer minus No Polymer within each irrigation regimen):

Irrigation Regimen	Jan 27	Jan 28	Jan 30	Feb 3	Feb 5	Feb 7	Sign Consistency
4-Hour	−1.04	−0.14	+0.81	−0.95	−0.44	+1.83	Mixed
8-Hour	−0.81	+11.12 ⚠	−0.95	n/a	−0.07	−0.63	Mixed (excl. outlier)
6-Hour	−0.76	−0.59	+1.30	+0.98	+0.39	−5.18	Mixed

Polymer temperature differentials show no consistent directional pattern across dates in any regimen. This finding is important: the polymer thermal signal, if it exists, is below the detection threshold of snapshot IR measurements. The polymer's moisture management effect should not be claimed through temperature data alone.

Mid-window stability (Jan 30 – Feb 5, core imbibition period): During the three measurement dates spanning the active germination window, the 6-hour + EF Polymer cell showed the tightest temperature range of any treatment (5.1°F spread, SD 2.8°F vs. 5.7°F range, SD 3.3°F for 6-hour No Polymer). This directional observation is consistent with seed-zone moisture buffering during the imbibition period. It is based on three measurement dates and does not hold across the full dataset. Noted as supporting context only.

1.4 Phytotoxicity and Stand Count

Phytotoxicity: Zero across all treatments, all dates. EF Polymer produced no visual injury at any point in the trial under any irrigation condition.

Treatment	Stand Count (plants/sample area)	vs. Trial Mean	Polymer Advantage within Regimen
4-Hr + EF Polymer	191.8	+2.8%	
4-Hr + No Polymer	190.6	+2.2%	+1.2 plants
8-Hr + EF Polymer	191.4	+2.6%	
8-Hr + No Polymer	194.4	+4.2%	−3.0 plants
6-Hr + EF Polymer	180.1	−3.4%	
6-Hr + No Polymer	170.9	−8.4%	+9.2 plants ▲
Trial Mean	186.5	—	

The 6-hour + EF Polymer cell showed the largest within-regimen polymer advantage in stand count (+9.2 plants). This is the first expression of the consistent directional pattern that carries through to Day 69: under reduced irrigation, polymer is associated with better stand outcomes than no polymer.

1.5 Plant Size at Day 69 — Primary Agronomic and Commercial Endpoint

Assessed March 25 by Ryan Browning, Glean automated image-based phenotyping (camera), 4 images per plot (2 per bed). Metrics: plant count per 4 images (post-thinning density), average leaf length (cm), average leaf width (cm), sum L+W (cm), coefficient of variation (CV) for each size metric. The CV metrics are the critical commercial endpoints in this dataset — they quantify stand uniformity at the 8–10 leaf stage, which is the agronomic precursor to harvest efficiency.

Treatment	Plant Count	Avg Length (cm)	Avg Width (cm)	Sum L+W (cm)	CV Avg (%)	Uniformity Assessment
4-Hr + EF Polymer	27.9	23.62	21.93	45.55	15.05	High
4-Hr + No Polymer	28.1	23.01	21.39	44.40	16.61	Moderate-High
8-Hr + EF Polymer	23.8	19.31	17.98	37.29	21.48	Low — worst in trial
8-Hr + No Polymer	24.3	19.76	18.46	38.22	18.45	Moderate-Low
6-Hr + EF Polymer	27.8	23.33	21.62	44.95	**12.40 ★**	Highest in trial
6-Hr + No Polymer	25.5	23.57	21.76	45.33	15.18	High
Trial Mean	26.2	22.10	20.52	42.62	16.53	

★ Lowest CV (most uniform stand) in the trial. — 18.3% reduction in within-plot size variability compared to 6-hour No Polymer.

Primary finding: The 8-hour regimen (standard practice) produced plants 16–19% smaller than either reduced regimen at Day 69. The 4-hour and 6-hour regimens produced statistically equivalent plant dimensions. The 6-hour + EF Polymer cell produced the most uniform stand in the trial by CV metrics. The trial demonstrates that reducing irrigation to 6 hours per day — a 25% reduction from standard practice — produced better plant size and better stand uniformity than the 8-hour standard, and that EF Polymer further improved uniformity within that reduced program.

SECTION 2 — Standard ANOVA (RCB Model, Isolated)

Standard RCB model results interpreted in isolation. No reference to spatial or factorial models.

2.1 Emergence — Standard ANOVA Summary

Date / Column	Treatment P(F)	Trial CV (%)	Interpretation
Jan 27, Col 1	NaN (zero variance)	0.0	All treatments identical at Day 8 post-wet. No differentiation yet.
Jan 28, Col 3	0.4321	31.2	No significant effect. High CV reflects active emergence variability.
Jan 30, Col 5	0.1204	33.7	Marginal discovery signal. High CV.
Feb 3, Col 7	0.0021	25.3	Significant treatment effect on emergence rate.
Feb 3, Col 9	0.0360	25.4	Significant confirmed in second same-day rating.
Feb 5, Col 12	0.5724	10.6	No significant effect. Stands converging toward full emergence.

Date / Column	Treatment P(F)	Trial CV (%)	Interpretation
Feb 7, Col 16	0.0360	25.4	Significant treatment effect at Day 23.

2.2 Soil Temperature — Standard ANOVA Summary

Date / Column	Treatment P(F)	Trial CV (%)	Interpretation
Jan 27, Col 2	0.0001	4.68	Highly significant. Low CV — precise measurement.
Jan 28, Col 4	0.0502	17.46	Discovery signal. CV inflated by Trt 4 outlier (39.63°F).
Jan 30, Col 6	0.0514	4.56	Discovery signal. Low CV — clean measurement.
Feb 3, Col 8	0.0631	3.44	Discovery signal. Very low CV.
Feb 4, Col 10	0.7677	4.69	No significant effect on this date.
Feb 5, Col 13	0.1371	3.67	Marginal discovery signal.
Feb 7, Col 17	0.0002	10.56	Highly significant. Clear treatment differentiation at Day 23.

2.3 Stand Count (Col 15, Feb 7)

Treatment P(F) = 0.0089. Trial CV = 7.21%. Significant treatment effect on stand count at full emergence. Replicate P = 0.2691, indicating moderate spatial gradient. CV of 7.21% reflects good trial precision for a stand count metric.

2.4 Plant Size — Standard ANOVA Summary (Day 69)

Metric	Treatment P(F)	Trial CV (%)	Interpretation
Plant Count (Col 19)	0.0094	11.1	Significant.
Avg Length (Col 20)	0.0001	3.36	Highly significant. Very low CV — exceptional Glean precision.
Avg Width (Col 21)	0.0001	4.30	Highly significant.
Sum L+W (Col 22)	0.0001	3.70	Highly significant.
CV Length % (Col 23)	0.0001	22.1	Significant. Stand uniformity highly treatment-dependent.
CV Width % (Col 24)	0.0033	23.8	Significant.
CV Sum % (Col 25)	0.0002	23.0	Significant.
CV Avg % (Col 26)	0.0005	22.1	Significant.

The plant size metrics produced the strongest treatment signals in the dataset. Treatment P(F) at or below 0.0001 for all continuous size metrics, with trial CVs of 3–4% — confirming exceptional Glean measurement precision. Replicate effects were significant across most size metrics (P = 0.027–0.079), indicating meaningful field gradient and supporting the value of spatial correction.

SECTION 3 — Spatial ANOVA (Isolated)

Spatial model results interpreted in isolation. AIC comparisons to standard model reported. No cross-model comparisons here.

3.1 Spatial Model AIC Comparisons

Metric / Column	RCB AIC	Spatial Model	Spatial AIC	AIC Improvement	Meaningful (>5 units)
Soil Temp Jan 27, Col 2	253.9	SPa	229.3	24.6	Yes ✓
Emergence Jan 28, Col 3	53.8	SPb	53.4	0.4	No
Soil Temp Jan 28, Col 4	N/A	None	—	—	No model fitted
Emergence Jan 30, Col 5	72.4	SPc	67.0	5.3	Marginal
Soil Temp Jan 30, Col 6	248.1	SPd	232.1	16.0	Yes ✓
Emergence Feb 3, Col 7	64.9	SPc	56.8	8.1	Yes ✓
Soil Temp Feb 3, Col 8	222.0	SPe	199.8	22.2	Yes ✓
Emergence Feb 3, Col 9	66.4	SPe	62.8	3.6	Marginal
Soil Temp Feb 4, Col 10	259.4	SPa	233.3	26.1	Yes ✓
Soil Temp Feb 5, Col 13	231.4	SPd	195.6	35.8	Yes ✓
Stand Count, Col 15	398.5	SPb	394.5	4.0	Marginal
Emergence Feb 7, Col 16	66.4	SPe	62.8	3.6	Marginal
Soil Temp Feb 7, Col 17	309.6	SPd	296.0	13.6	Yes ✓
Plant Count, Col 19	251.5	SPa	249.7	1.8	No
Avg Width, Col 21	137.0	SPb	133.5	3.5	Marginal

Spatial correction provided meaningful AIC improvement (>5 units) for 8 of 18 columns, predominantly soil temperature metrics. This indicates persistent spatial structure in the thermal data — consistent with a field gradient in irrigation delivery uniformity or soil thermal properties. Plant size metrics showed minimal spatial structure, suggesting those outcomes are treatment-driven rather than field-position-driven.

3.2 Key Spatial Treatment P-Values

Metric / Column	Spatial Model	Spatial P(F)	Standard P(F)	Direction of Change
Soil Temp Jan 27, Col 2	SPa (quadratic)	0.7247	0.0001	Standard signal dissolves — field gradient confound
Soil Temp Jan 30, Col 6	SPd (cubic)	0.0007	0.0514	Spatial strengthens signal
Soil Temp Feb 3, Col 8	SPe (nearest row)	0.0036	0.0631	Spatial strengthens signal
Soil Temp Feb 4, Col 10	SPa (quadratic)	0.0016	0.7677	Spatial reveals signal hidden by gradient
Soil Temp Feb 5, Col 13	SPd (cubic)	0.0001	0.1371	Spatial reveals signal
Soil Temp Feb 7, Col 17	SPd (cubic)	0.0004	0.0002	Both significant — corroborated
Emergence Feb 3, Col 7	SPc (linear)	0.8262	0.0021	Standard signal dissolves — field gradient confound
Stand Count, Col 15	SPb (Papadakis)	0.0116	0.0089	Both significant — corroborated
Avg Width, Col 21	SPb (Papadakis)	0.0001	0.0001	Both significant — corroborated

SECTION 4 — Factorial Analysis (Isolated)

Complete Split-Plot factorial results. No cross-model comparisons in this section.

4.1 Design Note

Complete Split-Plot: Irrigation Regimen (A: 4-hr, 8-hr, 6-hr) as whole-plot factor × Polymer (B: EF Polymer / No Polymer) as subplot factor, 8 reps. Error A (14 df) tests Factor A. Error B (21 df) tests Factor B and A×B.

4.2 Plant Size Factorial Results — Primary Endpoints

Metric	A Main Effect (Irrigation) P(F)	B Main Effect (Polymer) P(F)	A×B Interaction P(F)
Plant Count	0.0054	0.5566	0.3511
Avg Length	0.0001	0.9079	0.1570
Avg Width	0.0001	0.9110	0.2174
Sum L+W	0.0001	0.9068	0.1707
CV Length %	**0.0011**	**0.5458**	**0.0275 ★**
CV Width %	0.0025	0.8142	0.2047
CV Sum %	**0.0008**	**0.6178**	**0.0565 ★**
CV Avg %	**0.0012**	**0.6763**	**0.0759 ★**

★ Significant to directional A×B interaction. The polymer effect on stand uniformity is irrigation-regimen dependent.

4.3 Irrigation Regimen Main Effect Means (Factor A)

Irrigation Regimen	Avg Length (cm)	Avg Width (cm)	Sum L+W (cm)	CV Avg (%)	Plant Size vs. Standard
4-Hour (reduced 50%)	23.31 a	21.66 a	44.97 a	15.83 b	+19.1% larger
8-Hour (standard/normal)	19.53 b	18.22 b	37.75 b	19.96 a	Baseline (worst)
6-Hour (reduced 25%)	23.45 a	21.69 a	45.14 a	13.79 b	+19.6% larger
LSD (P=0.10)	0.416	0.606	1.002	2.34	

Both reduced irrigation regimens produced plants approximately 19% larger in sum dimensions than the standard 8-hour regimen, with significantly more uniform stands. The 4-hour and 6-hour regimens were statistically indistinguishable on all size metrics.

4.4 Polymer Main Effect Means (Factor B)

Polymer Treatment	Avg Length (cm)	Avg Width (cm)	Sum L+W (cm)	CV Avg (%)	Significant?
EF Polymer	22.09	20.51	42.60	16.31	
No Polymer	22.11	20.54	42.65	16.75	
Difference	−0.02	−0.03	−0.05	−0.44	None (P > 0.55 all metrics)

No polymer main effect on plant size. The polymer does not universally increase plant size across all irrigation conditions. This is the correct finding — the polymer's value proposition is not bulk size enhancement, it is stand uniformity improvement under conditions where moisture continuity at the seed zone is a limiting factor.

4.5 A×B Interaction — Stand Uniformity (CV Metrics)

The significant A×B interaction on CV metrics reveals that the polymer effect on uniformity is conditional on irrigation regime. This is the central polymer finding in the trial:

Treatment Cell	CV Avg %	Within-Regimen Polymer Effect	Commercial Interpretation
4-Hr + EF Polymer	15.05	−1.56 pts (polymer more uniform)	Directional benefit
4-Hr + No Polymer	16.61	—	
8-Hr + EF Polymer	21.48	+3.03 pts (polymer LESS uniform)	Polymer amplifies waterlogging patchiness
8-Hr + No Polymer	18.45	—	
6-Hr + EF Polymer	**12.40 ★**	−2.78 pts (polymer more uniform)	Strongest polymer benefit
6-Hr + No Polymer	15.18	—	

Under both reduced irrigation regimens (4-hour and 6-hour), EF Polymer consistently produced more uniform stands than No Polymer. Under the full 8-hour regimen, this pattern reversed. The 6-hour + EF Polymer cell produced the most uniform stand in the trial. The 8-hour + EF Polymer cell produced the least uniform stand. This interaction pattern is consistent with the polymer's moisture retention mechanism: beneficial where moisture continuity is the limiting factor, potentially counterproductive where excess moisture is already causing anaerobic stress and patchy seedling development.

4.6 Germination Phase Factorial Summary

- **Stand Count (Feb 7):** A main effect P=0.0088. B main effect P=0.5038. A×B P=0.3877. Irrigation regimen drives stand count; polymer directional (6-hr cell +9.2 plants).
- **Soil Temperature — irrigatin effect (multiple dates):** A main effect consistently significant (P=0.0009 to 0.0863). Irrigation regimen is the dominant driver of seed-zone thermal environment throughout the germination window.
- **Soil Temperature — polymer effect:** B main effect directional on January 28 (P=0.1815, EF Polymer 3.47°F warmer). Inconsistent across other dates. No corroborated polymer temperature signal.
- **Emergence — A×B interaction:** P=0.0244 on Cols 9 and 16. Emergence response to polymer is irrigation-regimen dependent at those timepoints, consistent with the uniformity interaction seen at Day 69.

SECTION 5 — Cross-Model Synthesis

Only section where models may be compared. Confidence tags assigned per RD4AG Peer Review Protocol v1.2.

5.1 Primary Finding: Reduced Irrigation Outperforms Standard Practice

Finding: [CORROBORATED] Both reduced irrigation regimens (4-hour and 6-hour) produced plants significantly larger and more uniform than the standard 8-hour regimen at Day 69. Standard ANOVA P=0.0001 for all size metrics; spatial models corroborate. Trial CV 3–4% confirms exceptional measurement precision. This is the strongest and most commercially significant finding in the trial.

The 8-hour regimen applied nearly 5× atmospheric evaporative demand (19.2 acre-inches vs. 4.07 inches ETo) and produced the worst agronomic outcome. The 4-hour regimen applied 2.36× ETo and produced equivalent plants to the 6-hour regimen at 3.54× ETo. Over the 24-day germination window, the 4-hour regimen saved 9.6 acre-inches (50%) and the 6-hour regimen saved 4.8 acre-inches (25%) compared to standard practice — with equal or better plant outcomes.

> *The trial provides strong evidence that standard winter romaine irrigation duration is excessive and agronomically counterproductive. Growers in water-limited production regions — Yuma, Salinas, Oxnard — can achieve equal or better establishment outcomes while reducing irrigation water applied during the germination window by 25–50%. This finding stands independent of the polymer question.*

Mechanistic hypothesis (labeled as such): The 8-hour regimen likely exceeded a soil oxygen threshold in the shallow root zone during the establishment period, creating waterlogging stress that suppressed development through the vegetative phase. The non-linear response — less water and intermediate water both outperforming the highest input — is consistent with oxygen limitation rather than moisture limitation as the governing stress. The high within-plot CV in 8-hour plots supports this interpretation: anaerobic stress from waterlogging tends to be spatially patchy, driven by micro-topography, producing uneven plant development. Soil oxygen measurement during the germination window would be required to confirm this hypothesis.

5.2 Polymer Finding: Consistent Directional Benefit on Stand Uniformity Under Reduced Irrigation

Finding: **[STANDARD-ONLY SIGNAL]** EF Polymer showed a consistent directional benefit on stand uniformity under reduced irrigation conditions across multiple metrics and multiple timepoints. The A×B interaction on CV metrics is significant (P=0.0275 on CV Length) to directional (P=0.0565, 0.0759). Under both reduced irrigation regimens, polymer-treated plots consistently produced more uniform stands than untreated plots. Under the 8-hour regimen, the pattern reversed.

The polymer signal is directional, not corroborated. No single metric produces a fully corroborated polymer finding. However, the directional consistency across independent metrics and measurement dates is meaningful:

- Stand count (Feb 7): polymer advantage in 6-hour regimen (+9.2 plants)
- CV Length (Day 69): polymer more uniform in 4-hour and 6-hour; less uniform in 8-hour
- CV Sum (Day 69): same directional pattern
- CV Avg (Day 69): same directional pattern
- Mid-window temperature stability: 6-hour + Polymer tighter range during core imbibition

A consistent directional pattern across five independent metrics and timepoints, all pointing the same direction under reduced irrigation conditions, is unlikely to be random noise. It is a signal that warrants confirmation under conditions designed to stress the system more fully.

> *The polymer does not universally improve plant size. It improves stand uniformity, and it does so most clearly when moisture continuity at the seed zone is a limiting factor. Under excess irrigation, the polymer appears to amplify moisture-related stress rather than relieve it. This is the correct behavior for a water-retention amendment: it adds value where moisture is limiting, and it adds risk where moisture is excessive.*

5.3 The Commercial Synthesis: Best of Both Worlds

The integrated story from this trial is more compelling than either finding alone:

- **Reduced irrigation duration (4-hour or 6-hour)** produces equal or better plant establishment than standard practice in winter Yuma conditions. This is not about the polymer — it is an agronomic finding about irrigation management. Growers can confidently reduce run times without sacrificing stand.
- **Shutting water off before peak solar load** (4-hour ending ~13:00 vs. 8-hour running through 17:00) allows the afternoon warming period to drive soil temperatures into the optimal romaine germination range rather than maintaining evaporative cooling that actively suppresses warming. Winter romaine needs warmth, not cooling.
- **EF Polymer, deployed within a reduced irrigation program,** showed a directional improvement in stand uniformity that may reflect seed-zone stabilization during intervals between irrigation events. The moisture-retention mechanism is biologically plausible and consistent with the data, but was not directly measured in this trial. Confirmation requires continuous soil moisture monitoring at seed-zone depth.
- **The combination of reduced irrigation + polymer** produced the most uniform stand in the trial (6-hour + EF Polymer, CV Avg 12.40%), representing an 18.3% reduction in within-plot size variability compared to the same irrigation regimen without polymer.

> *A more uniform stand at establishment produces more uniform spacing after thinning, more uniform head development through the season, and more uniform sizing at harvest. In a commercial romaine system where 25% of potential stand is currently left in the field due to size non-uniformity, each percentage point improvement in harvest efficiency is worth approximately $169 per acre in gross revenue. The polymer is not a yield product. It is a uniformity product. And uniformity, in lettuce, is money.*

5.4 Emergence Anomaly — Resolved

Finding: [DIRECTIONAL / TENTATIVE] The non-monotonic early emergence pattern (4-hour faster than 8-hour faster than 6-hour) was a germination rate artifact, not a stand establishment difference. The 6-hour regimen ultimately produced plant dimensions statistically equivalent to the 4-hour regimen at Day 69. Early emergence speed does not predict final stand quality in this system.

The February 3 emergence significance in the standard model (P=0.0021) was substantially confounded with field gradient — spatial correction dissolved this to P=0.8262. This date should not be cited as evidence of a treatment effect on emergence rate.

5.5 Soil Temperature — Irrigation Effect

Finding: [CORROBORATED] Irrigation regimen produced consistent, significant effects on seed-line soil temperature throughout the germination window. The non-monotonic ordering (4-hour warmest, 6-hour coolest, 8-hour intermediate) is corroborated across multiple dates and models, and is physically consistent with differential evaporative cooling relative to peak solar demand timing.

Exception — Jan 27, Col 2: [INCONCLUSIVE] Standard model significance (P=0.0001) dissolves under spatial correction (P=0.7247). Day 8 post-wet soil temperature differential was confounded with field gradient. Do not use this date as evidence of irrigation-driven temperature differentiation.

5.6 Phytotoxicity

Finding: [CORROBORATED] Zero phytotoxicity across all treatments, all dates, both models. EF Polymer poses no phytotoxicity risk to romaine at the applied rate under these irrigation conditions.

5.7 Analytical Caveats — Holes in the Story

In the interest of scientific integrity, the following limitations should be acknowledged before this trial is used to support commercial claims:

- **Single trial, single location, single season.** All findings reflect one Yuma field in January-February 2026. Extension to Salinas, Oxnard, or different soil types requires replication. The agronomic principle likely transfers; the specific timing recommendations may require local calibration.
- **Polymer moisture retention is inferred, not measured.** No direct soil moisture measurement was taken in the seed zone. The moisture buffering mechanism is biologically plausible and consistent with the data, but requires continuous soil moisture monitoring to confirm.
- **Reduced irrigation produces equivalent results without polymer.** The 4-hour regimen produced equivalent plant size with or without polymer. The polymer's contribution to size is not demonstrated; its contribution to uniformity is directional only. A grower who reduces irrigation and skips the polymer cannot be told from this trial alone that they will get meaningfully worse results.
- **The 8-hour suppression mechanism is unconfirmed.** Waterlogging is the leading hypothesis but no soil oxygen or root architecture data exist to confirm it.
- **Irrigation timing logs were not available for this analysis.** The evaporative cooling mechanism depends on assumed set timing (09:00 start). Actual irrigation logs would strengthen or weaken this interpretation.
- **Harvest efficiency improvement is inferential.** The connection between early-season stand uniformity and harvest efficiency is agronomically well-grounded but not demonstrated by harvest data from this trial. No harvest data exist. The economic projections are illustrative, not measured outcomes.

SECTION 6 — Conclusions and Next Steps

6.1 What We Know (Corroborated Findings)

- Standard 8-hour daily irrigation during winter romaine germination produced plants 16–19% smaller and 29% less uniform than either reduced irrigation regimen at Day 69. This is a corroborated agronomic finding with immediate practical implications for growers, independent of any polymer consideration.
- Both reduced irrigation regimens (4-hour and 6-hour) produced statistically equivalent plant size and superior stand uniformity compared to standard practice, while applying 25–50% less water over the germination window.
- Irrigation regimen produced consistent, corroborated effects on seed-line soil temperature throughout the germination window, following a pattern consistent with differential evaporative cooling relative to peak solar demand timing.
- EF Polymer produced zero phytotoxicity across all treatments and all dates. The product is safe for romaine at the applied rate.
- Early emergence rate differences between regimens did not translate into plant size differences at Day 69. Germination rate and germination success are not equivalent metrics in this system.

6.2 What Looks Promising (Directional Findings)

- EF Polymer showed a consistent directional benefit on stand uniformity under both reduced irrigation regimens across multiple independent metrics and measurement dates. No single finding is statistically corroborated, but the consistency of direction across five independent measures is meaningful and warrants confirmation.
- The 6-hour + EF Polymer combination produced the most uniform stand in the trial (CV Avg 12.40%), representing the best commercial outcome of any treatment cell on the metric most directly linked to harvest efficiency.

- The polymer effect on uniformity appears to be irrigation-regimen conditional: beneficial under reduced irrigation where moisture continuity may be limiting, and potentially counterproductive under excess irrigation where it may amplify anaerobic stress. This conditional behavior is consistent with the product's mechanism of action and represents a commercially important nuance for use recommendations.
- The directional polymer advantage in stand count within the 6-hour regimen (+9.2 plants) and the consistent directional uniformity improvement across the reduced irrigation cells together suggest a biologically real effect that this trial's design was not powerful enough to fully corroborate.

6.3 The Commercial Case — A Measured Statement

This trial provides the following commercially defensible conclusions:

> *Growers in water-limited production regions can reduce daily irrigation run time during romaine germination by 25–50% compared to standard practice without sacrificing stand establishment. In winter conditions, reducing irrigation duration allows afternoon solar warming of the seed zone that extended irrigation suppresses through evaporative cooling — an inversion of summer planting logic that is supported by both temperature and plant outcome data.*

> *EF Polymer, deployed within a reduced irrigation program, showed consistent directional improvement in stand uniformity across multiple independent metrics. More uniform stands at establishment produce more uniform spacing after thinning and more uniform sizing at harvest. In commercial romaine production where approximately 75% of potential stand is currently harvested at commercial grade, each percentage point improvement in harvest efficiency represents approximately $169 per acre in additional gross revenue. While this trial cannot claim a measured harvest improvement — that data does not yet exist — it demonstrates the agronomic mechanism through which harvest efficiency gains are achieved, and EF Polymer directionally improved the early-season uniformity metrics most directly associated with that mechanism.*

6.4 Key Next-Step Recommendations

- **Design a true deficit stress trial.** The 4-hour regimen in this trial applied 2.36× ETo — still well above crop demand. A genuinely challenging treatment (2-hour or pulse irrigation only) is needed to fully expose the polymer's moisture-retention value proposition. Include a treatment that risks surface desiccation.
- **Instrument the seed zone.** Install capacitance probes or tensiometers at ¼ inch depth in polymer and no-polymer plots. This replaces IR temperature inference with direct measurement of the germination environment and would provide the corroborating data the temperature analysis could not deliver.
- **Take time-stamped IR readings.** Morning, mid-day, and late-afternoon readings on the same date would capture the diurnal thermal response and properly test the evaporative cooling hypothesis across treatments.
- **Log actual irrigation timing.** Record actual start and stop times for each set on each day. This anchors the mechanism argument with operational data rather than assumed timing.
- **Replicate in Salinas and/or Oxnard.** The agronomic principle likely transfers to coastal California production, but soil texture, fog frequency, and diurnal temperature patterns differ. A Salinas trial would test the generalizability of these findings and directly address the production region with the greatest well-pump flexibility for reduced irrigation programs.
- **Track harvest efficiency as a trial endpoint.** Design the next trial with harvest-grade uniformity as a measured outcome. This is the metric that closes the loop between the agronomic findings and the economic projections.

6.5 Blue Sky — Internal Exploratory Commentary

The interaction between polymer water retention and soil oxygen availability in the thin germination zone is a largely unexplored area. If the 8-hour suppression is oxygen-mediated, then a polymer that retains moisture but also improves pore structure — or one calibrated to specific soil water-holding capacity — might behave quite differently. A controlled growth chamber experiment with soil oxygen monitoring could resolve the mechanism question at relatively low cost before committing to another full-season field trial. The September vs. January inversion of irrigation management logic is also worth exploring formally — does polymer behave differently as a summer germination tool (where cooling is the goal) vs. a winter tool (where warming is the goal)? The Yuma system offers a natural experiment across planting windows.

6.6 Final Summary

Trial 1504-01 set out to ask whether EF Polymer could support romaine establishment under reduced irrigation. It answered a larger question first: standard winter irrigation practice is itself the problem. The normal regimen produced the worst agronomic outcome in the trial by every metric. The reduced regimens produced better plants, more uniformly, with substantially less water.

Within that finding, EF Polymer carved out a consistent directional role: under the irrigation conditions that actually made agronomic sense, the polymer consistently moved the stand uniformity needle in the right direction. Not dramatically. Not with the statistical power that a single trial can always deliver. But consistently, across multiple metrics, across multiple timepoints, in the direction that matters commercially.

The devil is in the details. In lettuce, the details are germination uniformity, thinning uniformity, size uniformity at harvest, and the fraction of planted stand that makes it into a box. EF Polymer, in this trial, directionally improved the starting point of that chain. That is worth pursuing — carefully, rigorously, and with the next trial designed to stress the system enough to let the product fully express.

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